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Inside Perspectives on Ceramic Manufacturing: Visualizing Ancient Potting Practices through Micro-CT Scanning

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Abstract

Micro-computed tomography (CT) analysis offers a new perspective on archaeological ceramic manufacture, augmenting traditional studies that focus on decorative and morphological aspects of ceramic vessels. High resolution, three dimensional, micro-CT images reveal different ceramic forming methods by identifying the characteristic gestures and techniques, as well as idiosyncratic corrective measures used by potters to form vessel rims. These techniques or "tools of the trade" reflect potters' engagement with tradition and innovation while working within a community of practice.

This study adopted two research questions. First, what is the value and potential of micro-CT as a method of ceramic analysis in archaeology? Second, as a case study to illuminate the first question: what insights can be advanced about the craft of pottery manufacture from the ceramic assemblages of the Late Woodland Arkona Cluster archeological sites? To answer these questions I scanned sherds representing 67 vessels from the Arkona Cluster sites (located near Arkona, Ontario). These vessels come from a series of contemporaneous and/or sequentially occupied sites dating to between ca. 1000-1270 CE. They existed within a material borderland, generally located in space and time between what conventionally has been defined and labelled in archaeological culture history as the Western Basin and Ontario Iroquoian Late Woodland material culture traditions.

Though accompanied by a steep learning curve, micro-CT analysis proved an effective method for accessing hidden steps in the ceramic production sequence used by potters at the Arkona Cluster. The ability to highlight, in three dimensions (3D), inclusions and void spaces in the ceramic fabric, allow scanned images to reveal aspects of ceramic preparation and manufacturing practices that could not be accessed using conventional analysis methods. The capacity to see these practices, and how they related to ceramic design, revealed that potters at the Arkona Cluster were engaging with and incorporating elements from multiple ceramic traditions, reflecting a distinct regional material expression. Through micro-CT analysis, the ceramics at the Arkona Cluster suggest idiosyncratic expressions of an artisan community sustaining tradition and innovation, which characterizes an archaeological material borderland at this specific time and place.

Lay Summary

Micro-computed tomography (CT) analysis allows archaeologists to view the interior structures of pots, offering a new perspective on archaeological ceramic manufacture. High resolution, three dimensional, micro-CT images reveal different ceramic forming methods by identifying the characteristic gestures and techniques used by potters to form different parts of a vessel. These techniques or "tools of the trade" reflect potters' engagement with tradition and innovation while working within their community.

This study adopted two research questions. First, what is the value and potential of micro-CT as a method of ceramic analysis in archaeology? Second, as a case study to illuminate the first question: what can we learn about the craft of pottery manufacture from the ceramic assemblages of the Late Woodland Arkona Cluster archeological sites? To answer these questions I scanned sherds representing 67 vessels from the Arkona Cluster sites (located near Arkona, Ontario), dating to between ca. 1000-1270 CE. The materials, including ceramics, from these archaeological sites show influences from what have conventionally been defined in archaeological culture history as the Western Basin and Ontario Late Woodland material culture traditions.

Though accompanied by a steep learning curve, micro-CT analysis proved an effective method for accessing hidden steps in ceramic production used by potters at the Arkona Cluster. The ability to highlight, in three dimensions (3D), inclusions and void spaces in the clay used to make pots allows scanned images to reveal aspects of ceramic preparation and manufacturing practices that could not be accessed using conventional methods. The results revealed that potters at the Arkona Cluster were engaging with and incorporating elements from multiple ceramic traditions into their work. Through micro-CT analysis, the ceramics at the Arkona Cluster reveal expressions of an artisan community sustaining tradition and innovation, within the context of a specific time and place.

Keywords

Micro-computed tomography, ceramic manufacture, ceramic analysis, Late Woodland ceramics, Ontario Woodland borderlands, Ontario archaeology, potting communities, potting traditions, material sciences

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Preface

I remember quite clearly sitting at the grad club one evening in the second year of my PhD studies and chatting with a colleague about our research. He asked something along the lines of "so why are you interested in pottery?" At the time, I was in the midst of readings for one of my comprehensive exam papers dominated by ethnographic and ethnoarchaeological research on how and why people make pots. I somewhat jokingly replied, "Well, what I'm really interested in is not pottery but *potters*." He laughed and said, "Stick with that. That will serve you well." From my material culture and technology-focused, archaeology background, in that crystalizing moment, I realized that I might be becoming a more rounded anthropologist and that my research would be all the more interesting for it. I had always loved the connection that past people's belongings gives us to them, whether it be teeth marks on a pipe stem, initials carved in a bone utensil handle, retouch flakes taken off a stone tool, or fingerprints left in the wet clay of a pot, but now I was learning the theory and language to articulate this connection. So, as I wrote this dissertation, I tried to "stick with" the potters. While this is essentially a methodology based dissertation, exploring the use of an innovative new technology in archaeology, I hope the potters are not lost or forgotten, and the micro-CT technology is not only used for the sake of making pretty pictures, but because it can tell us something about the context in which these potters worked, interacted with each other and lived their lives.

Chapter 1

1 Introduction

This dissertation explores the analytical potential of non-invasive, micro-computed tomography (CT) scanning in archaeological ceramic studies. To explore this potential, I used a collection of ceramics from a cluster of Late Woodland archaeological sites within a material borderland in southwestern Ontario as a case study. Conventional research on ceramics, especially on Indigenous ceramics in Ontario, has been almost universally limited to superficial, macro-visual classification and description. Only rarely have researchers in Ontario used destructive, inherently two-dimensional thin section petrography to view the interior structures of ceramics (Braun 2012, 2015; Cheng 2012; Howie 2012; Michelaki et al. 2014; Striker 2018; Weglorz 2018). Describing decoration has been the primary focus of ceramic analysis, with a few notable exceptions (e.g., Braun 2012, 2015; Dorland 2018; Martelle 2002; Michelaki 2007; Striker 2018; Striker et al. 2018; Watts 2006, 2008). I hope that this dissertation adds another line of evidence to these approaches beyond trait list classifications and macro descriptions.

I conducted my research at the Museum of Ontario Archaeology, where I had access to archaeological collections and the Western University operated Nikon XTH 225 ST micro-focus X-ray tomography system, and imaging software. Micro-CT scans provide high magnification, volumetric, digital, three-dimensional (3D) X-ray images of the interior and exterior of archaeological artifacts (Stock 1999, 2009). Recent studies (e.g. Bernadini et al. 2016; Kahl and Ramminger 2012; Kahl et al. 2012; Machado et al. 2013; Sobott et al. 2014; Tuniz et al. 2013) have shown micro-CT scanning to be an extremely promising method for determining how ceramic vessels were manufactured and for identifying variation within these techniques. However, these studies have been preliminary, based on sample sizes of only five to ten ceramic sherds. Some micro-CT and CT studies (Kozatsas et al. 2018; Sanger et al. 2013; Sanger 2016) have started to explore the research potential these techniques have for larger datasets. In this dissertation, I hope to advance the transformative opportunities micro-CT scanning provides for the analysis of ancient ceramics, determine the extent we can access patterns in ceramic manufacture that are not obtainable through visual, macro-examination, and define some of the methodological protocols needed to establish micro-CT as an essential tool for ceramic research globally.

Micro-CT scanning allows us to isolate micro features in clay such as temper, inclusions, voids, and micro-folds in 3D that enable the researcher to begin to understand the unique internal structures of the vessel and the process of manufacturing that created those internal structures. The 3D images generated are based on the density of the material scanned, depicted in greyscale (Stock 2009). The resulting scans mean that isolating air from clay, organics from clay and more dense minerals from clay is fairly easy to do; whereas isolating one type of clay from another, or minerals of similar densities from each other, is more difficult. Visualizing these features in 3D is unique to CT scanning. As such, micro-CT has great potential to augment traditional techniques when examining ceramic technology, especially when viewing complete, 3D representations of interior structures in clay. Throughout the course of this research, I had to tackle a steep learning curve, which resulted from viewing archaeological materials in an entirely new way: analyzing, thinking about and describing ceramic structures in 3D, across the X, Y and Z planes.

This research examines the range of analytical applications that micro-CT scanning can provide to the field of ceramic analysis, and focuses explicitly on formation (or manufacturing techniques), and material selection. In terms of formation techniques, micro-CT analysis allows for the study and mapping of internal features. These features include voids or air pockets within or between pieces of clay that indicate where the potter folded, compressed or joined pieces of clay, including compression from tools used in both forming and decorating vessels. In terms of material selection, micro-CT scans depict both intentionally added temper material (i.e., mineral and/or organic matter added to pots to reduce breakage during firing) and natural inclusions (mineral and/or organic matter found in the clay matrix). Preliminary micro-CT studies at the Museum of Ontario Archaeology, on the scanner operated by Western University, and elsewhere, have shown promise for isolating temper from clay material and illustrating voids in vessel structures (Kahl and Ramminger 2012; Machado et al. 2013). This dissertation builds on these preliminary studies. The ability of micro-CT scans to identify idiosyncratic artisan practices in ceramic manufacture through patterns in internal features also offers promise for a better understanding of what have long been recognized as critical, individualistic dimensions of pot making (Berg 2008, 201; Carr 1990, 1993; Middleton 2005; Rye 1977; Tite 1999); or in some cases the artistic endevours of multiple artisans (Crown 2007). In this way, micro-CT analysis of formation techniques and material choices will show how these factors in making ceramic vessels changed over time and across and within artisan groups – changes that provide insight into the transfer of knowledge, skill, and enculturation of the next generation of potters within a community (Wendrich 2012).

Micro-CT analysis is a relatively new and burgeoning field. Though primarily used in bioarchaeological applications (e.g., Friedman et al. 2012; Kaick and Delorme 2005; Morgan 2014; Nicklisch et al. 2012; Swanston et al. 2013), the use of micro-CT analysis holds promise for most classes of archeological materials (e.g., Bird et al. 2008; Ellis et al. 2019; Tuniz et al. 2013; Tuniz and Zanini 2014). Other material sciences have also begun using micro-CT technologies, notably in meteorite studies (Griffin et al. 2012; Hsu et al. 2008), and cultural heritage and museum studies (e.g., Able et al. 2011; Ball et al. 2011; Casali 2006; Séguin 1990).

It is within this context of rapidly growing micro-CT research that I situate this dissertation. I consider the strengths and limitations of using this technology and how it can help us to better understand the material lives of people in the past. I explore how notions of community and practice can be seen through the way people performed their craft within daily life, and how minute differences in the way things were done might tell us about artisan practices and how individuals and communities were creating, maintaining, and changing over time. Micro-CT provides a real way to move away from static notions of ceramic style representing an ethnic group in a place and time, towards examining how artisans were practicing potting and actively interacting with both innovation and tradition in place and time.

1.1 Craft Production, Communities of Practice, and Technical Gestures

Throughout this research, I have been aware that these pots were not created in isolation; they were made in a specific moment in time, by a group of people with interpersonal relationships. Functional and mechanical constraints are never severe enough to dictate the choices of potters, and we need to recognize that there is a human at every step of the production who is making a decision (Michelaki 2007:150). We need to move away from what Marcia-Anne Dobres calls the “disembodied hands” (2000:21) of technological studies that separate technology and the technician from their social context. Material culture is influenced by the context of production, not just production techniques (Watts 2006).

Objects carry in them records of human decisions that are part of social identities, relationships and practices, and through micro-CT scans we can access some of these past practices and production decisions. A new wave of archaeologists focused on the examination of craft production emerged in the 1990s (e.g. Bowser 2000; Costin 1991, 1998, 2001; Dietler and Herbich 1994, 1998; Hardin and Mills 2000; Miller 2007; Minar and Crown 2001; Rowlands 1993; Sassaman 1998; Shimada 2007; Sillar 2000; Van der Leeuw 1993). These archaeologists noted that atomization of motor skills: posture, gestural movements, handedness, and muscle memory resist change as artisans work in regular ways to establish rhythms and ensure success (Dobres 2000; Hagstrum 1985; Michelaki 2008; Roddick and Hastorf 2010; Stark 1999). Change in craft production may result from new learning configurations, shifting social identities, and new connections between communities of practice (Roddick and Hastorf 2010). Social identities of artisans are not simple: aspects such as kinship, gender, age, and the contexts of craft production all come into play in establishing and maintaining social connections (Eckert 2008; Sassaman 1998). These identities and boundaries can be fluid, oppose or complement one another, change over time, and can crosscut social and ethnic lines (Bowser and Patton 2008; Cunningham 2010; Dietler and Herbich 1994; Eckert 2008; MacEachern 1998).

Archaeologists use ceramics as a way to access the individual in the past and their communities. Many archaeologists frame potter artisans within the notion of a "community of practice" or "community of potters" (e.g.; Bowser and Patton 2008; Cordell and Habicht-Mauche 2012; Crown 1999, 2007; Gosselain 1992; Huntley 2006; Peelo 2011; Michelaki 2008; Minar 2001; Minar and Crown 2001; Ortner 1999; Sassaman and Rudolphi 2001; Stark 2006; Van Keuren 2006; Wegner 1999). By community of potters I mean the social unit that produces pots from raw materials, or more simply those who share "a way of being in the world" (Peelo 2011:646). This community interacts with each other as artisans more often than with other communities of potters elsewhere, are distinct from non-potters by their shared craft, and produce similar but not identical products to each other (Arnold 2005:16).

The concept of a community of practice draws on Lave and Wenger's (1991) "situated learning" in which members of a community are created based on their participation in tasks (Joyce 2012). These communities, sometimes known as "pottery lineages" (Wray et al. 1991:291), are defined by a shared history of practice and regularities of production and use and learning, not necessarily by spatial or ethnic constraints (Eckert 2008; MacEachern 2008), and are people whose craft creates a shared history and common understanding of the production and use of their craft – their practice.

Communities of practice can include not only learning, but procurement, manufacture, distribution, consumption and disposal of artifacts and resources (Roddick and Stahl 2016). In this research I focus on a community involved in the manufacture of pots. Communities of practice are learning communities, but they are not homogenous or bounded (Gosselain 2016). Roddick (2016:126) describes them as the "*process* of community including the formation, reproduction and particular senses of community." Different members of a potting community of practice can engage differently, often learning initial skills through peripheral participation, then increasing their engagement, sense of belonging and integration into a community as those skills develop (Roddick 2016:126). These learned skills, or sets of practices, can be reproduced by successive generations of participants (Roddick and Stahl 2016).

These communities of practice can exist as distinct within a wider village or otherwise defined socio-cultural or geo-political community. Likewise, a community of practice can transcend multiple distinct, larger socio-cultural or political communities, connected through that shared practice. And notably, all the members of these communities of practice are still also at the same time members of those larger socio-cultural and geo-political communities, as well as members of various other forms of identity groups (i.e., gendered and aged, by marital or socio-economic status, and family relations). In this way, multiple communities of practice can exist in a single village while a single community of practice can exist across multiple villages (Eckert 2008).

Constellations of practice refer to "the articulation of distinct communities of practice that share a history, or members, or particular objects, or that engage in similar techniques or compete for the same resources." (Roddick 2016:130). Constellations of practice allow archaeologists to compare different communities of practice and this approach recognizes that communities and constellations of practice can operate at differing geographic scales (Roddick and Stahl 2016). In this way, a community or constellation of practice is not necessarily a thing that archaeologists look for in the archaeological record, but provides a useful way examining the archaeological record more holistically.

Approaches to the individual, pioneered by Hill and Gunn in their 1977 volume *The Individual in Prehistory*, laid down the framework for the sort of microscale analysis that I was able to undertake using micro-CT analysis. Attempts to recognize individuals shifted the focus of material culture analysis from typological and cultural historical concerns to the actions of artisans; traces of which can be seen in micro-CT scans. Through the ceramic scans I was able to study individual artisans or "analytical individuals," meaning an individual or socially close individuals (Hawkins 2004:68). This scale of study can explore individual pots made by individual potters, and closely examine different teaching strategies (Crown 2007:677). Individual potters can be recognized through the individual mannerisms, material constraints, motor skills, abilities, and aesthetic criteria that artisans contribute to the ceramic vessel design and embodied as the outcome of artisan decisions (Creese 2012; Hill 1977, 1978; Longacre

1991; Van Keuren 1994). Variation in decorative patterns, errors and corrections, integration of motifs, symmetry of motif proportions and stylistic appropriateness can also help identify potters at the individual level (Crown 2007; Van Keuren 1994). Symmetry analysis (Washburn 1978), sequences of design elements (Hardin 1983), and other attributes also have been used to define the microstyles of individual potters (Martelle 2002; Hawkins 2004). While these studies emphasize exterior decorative motifs, and not all the steps involved in ceramic manufacture, they provide a way of accessing the individual potter, or at least analytical individuals. Crown (2007:684) also links consistency (in decoration) with production frequency and quantity to suggest one can recognize the work of a mature artisan. However, individual artisans are best understood as situated in a community of learners, practitioners, and a lineage of producers (Crown 2007:687).

Other archaeological research studying artisan practices and craft production emerged alongside explorations of communities of practice. This includes research on cultural transmission, learning and apprenticeship, the examination of differing learning frameworks, as well as the archaeology of childhood (Bagwell 2002; Creese 2012; Crown 2001, 2002, 2007; Kamp 2001; Menon and Varma 2010; Miller 2012; Minar 2001; Minar and Crown 2001; Smith 2003, 2005; Wallaeret-Pêtre 2001; Wendrich 2012). These various works began to address conformity and innovation in intergenerational pottery manufacture that had not been considered previously (Stark et al. 2008).

Practice-based approaches allow archaeologists to conceptualize the fluidity of social contexts, and the relationships between material culture, making things, identities and social boundaries as “something people do” (Eckert 2008:3; Hegmon 1998; Stark 2006). While conventional approaches to ceramics remind us to closely examine decorative attributes and classification, they only further understandings of one step in the process of vessel manufacture. Vessel morphology and the motor performance gestures associated with ceramic formation are not as likely to be subject to discursive manipulation by artisans as decorative motifs are, because they are grounded in the unconscious and likely to change little through time and in response to tools or media (Creese 2012; Michelaki 2007: 159; Martelle 2002:124; Watts 2006:195). Not only is there a difference *between* forming methods but also *within* them, determined by the particular gestures and motor habits of a potter (Michelaki 2007:160). These subtle variations are something that can be seen more easily through micro-CT scans than through any other technique, as internal structures are telling of formation processes (Berg 2008; Carr 1990). Comprehensive approaches to ceramic analysis remind us that we need to think of pottery production as a practice which occurs in a particular context of people engaging with each other and materials (Dietler and Herbich 1998). Thus, archaeologists have thought of ceramic pots as a number of things over time: material culture, chronological and ethno-linguistic signifiers, social agents, and a craft product.

Anthropology of techniques approaches have been adopted by many ethnoarchaeological studies (Degoy 2008; Gosselain 1992, 1994, 1998, 2000; Gosselain and Livingstone Smith 1995, 2005; Mahias 1993; Wallaert-Pêtre 2001; Wayessa 2011). Often incorporated in these are "technical gestures", the "corporeal basis of bodily engagement with the material and social conditions of their productive activities" (De La Fuente 2011:89). These technical gestures are embodied, mediated, meaningful and collective practices (Dobres 2000). De La Feunte (2011), based in part on the work of Gosselain and Livingstone Smith (2005), focused on technical identity, or a final expression of technical practices by ancient technicians (2011:90).

Other archaeological work has meshed techniques and bodily gestures with material culture and linked this back to the French anthropological focus on identity through gestures (Knappet et al. 2010:593). In anthropological materiality research the gesture is often seen as the locus of engagement between mind and material (Knappet 2011). The notion of "praxology" allows for the embodied mind and movements, gestures and material culture to be examined (Knappet et al. 2010:596). Roddick and Hastorf (2010) emphasize the importance of bodily practice in maintaining society and forming social identities to examine the discursive and non-discursive aspects of the tradition of potting and other social practices. They argue that potting is "a bodily practice, in which the subtle cultural choices in production are seen in changing paste recipes, firing patterns, and surface finishes." (Roddick and Hastorf 2010:159).

Potter's gestures or actions transform matter, and traces of these actions and interactions can be seen in the physical traces left in material. To access these actions archaeologists have examined ceramic manufacturing techniques (De La Feunte 2011) sometimes through experimental studies. These are essentially a study of pressures, or the physical actions or gestures applied to clay (Berg 2008; De La Feunte 2011; Forte 2019). Through this, it can be seen how artifacts preserve attributes related to the technique that created them (Dietler and Herbich 1998).

These technical gestures left behind in the archaeological material are the result of the expertise or skill of a craftsperson, or lack thereof. Such expertise is not intrinsic but requires repeated practice and dedication of attention and time to a specific activity (Crown 2014; Forte 2019). Expertise of a craftsperson is expressed through the "correct sequence of steps and the ease of gesture reproduction" (Forte 2019:2). The craftsperson also has the ability to resolve and recognize the properties of raw materials they are working with while repeating the steps and gestures required (Bleed 2008; Forte 2009; Kuijpers 2017; Sennett 2008). The development of skill in potting (or other crafts) requires repeated practice of the steps required to manufacture a vessel. The repetition of intentional gestures, over time, produces a "habituated skill" (Forte 2019:4). The movements, pressure and efficacy of these repeated gestures can leave traces that can be tracked by closely examining the material record (Forte 2019).

In *The Craftsman* Sennett posits "the craftsman represents the special human condition of being *engaged*" (2008:20). Sennett argues that when the craftsperson is fully engaged, the hand, brain and eye are working in coordination using an "intelligent hand" to grip, touch and grasp materials as the craft is practiced (2008:174). Repeating "hand skills" or gestures over and over establishes a rhythm in which the craftsperson practices (Sennett 2008:175). When a craftsperson is able to perform actions again and again they have acquired a "technical skill, the rhythmic skill of a craftsman…" (Sennett 2008:177-8). Within this rhythmic skill, and with the repetition of bodily movements, the craftsperson has acquired a "repertoire of learned gestures" (Sennett 2008:178). In archaeological ceramic analysis we cannot watch these gestures in motion but strive to access the craftsperson through their products, hoping to gain a glimpse into the link between the head of the potter and hand of the potter so artfully described by Sennett.

When learning a skill, the repeated practice of steps involved is important. A craftsperson who has established a rhythm by repetition of these steps, and reached the higher stages of skill, practices within a constant interplay of "tacit knowledge and self-conscious awareness" (Sennett 2008:50). Artisans or craftspeople therefore make judgement calls while crafting based on tacit habits, learned through the repetition of gestures and coordination of the hand, brain and eye, and suppositions (Sennett 2008:50). This interplay sometimes results in what Sennett refers to as "adaptive irregularities" (2008:134), flourishes or additions used by craftspeople to cover, mask, or resolve an imperfection. Ingold explores similar notions when talking about "making" (2010, 2013), and how this involves the movement and continual response between material and maker, the goal of which is "not to give effect to a preconceived idea, novel or not, but to join with and follow the forces and flows of material that bring the form of the work into being." (2010:97). It is only once the craftsperson is skilled in their craft that they can continually correct as they work, monitoring and responding to the task as it unfolds (Ingold 2006:76-7). In this way, the skilled maker or craftsperson "improvises" by following "the ways of the world"; a process of making that is rhythmic, itinerant and looping between maker and material (Ingold 2010:99). These instances of improvisation and adaptive irregularities are used by skilled craftspeople as they engage in the practice of making, and the traces left behind in the archaeological record hint at the presence and existence of the craftsperson(s) (Sennett 2008:135). In the case of this research the craftspeople were the potters at the Arkona Cluster.

By using a communities of practice based approach, and micro-CT scanning, I observe the craft of ceramic making and attempt to move towards understanding the social practice of ceramic production. I examine intergenerational transmissions, and social change as it might be visible in ceramic manufacture. I use archaeological ceramic collections to access the *context* of production, not just production techniques, and seek to determine what this can tell us about communities in the past.

1.2 Case Study: The Arkona Cluster

As a case study, I scanned sherds representing 67 vessels from a tight, 3 km cluster of Late Woodland archaeological sites near Arkona, Ontario (about 40-50 km northwest of London). These vessels come from a series of contemporaneous and/or sequentially occupied sites dating to between ca. 1000-1270 CE. They existed within an archaeological borderland, generally located in space and time between what conventionally has been defined and labelled in archaeological culture history as the Western Basin and Ontario Iroquoian Late Woodland material culture traditions (Cunningham 2001; Watts 2006; St. John and Ferris 2019; see also Murphy and Ferris 1990). The material record of the Arkona sites, which is the resultant materiality of those communities living their everyday lives, challenges conventional archaeological type and trait classifications through variations evident in, among other dimensions of the archaeological record, ceramic manufacture and use of ceramic decorative styles. The communities and artisans from these sites were actively negotiating tradition and innovation in their material expression, and in doing so, left behind an archaeological record that underscores, for that time and space, a place between archaeological classifications.

Studies of borderlands in anthropology and archaeology examine areas where boundaries include not only physical, but social, cultural and political boundaries (Diener and Hagan 2012); boundaries that people “create and re-create” (Alvarez 1995:457). The actual lines are an “abstraction” (Donnan and Wilson 2010:8), while the reality consists of the border zones or lands where interaction takes place and where continual negotiation between boundedness and fluidity of people, goods, capital and information is practiced (Diener and Hagan 2012:9).

Borderlands are “places in between” (Parker 2006:77) where and “cultures and identities are constructed and negotiated” (Wendl and Rösier 1999:2); places where cultural innovations create and transform each other to from novel and unique social constructs (Lightfoot and Martinez 1995:472). Archaeological approaches have worked to redefine borderlands as spaces where people engage the material world under very specific geopolitical circumstances (Ylimaunu et al. 2014: 245) and where “two or more groups come into contact with each other, where people of different cultural backgrounds occupy the same territory and where space between them grows intimate" (Naum 2010:101). They are ambivalent and shifting landscapes that can contract into thin borders or expand into their own regions, and tent to be multicultural (Cusick 2000:48, Naum 2010:102).

Because of their ambiguous and frequently contested and renegotiated nature, identities on borderlands tend to be shifting, multiple, and locally constructed; nationality, ethnicity, class, gender, religion, sexuality and other factors are constructed differently at the border than elsewhere (Alvarez 1995:452; Cusick 2000; Mullin 2011c:103; Naum 2012:68; Newman 2006; Wilson and Donnan 1998:13). Individuals use aspects of common history, place, ancestry, occupation, ritual practices, gender, or symbols to identify themselves and most will maintain "overlapping, multiple nested identities" that may shift from one context to the next (Janusek 2002:36-37). Border areas are well documented to be areas for the creation of new identities and for the blending of languages, traditions, and peoples; in other words "hybridity" (Naum 2012). Social identities in borderlands are constantly in flux because the borderlands themselves are subject to ever changing conditions (Cusick 2000:46). By placing material culture within a borderlands context and acknowledging its situated and shifting nature, we can attempt to avoid and challenge interpretations of material culture linked one-to-one to ethnic identities and try to see variation in material as the result of the daily lives of individuals and communities.

These borderlands at Arkona provide a complex environment where old notions of "culture" as neatly bounded ethnic groups can be thrown out and people can be seen living in continuous social networks that transcend boundaries (Cunningham 2001:2). Because of the uncertainty surrounding the relationship between Western Basin and Ontario Late Woodland Traditions, researchers in this region have been able to problematize the notion of "peoples" represented ceramically by a suite of decorative attributes (St. John and Ferris 2019; Watts 1999:37). Negotiations and choices available to individuals living on or to either side of the imagined border might be notably different. Research on this borderland explores a place of tradition and transition, and engagement between individuals, families and communities. It is by adopting an approach that recognizes the fluidity of borders and the arbitrary nature of lines on the ground that the interactions at Arkona can begin to be understood.

The implications of this archaeology for a understanding of materiality and identity beyond archaeological classifications is a core focus of the SSHRC funded research undertaken on this cluster of sites directed by my supervisor, Dr. Neal Ferris, over the last decade (e.g., Armstrong 2013; Cunningham 1999, 2001; Ferris 2012, 2013, 2018; Foreman 2011; Gostick 2017; McCartney 2018; Morris 2015; Spence and George 2017; Suko 2016; Watts 2006). To date, at least nine Indigenous locales have been documented from this cluster of Late Woodland sites **(**Archaeologix Inc.1998, 2005, 2012; Golder Associates 2006, 2012).

The data from these sites reflects a hybridity and a "continually revising settlement, subsistence, and material tradition" (Ferris 2013:4). This complex archaeological setting allows for the exploration of the material tradition of ceramic craft, in order to understand embodied practices, human lives and continuity and change in the past (Roddick and Hastorf 2010). Research on the Late Woodland borderland area in Arkona explores a place of tradition and transition, of heightened innovation of expression and lifeways, and engagement with communities both within and beyond the Arkona (Ferris 2013).

Petrographic analysis comparing clay in pots found at Arkona to the local landscape would need to be completed to confirm if potters were harvesting their clay locally (Braun 2015; Ionico 2018; Michelaki et al. 2015; Striker et al. 2018). However, Late Woodland pots in Ontario are generally assumed to be made with clay from local sources. This local context is also assumed to have had an important role in encouraging or constraining practice and design choices made by potters (Watts 2006). In other words, the materials available to potters in their local contexts played a role in how they constructed pots. More generally, ceramic material assemblages from this period of the Late Woodland in Ontario consists of vessels that are grit-tempered coarse earthenwares, ranging from 4-15 litres in volume, with vertical to everted rims. They can be collared or not, and they have constricted necks, pronounced shoulders and globular bodies. They can be decorated on the interior, lip and exterior above the shoulder either on cord roughened or smoothed surfaces (Watts 2006:8). Decoration typically consists of stamping or incision in a series of horizontal bands, extending down from the top of the rim and through the bottom of the neck. Some vessels with more elongated necks are known to have multiple decorative zones, with neck designs often distinct from rim designs (Murphy and Ferris 1990; Watts 2006:9).

Conventional classifications and typologies can limit the understanding of how Late Woodland ceramics were manufactured. Essentially, what those studies have accomplished is that we know what Late Woodland ceramics look like from across this region and over time. This emphasis on description offers very little about how pots were made. More than two decades ago Howie-Langs (1998:8) stated “Almost nothing is currently known about the organization of Iroquoian ceramic production,” and this body of knowledge has grown only marginally since. Generally, in Ontario, archaeologists disassociate pottery from its producers and the social, technological and symbolic contexts of which they were a part, as Martelle (2002:10) noted. Emphasizing vessel manufacture shifts the focus of research from broad patterning and description to the learning, practices, and flexibility embodied in the technological decision making of potters (Martelle 2002; Michelaki 2007). While normative interpretations of decorative classification have been questioned as a reliable reflection of social boundaries or identity, the exploration of production techniques helps situate group and individual potters and their potting traditions (Cunningham 2001; Martelle 2002; Schumacher 2013). Using micro-CT analysis, I was more interested in different and similar practices, and the social boundaries these might represent, rather than where these might fall on either side of an imagined line between artifact typologies and traditions. Keeping in mind the borderland context of the Arkona Cluster, I tried to focus on micro traditions, artisan practices, knowledge transmission and generally how potters were making decisions across these sites.

By examining pottery manufacture, and not just macro descriptions of sherds, we can explore identities on archaeological borderlands in new ways (St. John and Ferris 2019). The variation in manufacturing techniques and micro traditions visible within and across assemblages of ceramics may be explained by the context in which they were produced, and through production, provide insight into material expression of community and social identity (e.g. Alvarez 1995:452; Cusick 2000; Gupta and Ferguson 1992; Janusek 2002; Jones 1997; Lightfoot and Martinez 1995:478-480; Mullin 2011a, 2011b, 2011c; Naum 2012:68; Newman 2006; Parker 2006; Wilson and Donnan 1998:13; Ylimaunu et al. 2014:248).

1.3 Analysis of Variables Relating to Ceramic Manufacture, Material Choices and Finishing

In the research conducted for this dissertation, much of my attention was focused on the strength of CT scans in examining how the potter was manipulating clay with their hands and other tools. A micro-CT scan is an excellent tool for exploring micro traditions or structural "fingerprints" (Sanger 2016) within the ceramics, which relate to production techniques and decisions that potters were making. Micro-CT scans can access many variables that relate to manufacturing, clay mixing and decorative choices made by potters. Visualizing these features and variables tied to the process of ceramic making in 3D is unique to CT scanning. Image analysis highlights micro scale similarities and differences in ceramic production techniques and idiosyncratic artisan practices. Image analysis in this dissertation was completed using VGStudioMAX 2.2 software, and a demo version of VGStudio MAX 3.0. This imaging software allowed me to record and analyze ceramic variables from volumetric data in 3D, sliced along X, Y and Z planes.

This dissertation also evaluates the potential of micro-CT alongside other micro ceramic analysis techniques, notably destructive petrographic thin sectioning. As micro-CT scans provide a complete visualization of the internal features in 3D across the entirety of a ceramic sherd instead of a limited 2D slice at a fixed location along the sherd provided by thin section techniques, micro-CT analyses have the potential to augment thin section studies with a more holistic understanding of vessel manufacture. 3D petrography is also an emerging field in the earth sciences, especially in the field of meteorite analysis (Griffin et al. 2012; Hsu et al. 2008; Johns et al. 1993), where researchers are working with unique, irreplaceable materials, like those we study in archaeology.

1.4 Chapter Summaries

Chapter 2 outlines what is known of Late Woodland ceramic manufacture in southern Ontario. This chapter explores work on archaeological ceramics in Ontario and especially what we know about ceramics for the early Late Woodland. Past work on ceramics in Ontario that have used different techniques and frameworks to interpret ceramics such as attribute analysis, *chaîne opératoire* approaches, petrography and microstylistic analysis are outlined. As well, I will review conventional cultural-historical constructions of the Western Basin and Ontario Iroquoian Traditions and ceramics, and the implications that work has had in understanding the Arkona Cluster of sites this study focuses on.

Chapter 3 provides a summary of different approaches archaeologists have used for ceramic analysis. This chapter sets up background for later discussion on how micro-CT studies can contribute to the existing field of ceramic material sciences.

Chapter 4 provides background and history on the use of X-rays in archaeology, and how CT and micro-CT has been used in archaeology, with a focus on ceramic analysis.

Chapter 5 outlines the micro-CT methods and protocols used in this study for scanning the Arkona ceramics. This chapter explains sample selection, how I conducted the scans, why I selected particular scanner settings and how I collected the data. It will conclude with what these protocols will allow me to explore and what their limits are.

Chapter 6 provides the results of image analysis. This chapter is divided into three main sections: elements of ceramic manufacture that can be examined with micro-CT images, variables relating to ceramic fabric recipes that can be examined with micro-CT images, and finishing and decorative elements that can be examined from micro-CT images. Comparisons between thin section and micro-CT data are also presented here.

Chapter 7 reviews how micro-CT analysis adds to our understanding of archaeological ceramic manufacture and how micro-CT interplays with other commonly used ceramic analysis techniques. I also consider what micro-CT scans can tell us about the craft of ceramic manufacture and potter community of practice at the Arkona Cluster. This chapter finishes by considering directions for further work including the potential for 3D petrography. More broadly, I consider the implications and limitations of micro-CT as a technique for archaeological ceramic analysis on a global scale.

Chapter 2

2 Late Woodland Ceramic Manufacture in Southern Ontario and at the Arkona Cluster

The research on Late Woodland ceramics in Southern Ontario is shifting from studying ceramics to studying all aspects of ceramics in daily life. This broadening of focus includes an emphasis on ceramic manufacture, as researchers begin to apply new analytical techniques and theoretical approaches. In the past, archaeologists used a culture-historical approach to ceramics (e.g. Fitting 1965; MacNeish 1952; Ritchie and MacNeish 1949; Stothers and Pratt 1981; Wright 1966, 1967, 1980) allowing us to orient ceramics and sites in time and space and within tenuous ethno-linguistic boundaries. Some more recent studies (e.g., Braun 2012, 2015; Cunningham 2001; Howie 2012; Mather 2015; Martelle 2002; Michelaki 2007; Parry 2019; Suko 2017a;Watts 2008), have begun to examine the technical properties, techniques, and social organization surrounding the craft production of Late Woodland ceramics. These researchers recognize the individuals and communities who were making ceramics and the complex negotiation of the material and decision-making that went into the production of vessels.

There have been several studies that focus on the role of women as potters (e.g., Kapches 2013; Latta 1999; Martelle 2002), though outright Feminist and Indigenous perspectives are mostly absent in Ontario ceramic research studies. Overall, the discussion of archaeological ceramics in Ontario has tended to focus on ceramics as things to describe and classify. Peter Ramsden's (1996:105) oft-cited lament about Huron-Wendat archaeology can, in some ways, be applied more generally to Ontario Late Woodland archaeology: there has been a reliance on the ethnohistoric record that has, at times, restricted novel interpretations and the application of contemporary theory. We can still see this in the study of Late Woodland ceramics: the methods of production have been assumed, rather than explored, and the discipline has sustained cultural-historical debates about types and attributes for a long time (e.g. Emerson 1954, 1968; Englebrecht 1980; MacNeish 1952; Ritchie and MacNeish 1949; Smith 1990; Wright 1966, 1980). Studies that focus on practices of production allow researchers to think about the craft, craftsperson, and the community those artisans interact within (Michelaki 2007). Likewise, studies that situate ceramics and broader lifeways within more nuanced, localized community formations engaging with material culture (Ferris 1999; Watts 2006) all invite a broader range of perspectives and interpretive frameworks applied to this material record. I hope to engage with and contribute to this growing body of research.

The case study in this dissertation will engage with and add to ongoing research by using an innovative means of accessing and "seeing" ceramic manufacture, knowledge and skill transmission in the assemblages from a series of the Late Woodland sites. These sites were situated in a part of southern Ontario that archaeologically was thought to fall within a material borderland between distinct archaeological traditions. Given this archaeological context, can micro-CT analysis of ceramics offer an innovative way to see beyond descriptive ceramic types and cultural-historical classifications, in order to access the craft and artisans making pottery in this time and place?

2.1 Defining Western Basin and Ontario Late Woodland Archaeological Traditions

The broad material expressions of commonality archaeologists classify and organize into defined suites of material traits are often known as "traditions" (Emerson 1954; Ferris 1999:6). Throughout this dissertation I will use "Ontario Late Woodland Tradition" to describe the material record associated with a material expression and group of traits that in past archaeological literature has been referred to as the "Ontario Iroquoian Tradition" (Wright 1966). While the Ontario Iroquoian Tradition reflects the connection that researchers have made between historical Iroquoian-speaking groups and past populations, I agree with Ferris (1999:18) and Schumacher (2013:7-8) in their discussions on how the term "Iroquoian" is a problematic label when assigned to Late Woodland peoples and how the societies of the 12th and 13th centuries may not have been "Iroquoian" in the way that later, historical groups were.

I also use the term "Western Basin Tradition" throughout this dissertation. This is not a reference to a group of ethnolinguistic Western Basin "People", but to an archaeological construct characterized by a suite of regionally similar material and settlement-subsistence expressions found in southwestern Ontario and extending around the western end of Lake Erie (Murphy and Ferris 1990). Conventionally, Late Woodland archaeology to the east of the Arkona Cluster through southern Ontario has been assumed to be the material expression of ancestral Iroquoian-speaking peoples first encountered by Europeans in the late sixteenth-early seventeenth centuries in that region. Archaeologists assume the Late Woodland archaeology in southwestern Ontario is the material expression of people who were ancestral to historically and ethnographically identified Algonquian-speaking or Anishinaabe peoples. These logics arise from twentieth-century archaeological conventions around social classification that fit these ethno-linguistic rubrics (e.g., Murphy and Ferris 1990; Wright 1966)

I am not comfortable saying these material traditions represent two distinct groups of people from two different language groups, especially across the broader region of southern Ontario where fluid ethnic identities and blending of languages may have been the norm. Language is only one aspect of ethnic identity, and ethnicity is self-defined (Jones 1997) and very difficult to push back beyond historic records, or even to define with historic records. As such, I have been careful to use Western Basin *Tradition* and Ontario Late Woodland *Tradition* throughout, emphasizing the material record, which archaeologists use to read lifeways and artisan craft, which offer insight into ancient peoples, however they may have thought of themselves as social groups in the past.

2.2 Background on Western Basin and Ontario Late Woodland Traditions

A complete history of the archaeology and taxonomy concerning and surrounding various groups of people associated with the early Late Woodland has been discussed at length elsewhere (e.g. Ferris 1999; Ferris and Spence 1995; Fitting 1965; Murphy and Ferris 1990; Stothers 1975, 1999; Stothers and Bechtel 2000; Stothers and Graves 1983; Watts 2006; Williamson 1990; Williamson and Robertson 1994; Wright 1966). It is not my purpose to re-examine the cultural syntheses of this region, but to examine how pottery manufacturing practices may have been interpreted in the context of these diverse cultural settings.

The differences between Ontario Late Woodland and Western Basin Traditions, once thought to be characterized by a clear boundary between village-dwelling agriculturalist "Iroquoians" and semi-sedentary hunting and gathering "Algonquian" ways of living, have become less and less clear as archaeological evidence accumulates and is re-examined from more nuanced viewpoints that try to escape dichotomizations between hunter-gatherer and agricultural ways of life (St. John and Ferris 2019)

The Western Basin Tradition was originally divided into temporal phases, labelled the Rivière au Vase (ca. CE 600-800 or 900), Younge (ca. CE 800 or 900-1200), Springwells (ca. CE 1200-1400) and Wolf (ca. CE 1400-1500 or 1600) phases (Murphy and Ferris 1990:194). The differences between these phases are blurred, but traditionally they are distinguished by changes in ceramic styles and settlement subsistence (Murphy and Ferris 1990). The earlier phases of the Western Basin Tradition are marked by the use of a diversity of site locales across a mobile landscape. Archaeological evidence suggests a diversified subsistence regime that leveraged increasing agricultural yields alongside harvesting seasonally abundant resources, in particular lacustrine and riverine foods (Lennox 1982; Kenyon et al. 1988; Murphy and Ferris 1990; Dewar et al. 2010; Armstrong 2013; Crawford 2014; Foreman 2011; Watts et al. 2011; Morris 2015). Increasing sedentism by the thirteenth century is seen in warm weather site locale shifts (Kenyon 1988; Lennox and Dodd 1991) and evidence of more substantial settlements, including bounded settlement patterns and presence of middens alongside smaller, seasonally based campsites (Fox 1982; Cunningham 1999; Watts 2008; Suko 2017a; Ferris 2018). Settlement patterns are marked by numbers of large, often deep pits, believed to represent storage or cache pits (Murphy and Ferris 1990). These storage pits are often the only features on a site, and are occasionally overlapping, suggesting multiple occupations (Gostick 2017).

The Ontario Late Woodland Tradition from the late 10^{th} century through the 14^{th} century witnessed noteworthy change, including more village-based lifestyles, greater emphasis on maize horticulture and changes in ceramic technology and style (Curtis 2004:44; Warrick 2000; Watts 2006; Williamson 1990). It is through this period that archaeologists suggest archaeological patterns reflect the emergence of "classic" ancestral Iroquoian expression (Smith 1900; Ferris and Spence 1995). Ontario Late Woodland Tradition settlement patterns also consisted of satellite communities, hamlets, agricultural cabins, and fishing and hunting camps (Lennox 1995).

Shifts in food procurement and production conventionally have been noted as a key element in understanding how these archaeological traditions differed (Armstrong 2013). People living on Western Basin Tradition sites were seen as being less reliant on cultigens, but this may not have been the case. There is growing evidence for a comparable level of maize consumption to that of their Ontario Late Woodland Tradition neighbours (Armstrong 2013; Booth 2015; Dewar et al. 2010; Morris 2015; Watts et al. 2011). These findings trigger questions about regional interaction, the role of food production and ceramic use, and how this relates to mobility and typical paradigmatic assumptions about how cultures change with agricultural production (Armstrong 2013:20). Foreman's (2011) zooarchaeological analysis of faunal remains indicated that Western Basin Tradition lifeways reflect a more diverse, mobile subsistence strategy than the more sedentary pattern to the east. However, people on Ontario Late Woodland Tradition sites also harvested a wide range of naturally occurring resources to diversify their agricultural economy, focusing on those close to their settlements (Williamson 1990)[1].

2.3 Ceramics in the Ontario Late Woodland

Archaeologists know what early Late Woodland ceramics look like, but very little has been said about how they were made and used. The ceramic material assemblage of the early Late Woodland in Ontario consists of pots that are generally grit-tempered coarse earthenwares, ranging from 4-15 litres in volume, with vertical to everted rims. Their rims can be collared (thickened band of clay) or not, and they have constricted necks, pronounced shoulders and globular bodies. They can be decorated on the interior, lip and

[1] Given that that grain processing and clay processing share similar skill sets (Martelle 2002:370-371; Michelaki 2007:156), it might be an interesting avenue of investigation to compare clay mixing and preparation, to explore whether the ceramic material belonging to the Ontario Late Woodland Tradition is mixed differently than the ceramic material with Western Basin Tradition traits.

exterior above the shoulder either on cord roughened or smoothed surfaces (Watts 2006:8). Decoration typically consists of stamping or incision in a series of horizontal bands (Murphy and Ferris 1990; Watts 2006:9).

Western Basin Tradition ceramics are well described in both Murphy and Ferris (1990) and Watts (2006). Ceramics from the eleventh to thirteenth centuries of the Western Basin Tradition exhibit a lot of experimentation resulting in different vessel forms, sizes and decoration. The vessels are generally 4-10 litres and elongated (Murphy and Ferris 1990:199-201). Rims often have castellations or incipient collars or "thickened" rims fashioned by folding or rolling clay from the lip and pressing it to the exterior before firing (Murphy and Ferris 1990:202-203; Watts 2006:88;). There may be single or multiple horizontal bands of vertical or oblique impressions on the exterior of the smoothed rim and lip fashioned with cord wrapped stick, dentate or linear stamping. Punctates or incised lines are often used as delimiters between decorative zones. The bodies are still cord roughened, but there may be a move from cord wrapped paddle to twined fabric on the paddle (Watts 2006:89). Diagnostic of the period through the eleventh and thirteenth centuries is elaborate and intricate decoration on a smoothed surface along elongated necks consisting of alternating open and filled triangle or diamond shapes (Watts 2006:88; Murphy and Ferris 1990:205). These vessels also have "bag shaped" bodies (Murphy and Ferris 1990:207). "Juvenile" or "learner" and miniature vessels are well made and frequently found in assemblages (Murphy and Ferris 1990:207).

Ontario Late Woodland Tradition ceramics are usually studied using attribute based approaches based on macro-analysis of exterior features (e.g. Howie-Langs 1998; Smith 1983; Timmins 1997b; Williamson 1985; Williamson and Powis 1998). They exhibit a high degree of similarity between assemblages in attributes including rim form, tool technique and design motif (Williamson 1985). By the twelfth century CE Ontario Late Woodland ceramics shift to rim and lip designs that consist of multiple rows of linear stamped oblique or incised horizontal lines (Watts 2006:92; Williamson 1985:287). There is some variation within these decorative techniques between regions and combinations of linear stamping, dentate stamping, crescent stamping and super-imposed linear stamped obliques all appear as common treatments (Watts 2006:92-93). Many of these trends continue for the next few centuries but decline after the mid-fourteenth century CE (Watts 2006:93). Vessel necks are generally short, and can be plain, decorated with bands of linear-stamped obliques, incised horizontal lines, or plaits of stamped obliques and often exhibit interior punctuation and exterior bossing on the neck (Watts 2006:93). Vessel bodies are cord-roughened below the shoulder and typically smoothed over on the neck and rim (Watts 2006:93), and have a globular shape and rounded bottoms (Williamson 1990:298). Rims are usually vertical to everted and often have castellations (Watts 2006:93), while vessels can be collarless or have incipient collaring (Williamson 1990:298).

That there has generally been very little said about the manufacture of ceramic vessels may in part be due to the fact that hard archaeological evidence for production is generally absent from the pre-contact archaeological record in southern Ontario. Multipurpose spaces within settlements and non-permanent manufacturing facilities make ceramic production in the archaeological record rather elusive (Allen 1992:144; Chilton 1998:143; Martelle 2002:49). Firing locations may have been located outside of village palisades or at peripheries of sites; areas that are rarely excavated in southern Ontario (Martelle 2002:368). Allen (2010) makes a tenuous case for evidence of pottery production within a longhouse structure from the mid to late 1500s in Haudenosaunee territory in New York State (based on high percentages of ceramic sherds and one piece of unfired, tempered, and shaped clay in features in one area of the longhouse), so it is perhaps the norm that evidence of these areas remains unrecognized rather than unexcavated. Some evidence of production has been uncovered in the form of small masses of clay and tempered clay (Martelle 2002; Pearce 1982; Timmins 1997a, 1997b; Wright 1974; Wright 1979), suspected “wasters” (Martelle 2002:380), and suspected production and firing sites (Kapches 1994; Lennox 2000). Most of the tools used for pottery making were probably expedient, used for other activities and were also organic, making them difficult to recognize within or absent from artifact collections (Cunningham 2001; Martelle 2002; Michelaki 2007). Often, the evidence cited for pottery production occurring on Late Woodland sites in Ontario is the presence of so-called “juvenile” or “learner” vessels, which potentially indicate that potting was likely being taught at the location (Martelle 2002; Mather 2015), though this does not account for the possibility that these small vessels moved with people.

Because there is such scarce archaeological data relating to ceramic production, archaeologists have often turned to historical sources. Studies of Late Woodland ceramics often rely on the scanty ethnohistoric record, though it tends to say very little concerning pottery or pottery making (Martelle 2002:6; Michelaki 2007:157). Mann (2014:273) went so far as to say there are "virtually no ethnohistorical accounts of pottery manufacture among Great Lakes Native societies". In reality, only a few brief descriptions have been documented (Martelle 2002:6-7; 2004:26), and Martelle's summary is often cited by archaeologists (e.g. Mann 2014; Striker et al. 2018). These accounts are also summarized in detail by Elizabeth Tooker (1964) and include Boucher in CE 1664 (translation in Kapches 1994:93), Sagard in CE 1632 (Sagard 1939; translation in Wrong 1968:109), and Lafitau's descriptions (cited in Waugh 1916:54). Sagard's is the most detailed account, describing vessel forming using a paddle and anvil technique (Martelle 2002: 6-9).While there is a lack of ethnohistoric and archaeological evidence related to pottery manufacture, this has not stopped archaeologists from suggesting techniques that the potters in the Ontario Late Woodland used. Some archaeologists note the introduction of the paddle and anvil technique in the Middle Woodland (Spence et al. 1990:148), and many archaeologists describe a shift from coiling techniques to paddle and anvil techniques at or around the beginning of the Late Woodland (Spence et al. 1990:144, Fox 1990:172; Murphy and Ferris 1990:195). This assumed shift from coiling to paddle and anvil is based on the appearance of thinner vessel walls through this transition, and the presence of paddle impressions on the bodies of vessels. Murphy and Ferris (1990:195), in their description of Western Basin Tradition ceramics, state that "thin vessels appear to be a result of replacing coiling techniques with paddle and anvil methods of manufacture, although Wayne wares of the Riviere au Vase Phase may often display coil breaks in the rim or neck area". Archaeologists have suggested a shift from coiling to paddle and anvil techniques as a key difference between Middle and Late Woodland pots, but this suggestion ignores the fact that both of these techniques can be used on the same pot. Speaking of one method "replacing" another in this time period is problematic (Mather 2015:55). Furthermore, certainly paddle and anvil techniques can help potters achieve thinner vessel walls, but implying that thin walls cannot be achieved simply by joining and pressing coils together indicates these archaeologists have not spent much time watching skilled potters work.

Undoubtedly, some Early Ontario Late Woodland Tradition pottery was made through the paddle and anvil technique (Stothers 1977). Ferris and Spence (1995:106) noted that later pots were formed through modelling, and walls were thinned using paddle and anvil techniques. Williamson (1990:298) describes the paddle and anvil process in some detail when describing Early Ontario Woodland Tradition ceramic production. However, other than noting paddle impressions on vessel surfaces, Williamson does not point to archaeological evidence to substantiate that description. In fact, when paddle and anvil technique is mentioned, much of the focus in the Late Woodland is not on the gestures or techniques involved in making these pots, but on the differences between paddle impressions: whether they be “cord-malleated” (Wright 1966:30; Williamson 1990:298), “fabric impressed” (Wright 1966:29-30), “ribbed” (Dodd et al. 1990:330; Murphy and Ferris 1990:216; Williamson 1990:298), “checkstamped” (Williamson 1990:298), or “smoothed over” (Williamson 1990:298). It is understandable that this has been an area of attention, since paddle impressions are readily visible on the exterior of pots, while the techniques and gestures of paddle use are more intangible. However, paddle impressions may indicate the ways in which the paddle was being used, and it is notable that this method of manufacture was shared widely between communities in the Late Woodland.

Ramsden (1990:365) describes Huron-Wendat vessels as appearing to be “…molded by the ‘paddle-and-anvil’ method, although a few instances of coil breaks exist. The pattern of breakage of vessels suggests that in many cases the body and neck were molded in one piece, and the flaring rim was fashioned separately and smoothed onto the neck”. While somewhat vague, here at least the “pattern of breakage” is cited as evidence for vessel manufacture. Although it is difficult to determine manufacturing techniques for most Woodland pot sherds (Mather 2015:55), there are some traits archaeologists can look for. These are summarized nicely in Mather’s (2015:43) thesis which cites Rye (1981) and Webb (1994). Coiling can be recognized by evidence of unsmoothed coils or coil breaks or the variation in wall thickness (Webb 1994). Pinch pots may show grooves related to fingerprints (Rye 1981:70) and molding can be recognized by impressions or reliefs of the mold on the interior surface and pressing on the exterior (Rye 1981:81). Paddle and anvil techniques can result in laminar fractures (a stepped breakage pattern), which may result from pressure and compression of the clay fabric, the presence of star shaped cracks that form around large mineral inclusions, or anvil impressions on the interior of the vessel (Rye 1981:85). Aside from noting coil breaks, these features are rarely noted or reported upon in any detail (Mather 2015 is the exception).

The manufacturing techniques used by Late Woodland potters have been assumed in Ontario archaeology, rather than demonstrated. Generalizing one manufacturing method to the entire Late Woodland is problematic, given that communities of practice were smaller than the distribution of these broad traits, and it is likely potting was an activity practiced at a community scale by individual artisans each with slightly differing ways of doing things. While there may have been a constellation of practice (Gosselain 2016) across the lower Great Lakes in the Late Woodland period, the community of practice in which potters were sharing knowledge and learning was more local.

Some archaeologists have suggested the causes for local variation in ceramic manufacture are the contexts in which these pots were manufactured. Chilton (1998) suggested that the degree of variability in ceramic manufacturing techniques was linked to degree of rigid social organization in examination of Algonquian and Iroquoian ceramics in the Northeast. Through a more nuanced approach, Watts (2006) also suggested that the regularity and results of ceramic production were influenced by the more permanent setting of potting production at Ontario Late Woodland Tradition villages compared to Western Basin Tradition settings that included fewer potters and more task scheduling around seasonal mobility. While there is little evidence for their methods of manufacture, the ceramics made at Western Basin Tradition sites and Ontario Late Woodland Tradition sites would have been manufactured in differing settings, as seen in the settlement trends. However pots were made, their manufacture was likely strongly influenced by the social environment in which they were being manufactured.

I am not the first to criticize the widespread assumptions about pottery making based on scanty evidence (Michelaki 2007; Latta 1991), but they also continue to be perpetrated in current literature. Archaeologists studying Woodland pottery in Ontario tend to give detailed descriptions of decorative and morphological attributes, while the process of manufacture remains largely assumed. As an extension of these assumptions, the variation in the craft of potting over time and space and what this variation might mean, is a neglected area of study.

2.4 Accessing Manufacturing Techniques: the Application of *Chaîne opératoire*, Petrography and Microstyles to Late Woodland Ontario Ceramics

Seeing "time and space" as the only viable interpretive use of ceramic variation has discouraged analysis of the manufacture and use of Late Woodland ceramics in Ontario (Martelle 2002:198; Michelaki 2007). Although it was noted decades ago as an interesting avenue for study (Latta 1980:159), it is only recently that researchers have begun to consider the choices available to potters in the operational sequence or *chaîne opératoire* (proposed by Leroi-Gourhan 1943, 1945, 1964, 1965; see discussion in De La Fuente 2011; Dobres 2000; Edmonds 1990; Lemonnier 1992; Ross et al. 2018; Schlanger 1994) of pottery production in the Late Woodland. This type of study examines all of the steps that go into making a pot.

French Anthropology of Technology approaches were developed independently in the 1960s and 1970s with their roots in Leroi-Gourhan's works on the notion of gestures, and the idea that technology is a "dialogue" between material and maker (1943, 1945, 1964, 1965). However, these *chaîne opératoire* and technological sequence approaches only really emerged in Anglo-archaeology at a later date with the 1993 translation of Leroi-Gourhan's ideas and English language proponents such as Lemmonier (1986, 1992, 1993) and others (e.g. Audouze 2002; Berg 2011; Edmonds 1990; Garcea 2005; Schlanger 1998; Van der Leeuw 1993, 1994) who advocated for *chaîne opératoire* approaches. *Chaîne opératoire* approaches focus on production sequences and the steps that go into the production of technology and material culture. *Chaînes opératoires* bring together raw materials, tools, learning, knowledge and representation systems, and a variety of agents together to define the context within which people work, and also how day to day practices are given meaning and shaped (Gosselain 2018). In this way, these approaches provide a valuable method of examining all of the steps of pottery production and also provide a framework or theoretical perspective in which to examine formation techniques.

Rye (1981:16-26) outlines the steps involved in the production sequence. Potters (or assistants) must first obtain materials. They then prepare materials, which usually involves removing coarse matter (including rocks and plant particles). This process of preparation is accomplished by drying and pounding clay, sieving wet clay or allowing wet clay to settle into its fine and coarse fractions. Next, the clay body (the blend of materials used for forming pottery; synonymous with "paste" or "fabric" when fired) is prepared. This stage of preparation involves blending additives (including temper) into the clay body, usually by hand or foot kneading. Once blended, the body must be brought to a workable consistency for forming vessels while reducing air pockets in the clay. This step can include drying, wedging or kneading.

Vessel forming operations are next. The potter judges the workability of the clay and then uses one of many techniques to form the vessel, including throwing, beating, coiling, slab building and moulding. In some forming techniques operations can be undertaken at different stages of plasticity, which can include primary forming completed on soft clay, while refinements, such as the application of paddle and anvil or attachments of handles, occurs as the vessel dries. Lastly, decorative elements are often applied at a "leather hard" stage when the vessel will "break rather than deform under pressure but can still be cut with a knife or fine wire" (Rye 1981:21). Once the vessel is formed, it must be dried slowly enough that it does not develop cracks. Potters become aware of appropriate drying rates for their materials and climates and pass this knowledge down to others. Sometimes surface treatments such as painting or adding a slip can occur at on the dry pots, but we rarely see this in Woodland ceramics.

Once completely dry, the pots are fired to temperatures high enough in order for clay-mineral crystals to break down (anywhere between about 500 and 700 degrees Celsius).

When heated to these temperatures clays develop the characteristic hardness, porosity and stability of pottery. Potters control the rate of heating, the maximum temperature and the atmosphere during the firing process. Firing can consist of open firing or kiln methods.

Attempting to study all of these steps in pottery production switches the focus from broad descriptive patterning of sherds to the study of the practice and flexibility that is available in technological decision making by potters (Mather 2015; Martelle 2002; Michelaki 2007; Woolsey 2018) and the dialogue between materials, tools, potters and the potting context (Gosselain 2018; Leroi-Gourhan 1993). While decoration alone has been questioned as a reliable reflection of social boundaries or identity, the combination of all production techniques is more likely to reliably identify individual potters, potting traditions, and communities (Cunningham 2001; Martelle 2002; Schumacher 2013).

There are a number of Ontario studies that have incorporated materials sciences and design theory approaches, often in combination with more social theory-oriented approaches (Michelaki 2007; Mather 2015; Martelle 2002, 2004; Schumacher 2013) to explore what a ceramic vessel does, and its use life, rather than just what it is as a collection of sherds. These studies examine one or several of the following patterns: sooting, encrustations, use alteration, orifice size and shapes, and carbonization patterns to determine function. Experimental archaeological work reproducing Late Woodland pottery, although informally done (e.g. Erika Johannsen, personal communication 2016; George 2004), is rarely formally published (see Sideroff 1980 as an exception). This exploration of the craft of Woodland ceramic making is mostly the domain of modern ceramic artisans; examples include the natural clay pottery courses run at the Museum of Ontario Archaeology in collaboration with FUSION: The Ontario Clay and Glass Association (Museum of Ontario Archaeology 2020), and the work of Wyandot artist Richard Zane Smith (Zane Smith et al. 2017).

Recent Ontario ceramic studies have also examined local clay properties and their importance in the sequence of ceramic manufacture, sometimes through petrographic analyses (e.g. Braun 2012; Cameron 2011; Curtis 2014; Howie-Langs 1998; Mather 2015; Martelle 2002; Striker et al. 2018). Others have studied local and non-local clay sources through petrography and their distribution within sites, to examine differing social processes such as coalescence (Howie 2012; Striker 2018; Cheng 2012). Howie's (2012) petrographic study of ceramics from the Mantle site determined that ceramics were made in highly variable ways, were produced both locally and non-locally, and juvenile vessels were fired, formed and sometimes tempered differently than adult vessels. Howie (2012:37) attributed this abundance of non-local fabrics and variability within the local production sequence to groups of people from different locations moving to this site, experimenting with local materials and being exposed to differing traditions (see also Striker 2018). Petrographic techniques allow for not only geographical recognition of source materials (although determining provenance in Ontario is difficult because of its glacial till geology), but also technological choices related to raw materials, fabric recipes, and vessel firing and forming (Howie 2012; Braun 2012; Cheng 2012; Striker et al. 2018).

Cheng's 2012 research focused on Wendat pottery from the Damiani Late Woodland Ontario Tradition site, looking at vessel production sequences and adopting a *chaîne opératoire* approach using petrography, chemical composition with SEM and microstructure analyses. Cheng's work aimed to fill the gap in Ontario ceramic research surrounding ceramic manufacture by exploring angularity and orientation of inclusions and air pockets. Based on observations of poorly mixed clay in well-formed pots and "juvenile" vessels, Cheng suggests that forming was probably taught before clay mixing and the application of decoration due to the lack of variation in production among juvenile vessels (all pinch pots). The lack of variation in forming techniques in Cheng's study indicates that perhaps children were being taught how to properly form a pot before being taught how to prepare fabrics, (2012:54-55).

Holterman (2007) examined ceramics from the Fonger site, a late sixteenth-early seventeenth century Ontario Late Woodland Tradition village, within a *chaîne opératoire* perspective. Holterman explored the choices potters made throughout the various stages of the manufacturing process and used a combination of raw materials survey and experimental approaches, along with macroscopic analysis, petrography, X-ray diffraction analysis, and re-firing tests. The author found that the way things were done was more of a reflection of social guidelines informing potters on how pots should be made than how pots needed to function. Slight differences in temper recipes also suggested the possible presence of two closely related yet separate groups of potters on the site (Holterman 2007:178).

Braun (2010, 2012, 2015), examined ceramics from middle and late Ontario Tradition sites, taking particular note of the choices made in manufacture. Based on an examination of manufacture, use, and discard, Braun (2010:81) divided the ceramics into four types, not the more typically used means of relying on decorative attributes. Braun's work has also focused on technological practices and how these can provide new insights into Late Woodland materiality and ritual. These various studies Braun undertook have focused on the social practices of production and distinct artisan communities within sites.

Some researchers in Ontario have examined vessel manufacture and microstyles (or micro-variation in the application of decoration) as a way to recognize artisanal skill, individual potters, and groups of potters (Gromoff 2000; Hawkins 2004; Martelle 2002; Watts 2006, 2008; Woolsey 2018). Microstyles are patterned behavior in individual, family and community manufacturing practices and traditions that are manifested through patterned combinations of features on ceramic vessels (Martelle 2002:256). Martelle examined vessel function, population relocation, ethnicity, and the organization of ceramic production, by adopting a multivariate approach that included the study of microstyles. Martelle (2002:39) used microstyles as a unit of analysis to examine individual potters, and closely interacting potters. Martelle focused on the "range of choices" available to potters when constructing pots such as materials, tools and techniques, as well as vessel form and decoration (Martelle 2004:26). These microstyles identified characteristic tendencies in motor habits and learned behaviours that were grounded in the specific contexts of learning and in unconscious kinesthetic actions in ceramic manufacture, such as differentiating tool use among individuals (Martelle 2002:38; see also Gromoff 2000; Schumacher 2013:40). Martelle's research was grounded in ethnographic and ethnoarchaeological literature that explored technical decision-making in traditional pottery manufacture and use, and the social contexts in which these took place, moving away from the overly simplistic view of ceramic making as simply one of women's many duties (Martelle 2002:6). Martelle's use of microstyles to describe the patterning and variability that results from habitual decision making in production has helped to shift the analytical focus on Late Woodland ceramics from describing decoration, to how things were actually done (Martelle 2002:14). Martelle (2002:20) used this more holistic perspective to examine raw materials, tools, the environment, potters, consumers, and the social, economic and ideological factors that surround pottery production.

2.5 Who Was Making Ceramics in Ontario? Examining the Individual and Community

While recognizing the individual in the ancient archaeological record emerged in the 1970s (e.g., Hill and Gunn 1977), this type of analysis has been only slowly integrated into Ontario Late Woodland ceramic studies. These studies shift the focus and scale of research from recognizing patterns of similar traits in ceramics and identifying "cultures", to examining the minute differences between individual vessels. Echoing works that have already explored the steps in manufacturing ceramics within their social context, research that examines the individual and community in ceramic manufacture is able to advance ceramic studies in Ontario beyond space and time classifications. Potting itself, when not practiced at an industrial scale, can be a social event which involves the transmission of knowledge from artisan to artisan. Outcomes of potting reflect norms and conventions followed and challenged by individual potters. Thus ceramic vessels are as much produced within the social constraints unique to each potter or group of potters, as they are mechanically the output of abstracted stages of manufacture. The steps in production that are learned communally may lead to identification within resultant archaeological assemblages of not only the individual but also the social group the individual participated within (Schumacher 2013).

2.5.1 Accessing Individual Potters and Communities of Potters Through Their Craft

When we look at potting as an artisan craft, no two potters will have used the exact same tools or gestures, decisions, and adjustments made in the process of making a vessel, nor will one potter always use repeated techniques. Several researchers have undertaken studies that aim to recognize individuals and social groups or communities of potters (Allen 1988:95-96; Braun 2015; Martelle 2002:12, Michelaki 2007; Schumacher 2013; Striker et al. 2018; Suko 2017a; Watts 2008). Functional and mechanical constraints are never severe enough to dictate the choices of potters. We need to recognize that there is a human, or sometimes several humans, at every step of production making a decision (Michelaki 2007:150).

Michelaki's 2007 study illustrates how we can begin to access potters by approaching Late Woodland ceramics through research grounded in ethnoarchaeological studies, social theory and the social nature of technology. Michelaki effectively uses shell tempered pottery that appears on late 16th and 17th century sites to shift the focus from broad trait patterning to the practice and flexibility in technological decision making and the lives of potters. Michelaki examined the choice of Late Woodland potters to adopt shell temper, keeping in mind the need for materials not only to be functionally viable but to fit into the "symbolically appropriate options" for potters (2007:149-150), emphasizing that a purely functional approach to ceramics is often limiting since ceramics are part of a "socio-technical web" in which each individual grows up and learns in an environment with ideas about which resources, tools and techniques are appropriate. Michelaki's is one of several studies that encourage archaeologists to think about potters and not just pots (e.g. Braun 2015; Martelle 2002; Watts 2006; Holterman 2007).

2.5.2 Accessing Aspects of Potters' Identity: Gender, Age and Craft Specialization

There is a general tendency in Ontario archaeology to assume that pots are equated with women and that women produced vessels for mostly their own family's use throughout the Late Woodland (Latta 1991). In the later Late Woodland, pottery was sometimes constructed by women who played a large role in the matrilocal, matrilineal Iroquoian societies recorded in ethnohistoric records (e.g., Heidenreich 1971; Trigger 1976; see also Brown 1970).

This general assumption cannot be extended uncritically into the more ancient past of the Late Woodland in Ontario. Nonetheless, there exists a strong tendency in Late Woodland archaeological research on ceramics that ideologically and physically women were tied to the household, food distribution, hospitality, and cooperation which includes being likely producers of "domestic crafts" such as ceramics (Allen 1988:108; Allen and Zubrow 1989; Englebrecht 1974; Martelle 1999, 2002:340-344; Smith 2005; Striker et al. 2018). In work on Huron-Wendat ceramics, Martelle (1999, 2002) examines the ways that gender and craft production and technological systems interplay in terms of labour organization. Martelle rejects the assumptions about simplicity, domesticity, and labour intensity of ceramic manufacture that relegated it to "housework" (2002:27) and acknowledges that these vessels were sophisticated technological achievements. In other words, regardless of gender tendencies, the craft of making pots required the training and experience of artisanal skill, and the scheduling of work within the broader rhythms of daily life.

Beyond gender, the labour of making vessels could also have been shared by age and skill (Martelle 2002:419). Smith's (2003, 2005) research on decorative trends suggested networks existed between three generations of potters: children, mothers, and grandmothers, all of whom were participating in making pots at Ontario Late Woodland sites in the 13th-16th centuries. Latta (1991:376) noted that potters could exhibit a lot of freedom in interpreting traditional concepts; daughters do not necessarily learn potting from their mothers, potters can make a range of different pots, and also exchange and borrow ideas over their life as an artisan. Certainly, some women were potters, but not all women were potters, and not all pots were necessarily made by women. While some iteration of shared practice among family members may have been the case, it is still important to note that a site assemblage encompasses a cacophony of practices, levels of learning, skills, and multiple divergent, fluid social interactions contributing to the eventual material assemblage.

Indeed, while adult women were probably often potters, children were also likely active participants in ceramic manufacture in Late Woodland communities (Birch and Williamson 2013:128; Howie 2012; Mather 2015; Martelle 2002; Pearce 1978; Smith

2003, 2005; Speirs 2019; Timmins 1997a). A whole range of small vessels ranging from roughly made specimens to well-made “miniature” vessels are found on Woodland sites in Ontario. These vessels can range from unfired, untempered or undecorated pinch pots or slightly formed hollowware objects to well-formed, tempered, and decorated vessels in miniature size. Conventionally, some or all of this part of a ceramic assemblage tends to be thought of as “juvenile” ceramics, reflecting an assumption that they encompassed children learning, playing, or emulating adult making.

While some of these ceramics can be thought of more properly as “learner” vessels, and some were certainly made by children, some vessels might more rightly be thought of as miniature vessels. These vessels ranged in size from a few centimetres to 15-20 cm in height and held a limited volume of content. Some of the “larger” of these miniature vessels may have served as person-sized food containers or otherwise met individual needs (e.g., Murphy and Ferris 1990). Miniature vessels may have also more socially have functioned in storytelling, represented some symbolic significance, or been used to store seeds, medicine, pigments, or had other functions (Martelle 2004:28). Of the studies that have examined ceramic production or manufacture in the Late Woodland, a high proportion have focused on “juvenile” or learner vessels, considering how these sherds suggest learning was passed on through manufacture (Retter 2001, Smith 2003, 2005, Timmins 1997a). These studies focus on a particular part of the learning process and transfer of knowledge, but have generally been cursory overviews. They do not examine the manufacturing process itself in detail or aim to recognize manufacturing techniques that may be specific to certain communities or individuals, or across entire ceramic assemblages.

Children are undeniably important when examining change or innovation, and tradition in potting techniques and have been the focus in much of the ceramic manufacture research in Ontario. Retter (2001:76) briefly examined differences between manufacturing techniques and made distinctions between older and younger juvenile producers. Retter also discussed how forming techniques seemed to be of primary importance when learning to make pots, while applying decoration came later, suggesting that decoration was not as critical as form for the non-cohesive Western Basin tradition materials examined (Retter 2001:99). Smith (2003, 2005) briefly examined motor skills and consistency of wall construction but primarily studied decoration in learner vessels. Smith (2006:72) also suggested that because so many learner pots are undecorated, forming may have been learned prior to learning decorating or finishing skills.

It has been assumed, in part, because of long-held beliefs regarding the absence of craft specialization in egalitarian societies that Late Woodland ceramics were made by non-specialists at the household level (Howie-Langs 1998: 11; Martelle 1999, 2002:41-44). A few studies have come to this conclusion based on the heterogeneity of ceramics within village assemblages and within longhouse collections from those villages, and citing the presence of learner vessel sherds as evidence that many individuals learned to make pottery (Allen 1988, 1992; Warrick 1984). Others (Martelle 1999, 2002; Cameron 2011:39-42) suggest craft specialization was present at least in some places and at some times, such as on contact period Huron-Wendat village sites. It is certainly worth reiterating that just because women were potters this does not mean that *all* women were. Only some women might be potting based on social position, ideological structures (taboos, rituals), technical aptitude and level of skill, or because of seasonal subsistence constraints that required the division of labour at certain times of year (Allen and Zubrow 1989; Cheng 2012; Martelle 1999, 2002). It is highly efficient to have a single potter or single potting group provisioning a community or larger household as it ensures quality and consistency; potting requires specialized knowledge and practice (Martelle 1999). Martelle argues that because pottery quality declines after European contact and endemic disease that potting skill and knowledge, at least in the contact period, was likely held by a few specialists who may not have passed it down. Ionico, when examining ceramic communities of practice in early 17th century Neutral Iroquoian assemblages, similarly suggested that socio-demographic turbulence lead to “an increasing movement away from regimentations in communities of practice” (2018:167) and heighted variability within production chains.

2.6 Archaeology of and on the Arkona Cluster

Conventional material analyses between sites identified as either Western Basin Tradition or Ontario Late Woodland Tradition have argued that there is a regional and temporal shift in the boundaries of these two material traditions in Southwestern Ontario throughout the Late Woodland Period. For example, Murphy and Ferris (1990) note a westward expansion of Ontario Late Woodland Tradition-like materials across southwestern Ontario from around 900 CE up to the 16th century. Around ca. 1100-1300 CE, this boundary or transition appears west of modern day London (Figure 2.1), with distinct Western Basin Tradition materials noted as far east as the Dymock site, near Glencoe Ontario and the Montoya site, near Strathroy Ontario (Foreman 2011; Fox 1982; Retter 2001), while Ontario Late Woodland Tradition materials are noted as far west as the Caradoc Sand Plain (Watts 2006; Williamson 1980).

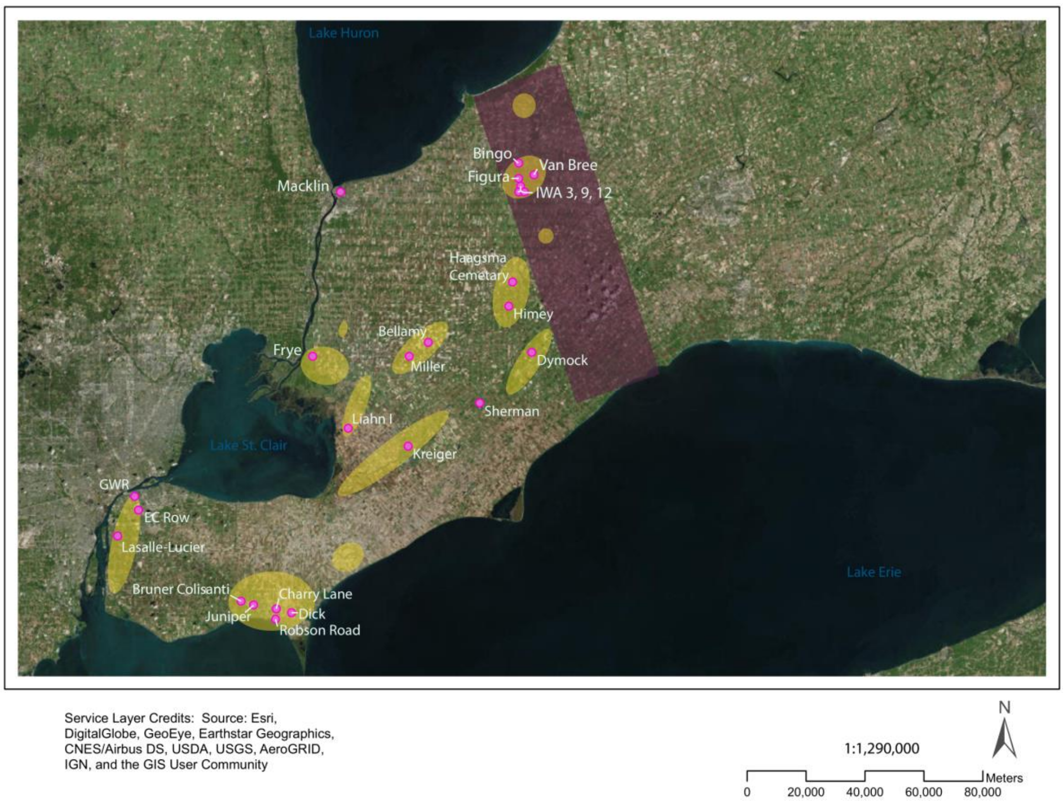

Figure 2.1: Archaeological Late Woodland site clusters across southwestern-most Ontario, ca. 1100 through the 1300s CE, encompassing Western Basin Tradition material expression. The extent of the transition or material borderland is depicted very broadly. To the east are extensive clusters of archaeological sites more commonly associated with Ontario Late Woodland Tradition material expression (Neal Ferris, modified with approval).

Sites consist of mostly smaller, seasonally-occupied locales to the west and village and "hamlet-like" settlements to the east. This pattern shifts westward through the 14th century, as noted by, among others, David Riddell (1998). In the ca. 1100-1300 CE period, a cluster of sites that geographically fall within the material transition between these two archaeological traditions have been documented in the Arkona, Ontario area (Ferris 2018). While there is some indication of a local settlement in the area by 1000 CE (Cunningham 2001), there remains a notable absence of sites in this area after 1300.

While preliminary analysis of the material culture from the Arkona Cluster has been attributed to the Western Basin Tradition due to ceramic styles and mortuary patterns, some Arkona Cluster sites also exhibited settlement patterning and ceramic attributes more typically associated with Ontario Late Woodland groups to the east (Ferris 2018; Spence and George 2018; St. John and Ferris 2019; see also Archaeologix Inc. 1998, 2005, Golder 2012a, 2012b). A total of 10 archaeological sites were subject to Stage 4CRM archaeological mitigation strategies between 1998 and 2008, seven of which contributed ceramic vessels for my micro-CT analysis. The sites include a range of different settlement patterns, including sites consisting of small clusters of storage pit features, and sites with more complex settlement patterns including houses and palisades (Figure 2.2).

A brief overview of the variable settlement patterns found at the Arkona sites sampled for micro-CT analysis follows.

At the Van Bree site (AgHk-32), there was an incomplete house structure, along with westerly, central and easterly pit feature clusters (Archaeologix 1998:47; Cunningham 2001).

At Bingo Pit Location 3 (AgHk-40) two house structures were inferred based on limited post mould and pit patterning, and presence of hearths (Archaeologix 2005).

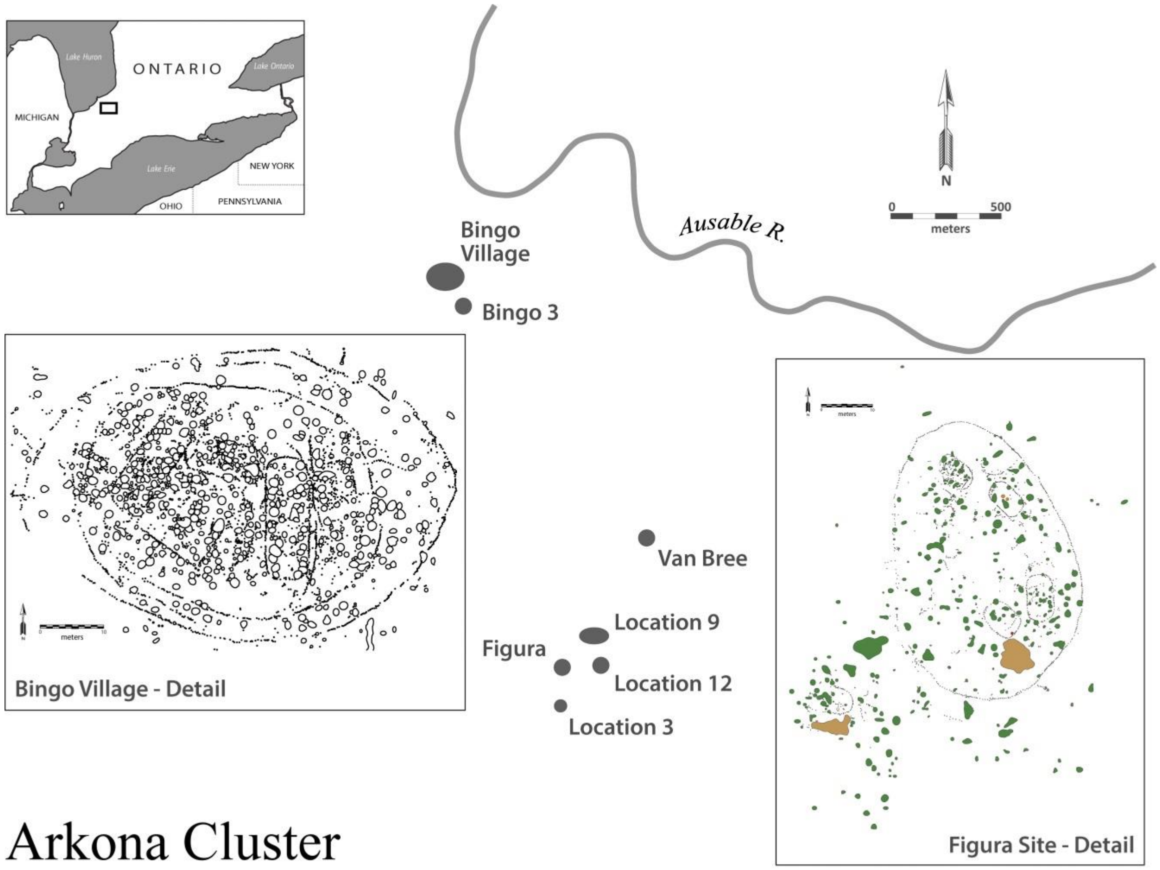

Figure 2.2: Arkona site cluster, southwestern Ontario. This map depicts the cluster of Late Woodland sites excavated in the Arkona area. Inset are settlement plans for the two larger sites excavated from this cluster. Originally published in Ferris 2018, from Christopher Watts; used with permission.

The Figura site (AgHk-52) excavations revealed a 0.5 hectare, single palisade village with five small houses and an associated midden (Golder 2012a:53; Gostick 2017). Exploration of the pit features on the site revealed that few of them were overlapping, suggesting that the site was occupied for a relatively short period of time and not repeatedly (Gostick 2017:104). The settlement pattern at Figura, with a palisade and several houses, was one that was not previously thought to be typical of Younge Phase Western Basin Tradition sites (Murphy and Ferris 1991:244).

The Inland West Location 3 site (AgHk-54), which was located immediately to the south of the Figura site, consisted of a number of features arranged in three clusters (Golder 2012a:79). At least one of the feature clusters was interpreted as evidence of a longhouse structure present on the site (Suko 2017a).

Inland West Location 9 (AgHk-58) was partially excavated. Excavations revealed a possible single row of palisade encompassing a range of feature clusters and limited structural remains (Golder 2012a), that may suggest a village-like settlement pattern.

Excavations at Inland West Location 6 (AgHk-56) revealed only 3 features and no substantial settlement pattern (Golder 2012a).

Located in close proximity to Bingo Pit Locations 3 and 5, about 1.5 km from Figura and the other Inland West sites, the Bingo Pit village (AgHk-42) was dramatically different from other sites excavated at Arkona (see Figure 2.2). Excavations revealed a triple palisaded village, with four house structures surrounding a central plaza area that was marked by heavily overlapping pit clusters (Golder 2012b). The feature overlapping suggests intensive use of the area, through a suite of radiocarbon dates for the site also suggests the period of occupation of the site was relatively brief and occurred near the end of the Arkona Cluster occupation (Neal Ferris, personal communication 2019; also see Figure 2.3). There were also 13 burials on this site, which were reinterred by the Kettle and Stony Point First Nation (Spence and George 2017).

While radiocarbon dates from the Van Bree site suggest initial Late Woodland settlement of the Arkona area occurred in the eleventh-century CE (Cunningham 2001), the wide suite of radiocarbon dates from most of the sites used in this study point to a late twelfth-century through late thirteenth-century period of overlapping or sequential site occupations (Figure 2.3). Two radiocarbon dates from Van Bree provided calibrated dates of 1029 and 1038 CE (Cunningham 2001). The seven Bingo site dates suggest it was occupied sometime between 1220-1260 CE, and for Figura the greatest probability for the six dates falls between 1210-1230 CE (Neal Ferris personal communication 2020). One date from Location 3 yielded an AMS date of 800 ±30 BP, calibrated to a range of 1200-1270 CE (Suko 2017b:239). The remainder of the dates from the other sites also fall into the Bingo range, but with the Bingo site falling at the more recent end of the sequence. Over the approximately 270 years of occupation at the Arkona Cluster there were probably somewhere between ten to 14 generations of potters at work (Weiss 1979). However, all the sites excluding Van Bree fall into a roughly 50-70 year time period from the early to mid-13th century, meaning most of the pots in the cluster were produced by between three to five generations of potters. These unique settlement patterns, extensive collections of artifacts, and their location on a material borderland between Western Basin and Ontario Late Woodland Traditions have led to the Arkona Cluster becoming the focus of a growing group of researchers examining Arkona settlement patterns and material expressions (Ferris 2018).

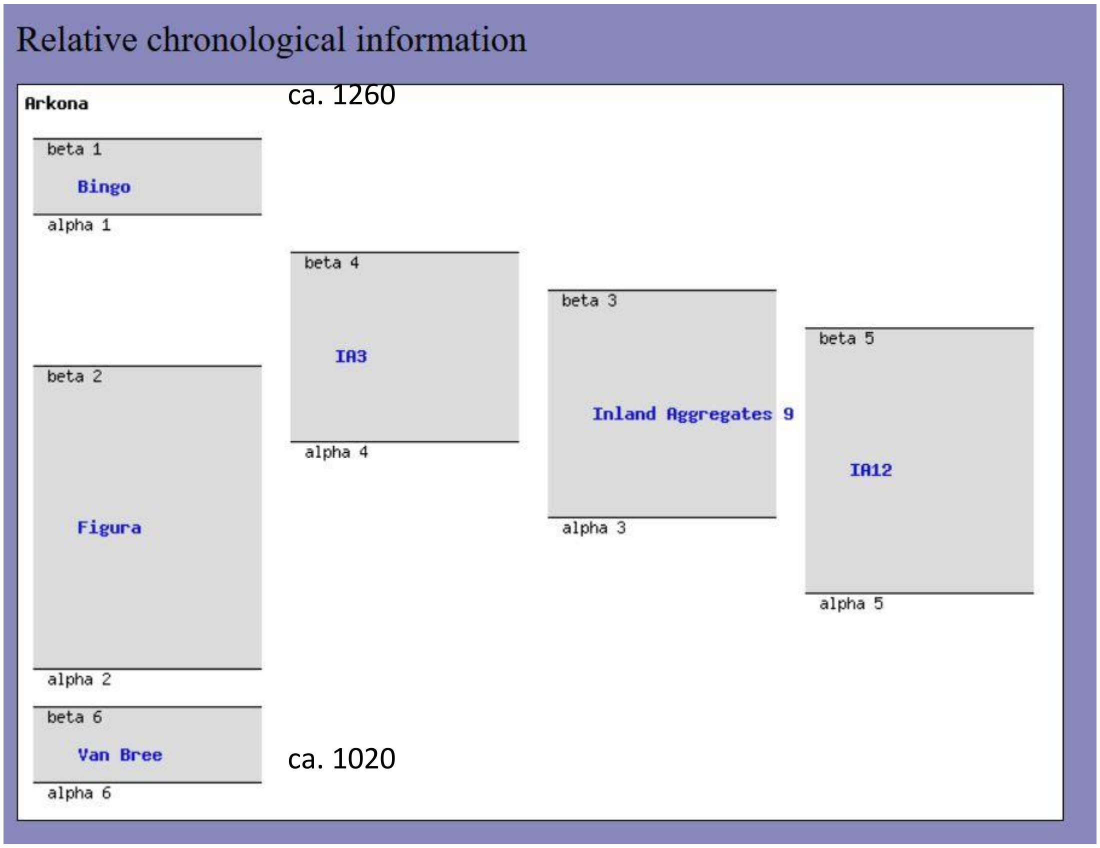

Figure 2.3: Ferris (personal communication 2019), reports that, to date, 19 dates (17 AMS, 2 conventional) were run on carbonized botanicals from six of the Arkona Cluster sites. A preliminary sorting of those dates using Sheffield University's BCal program (https://bcal.shef.ac.uk/) suggested a relative chronological ordering of those sites. Given the variable number of dates obtained for each site, this ordering is tentative. Note: IA or "Inland Aggregate" is referred to as "Inland West" throughout this study.

Research by Gostick (2017) on the Figura site explored the features and spatial patterning of features documented from this site. That research found that the characteristics of these pit features, when considered in context, can help to both reveal individual moments of daily life in a community and relate to spatial patterning over the entire life of a site. Another study on the ceramic and stone smoking pipes by McCartney (2018) from the Arkona Cluster explored how these pipes acted as a material expression of different communities of practice on this borderland. Further, pipe use, manufacture and discard varied from site to site at the Arkona Cluster, suggesting multiple distinct communities of practice were making pipes within this cluster of sites (McCartney 2018:104). Other studies have focused on floral and faunal patterns across the cluster, or as part of broader Late Woodland studies for southwestern Ontario (Armstrong 2013; Foreman 2011; Morris 2015).

Ceramics have been one of the main foci for researchers examining both differences between Western Basin and Ontario Late Woodland Traditions more widely (Murphy and Ferris 1990), and at the Arkona Cluster. Cunningham (1999, 2001) conducted an intra-site analysis of the Van Bree site ceramics, arguing that the assemblage included both Western Basin and Ontario Late Woodland vessels. This research relied on cross-mends (fitting pieces of ceramic together found from differing contexts) and feature clusters to suggest these ceramics were produced by potters expressing these two distinct ceramic Traditions (Cunningham 2001:3). Cunningham (2001:3) proposed that decorative variety did not correspond necessarily with ethnicity, but rather reflected processes such as the scale, frequency, and social context of ceramic production. Results indicated that when production is taking place on a "cultural borderland," the recognition that "others do things differently" results in normal practices being recognized as something culturally unique, though both groups in this case were influenced by each other and ethnicity does not appear to have been highly structured, typical of a borderland situation (Cunningham 2001:13).

More recently, Watts' (2006, 2008) study focused on ceramics from sites both east and west of the Arkona area, and also included the ceramics from the Van Bree site. Watts found distinct practices related to vessel production and shape, which indicated that potters from all sites tended to work from an intuitive understanding of "proper" design (2006:195-196). Watts also noted that decorative practices and symmetry for the Western Basin Tradition were not as firmly adhered to as he found within Ontario Late Woodland Tradition pottery (ibid). Watts (2006:7-8) suggested that Ontario Late Woodland Tradition potters expressed a fairly "well-knit" design repertoire; a unified design scheme and core elements of both form and decoration, which was internalized by potters at a pan-regional level. Potters producing Western Basin Tradition pots used more diversity in their pottery in terms of its morphology, decoration and patterns of symmetry that may reflect a community identity (Watts 2006:7-8). Murphy and Ferris (1990:201) also noted that "a wide range of vessel forms, sizes and decorative motifs" are present on Western Basin Tradition ceramics.

Watts examined how the qualities of form and decoration in pottery can be seen to have channeled artisanal practices that were enacted on a day-to-day basis, which contributed to either a continuance or alteration of structure (2006:3). Watts employed a phenomenological approach, emphasizing that it is through physical engagement of the human body with things that we come to know the world, focusing on the processes that go into making a pot and are scheduled across daily living (Watts 2006:5-6). Watts' (2006:37) solution to examining material culture amongst conflicting definitions of "style" in archaeology was to conceive of artifacts as embedded co-habitants in networks of social thoughts and actions, not just as signs of behavior or holders of meaning; parting from the notion that craft traditions are equal to "ethnic" or cultural norms (62-63).

Watts' (2006, 2008) work has greatly influenced subsequent studies undertaken by researchers exploring the ceramics of the Arkona Cluster (e.g. Suko 2017a). Suko's research focused on Location 3 of the Inland West sites investigated by the consultant archaeologists. Suko's analysis of the ceramics from that site also found potters engaging with both westerly and easterly ceramic practices, notably that potters applied Ontario Late Woodland Tradition elements within a Western Basin Tradition potter's sensibility.

Overall, previous research has suggested the presence of fixed, semi-permanent or permanent settlements thought to be typical of Early Ontario Late Woodland Tradition settlements (Williamson 1990:318-319), and the more informal, short term settlements typical of Western Basin Tradition settlements (Murphy and Ferris 1990:261) may have been partly responsible for the heterogeneity in ceramic attributes between and within Western Basin Tradition sites, and the relative design homogeneity of Ontario Late Woodland Tradition ceramics (Retter 2001; Watts 2006). It may be the case that potters working within the Ontario Late Woodland Tradition shared knowledge and passed down a more delimited set of ceramic attributes through a day-to-day production within a longhouse-oriented setting of permanence and stability (Watts 2006:100). Potters making pots that fall within the Western Basin Tradition may have differently made ceramics at regular intervals and at certain times of the year, but probably at a smaller scale and without a fixed social context; allowing for more experimentation and lessening the durability of designs (Cunningham 2001:14; Watts 2006:101). People producing Western Basin Tradition materials were probably loosely allied groups that gathered irregularly (Murphy and Ferris 1990:270). All of these patterns emerge in ceramic products as they are examined by the archaeologist, and these patterns can lead to a greater understanding of the social contexts of production (Watts 2006:209).

Archaeologists working in the Arkona Cluster have shown that a borderlands perspective is extremely useful for interpreting the complexity of material remains that cannot be easily slotted into either Western Basin or Ontario Late Woodland Traditions (St. John and Ferris 2019). Work on the Arkona Cluster of sites highlights the problems of tying material differences to normative constructs and cultural-historical typologies that have assumed ethno-linguistic affiliations. Research indicates that pottery design elements were the result of the unique positioning of the potters in their communities and had more to do with the circumstances of potting as part of their daily lives, and the communities of practice in which they belonged, than the ethnicity of the potters.

If we think of the activity of potting as an ongoing interaction between potter and materials, as Watts and Suko suggest we do in our approach to the Arkona assemblages (Suko 2017a:25; Watts 2009), then this interaction can be best understood by studying material traces that are left by this dynamic interaction and social process. This material borderland cluster of sites serves as an excellent example of how material culture, in particular ceramic material, has been instrumental in examining the materiality of ceramic making in place and time. Negotiations and choices made by individual artisans or communities of artisans living and practicing within a specific time and place, would have had to have “made sense” to individuals and communities (St. John and Ferris 2019). Recognizing the fluidity of borders and the arbitrary nature of lines drawn around archaeological material traditions, as the archaeology of the Arkona Cluster requires of us, may allow us to explore identities and cultural norms that may have been developed, maintained, and revised through practice, not inscribed on, or proscribed by, the material (Jones 1997; St. John and Ferris 2019).

2.7 Summary

Understanding communities of potters and individuals (analytical or otherwise) who were making ceramic vessels in the early Late Woodland period in southern Ontario is advancing away from normative tendencies of classifying and typing objects. Micro-CT analysis has the potential to enable us to look at potters and potting, including primary formation techniques, in a way that has not been done before. This method gives us a unique perspective on the types of ceramic features that can help to explore manufacture without the necessity of destructive thin sectioning (Cheng 2012; Braun 2012, 2015; Howie 2012). Morphology and the motor performance gestures associated with ceramic formation are not as likely to be subject to the kinds of discursive manipulation decorative motifs are, because they are grounded in the unconscious and are more slow to change over a few generations of potters (Creese 2012; Michelaki 2007: 159; Martelle 2002:124; Watts 2006:195). There are differences *between* forming methods but also *within* them, determined by the particular gestures and motor habits of a potter (Michelaki 2007:160). This subtle variation is something that may be seen more readily through micro-CT scans than through any other technique, since internal structures are telling of formation processes (Berg 2008; Carr 1990). Researchers in Ontario have begun to examine Woodland ceramic formation methods, but they focus on microstylistics, or aspects such as form, decorative techniques and external attributes such as symmetry, not the interior architecture of ceramics.

This micro-CT analysis is the first study in Ontario to examine not just the macroscopic properties of ancient vessel manufacture, but the interior of pottery with the intent of recognizing how these vessels were formed, and the choices potters made in that process of production. Production studies have brought about a new way to look at style and ceramic material expression, and can change the way we think about ceramics, considering the activity of pottery making, not just the attributes of pottery, in the Ontario Late Woodland.

This shift in focus applies specifically to ceramics in the early Late Woodland. Ceramic manufacture and decorative concepts were shared broadly across regions. These practices were also constantly being modified, redefined, and understood locally by individual potters (Curtis 2014:188). Broad ceramic innovations were not isolated to one small group, but tended to be circulated throughout southern Ontario and the Great Lakes through this time and across intense interregional interaction (e.g., Jamieson 1999; Nassaney and Sassaman 1995). These innovations became incorporated into or left out of local production through the "agency of communities of potters" (Curtis 2014:188).

The ceramics from the Arkona Cluster are an ideal test case for exploring the strengths of micro-CT for providing new insight into potters and pottery making from archaeological ceramics. These ceramics are also ideally situated to explore the implications of assumed differences between Ontario Late Woodland and Western Basin Tradition ceramic expression. Using micro-CT analysis to research the ceramic production methods—how the clay was mixed, manipulated, and formed into vessels by potters—in this Arkona borderland can speak to past research that has emphasized a blending of practices and knowledge traditions here (St. John and Ferris 2018). The insights from micro-CT analysis of these ceramics will reveal a community of local artisans intentionally engaging with and manipulating ceramic expression from these two traditions (Suko 2017a). By furthering research on this cluster of borderland sites I contribute to moving archaeology in Ontario away from equating ceramics with "ethnic" groups and cultural-historical norms, and towards an understanding that accounts for fluidity, variations in expression, communities of practice, and contributes to a larger discussion around what "material traditions" mean (St. John and Ferris 2019).

Chapter 3

3 Archaeological Approaches to Ceramic Vessel Manufacture

As long as archaeologists have been investigating ceramics, they have struggled to recognize how pots were made. Focus on ceramic manufacture has been limited by the techniques available to, and the practices of, archaeologists, because most traces of earlier stages of manufacture are either wiped away or covered over with decorative elements in the finishing stages of vessel making. As such, the focus of most ceramic analysis to date has been on the visible exterior attributes of ceramics and how they might allow for temporal, spatial and cultural associations. By allowing us access to interior elements of ceramics, micro-CT studies can supplement limited understanding of how pots were made in the past in Ontario. This chapter offers a summary of the different approaches archaeologists have used for accessing ceramic manufacture, including macroscopic examination, petrography, other archaeometric approaches, and X-radiography.

3.1 Macroscopic Examination

Macroscopic visual examination, which allows archaeologists to classify and compare assemblages has long been the default means of exploring archaeological ceramics. These techniques ae used to access everything from exterior decorative attributes, the morphology of the vessel or vessel parts, to attributes of manufacture visible on exterior surfaces of ceramic sherds (e.g., Courty and Roux 1995; Livingstone Smith et al. 2005; Rice 1987, Rye 1981). Some archaeologists have started to use technologies such as 3D scanning (Karasik and Smilansky 2008; Koutsoudis et al. 2009) as a method of ceramic analysis, as a replacement for time-consuming illustration procedures, and as a way to disseminate information.

I will not delve into notions of ceramic “style” here, as it has been discussed at length elsewhere (e.g., Conkey and Hastorf 1990; Hegmon 1995). Archaeologists have traditionally turned to stylistic elements of pottery to locate cultural meanings and distinctions of style, especially technological style (Dietler and Herbich 1989; Hegmon 1998; Hodder 1982, 1985, 1990; Plog 1980; Sackett 1977, 1986; Sassaman 1998; Sideroff 2005:41-42). Ceramic style has been explored as a way of transmitting information (Wobst 1977), or emblematic messages (Wiessner 1983, 1990). Lechtman (1977), and others (e.g. Braun 2010, 2012, 2015) have since began to study technical practices as not just survival and adaptation strategies, but as symbolically meaningful, developing notions of technological style. These practices were not just environmental but cultural choices that actively involved artisans and arose as the result of interaction between communities (Deetz 1965; Hill 1970; Longacre 1970).

Traditionally, in regional contexts like Ontario, pre-contact ceramic analysis has used visual examination to record different variables related to the form, function and stylistic characteristics of the pottery (e.g., MacNeish 1952; Ramsden 1977; Wright 1966). For much of the twentieth-century, archaeologists took a normative approach to ceramic studies, creating types that were assumed or asserted to be equated with social groups and cultures (e.g., MacNeish 1952; Ritchie and MacNeish 1949; Wright 1966, 1967). Archaeologists also described traits of ceramics and developed typologies and types based on ceramic styles and used these for chronology building. These early typologies allowed archaeologists to situate ceramics and sites in time and space, but said little if anything about the people and potters who were using and making pottery (Chilton 1998).

Most visual ceramic analyses in Ontario have fallen into two categories: qualitative typology or attribute-based systems of analysis and classification. While not all attribute analyses are used in this way, inventories of types and attributes have been used to as a material proxy for signaling “ethnicity” and linguistic affiliation both in the past (MacNeish 1952; Ritchie and MacNeish 1949; Wright 1966, 1967), and continue to be used this way in Ontario archaeology (e.g., Cunningham 2001; Hart 2012; Hart and Engelbrecht 2012:345; Hart et al. 2016; Hart et al. 2017). These normative frameworks are sustained in Late Woodland research even when these constructs arguing ceramic decoration as signaling ethnicity conflicts with Indigenous-led research and understandings of the past (Gaudreau and Lesage 2016). In archaeological consulting reports in Ontario, where ceramic decoration is one of the main factors used to determine affiliation for Woodland sites, MacNeish and Ritchie's ceramic types from the 1950s still hold sway.

Some attribute-based approaches are more sophisticated than others. As an example, Watts (2006) used the following attribute variables for data: which part of the pot is represented in the sherd examined, the profile of the sherd, castellation form, lip form, upper rim form, lip thickness, collar height, basal collar thickness, surface modification, decorative completeness, inferred tool used to make the decoration, decoration technique, motif, and symmetry of the decoration. This extensive study described each of these attributes and the percentages for each across the site assemblage studied, then ran a correspondence analysis between assemblages (Watts 2006:229), to offer observations about the similarities and differences of these visibly observed ceramic traits between site collections. Many attribute approaches, and most type-based approaches, stop at this point and use this data to affiliate archaeological sites with archaeological traditions in time and space, or more problematically to determine the ethnicity or linguistic affiliation of the pots.

However, Watts (2006:3) went further and examined how qualities of form and decoration in pottery can be seen to channel artisanal practices enacted on a day-to-day basis, and which contribute to either a continuance or alteration of structure. He employed a phenomenological approach, emphasizing that it is through the physical engagement of the human body with things that we come to know the world (Watts 2006:5-6). In this way, this research departs from the notion that craft traditions are equal to "ethnic" or cultural norms, (Watts 2006:62-63), which is so widespread in Ontario ceramic analysis.

Many archaeologists conducting visual examinations will look for evidence of the method of manufacture, and various stages of forming or finishing at a vessel- or sherd-level of analysis within assemblages. This evidence can include visible coil breaks and cracks where rims were folded over, or evidence of paddle and anvil manufacture, through secondary forming techniques can obscure these on the exterior of vessels (e.g., Mather 2015; Martelle 2002; Rye 1981). Macroscopic analysis, while valuable for describing morphological and decorative attributes on the exterior surfaces of pots, is typically only able to minimally comment on the manufacturing techniques and the overall production process followed by potters.

While visual examination is a vital, excellent starting point for ceramic analysis, my research is not focused on placing ceramic assemblages in time and space, or determining cultural affiliations without considering how potters were making pots. Analytical techniques from micro-CT scans that focus on how potters were interacting with their materials and each other in a community of practice is much more the primary aim of this research.

3.2 Petrography

By the late twentieth-century, micro-analyses and material science approaches to ceramic studies have come to augment and further advance research from macro visual analysis. In particular, petrography has long been recognized as a valuable, micro-analytical way to study archaeological materials (Worley 2009), and many archaeologists are engaged in ceramic petrography today. Primarily research is based on the analysis of 2D thin sections taken from ceramic sherds. Petrography requires destructive methods to obtain a useable thin-section (Bishop et al. 1982; Freestone 1995; Neff 1992; Bishop et al. 1982; Reedy 1994, 2008; Rice 1987). In particular, to create a thin-section, a sliver of pottery is cut from a larger sherd or vessel, encased in epoxy, and ground so that the specimen is flat. It is then mounted on a glass slide and polished so that it can be viewed under a microscope between two polarizing filters. Different minerals have different light polarizing properties and can be identified in this way (Rice 1987:379-381). Ceramic petrography is mostly undertaken on coarse low-fired utilitarian wares from archaeological assemblages. It is not as commonly used in North America as in Europe. Still, a recent interest in technology, craft traditions, identity and knowledge transmission has created an increase in the application of this form of analysis in North American contexts (Quinn 2013; Reedy 2008).

While Stoltman (1989, 1991) and Braun (2012), in earlier work, used a point-counting technique derived from geology to describe vessel clay matrices, inclusions, and voids visible in prepared thin sections, most petrographers tend to rely on a descriptive technique derived from both sedimentary petrography and soil morphology developed by Whitbread (1995; see for example Howie 2012; Quinn 2013; Quinn and Burton 2009; Teconi et al. 2013; Whitbread and Mari 2014), or an approach that combines elements of both methods (Braun 2015).

Petrographic studies can answer a number of questions relating to ceramics. The main aims are compositional characterization and classification, interpretation of provenance, and reconstruction of ceramic technology (Quinn 2013:4-5; Reedy 2008; Riederer 2004). Primarily though, it has been used to examine provenance: to source the material origins of clay, temper and natural inclusions in ceramic fabrics, in order to determine networks of exchange (e.g. Dickson et al. 2013; Maritan et al. 2009; Michelaki et al. 2012; Teconi et al. 2013; Thompson et al. 2008; Whitbread and Mari 2014).

Some researchers have taken a more holistic approach to their findings, using ceramic petrography to also examine raw material processing, the intentional addition of temper, vessel forming techniques, and the degree of firing as choices made by artisans related to pottery production (e.g. Cheng 2012; Braun 2012, 2015; Day et al. 1999; Druc and Gwyn 1998; Howie 2012; Pentedeka and Dimoula 2009; Quinn 2013; Quinn and Burton 2009; Thér 2015; van Doosselaere et al. 2014; Whitbread et al. 2007; Whitbread and Mari 2014). Several studies use petrographic data to examine possible firing temperatures based on the vitrosity of ceramics or the minerals present (Quinn and Burton 2009; Teconi et al. 2013). Some petrographic studies (Braun 2015; Ixer and Vince 2009; Jorge 2009) attempt to account for decisions made by potters in early stages of production, such as the choice to select easily recognizable mineral types or the use of fire-cracked rocks as temper. All of these technological choices seen through petrography reflect traditions of pottery making, suggesting that, “potting may say as much about the society as pots” (Kreiter et al. 2009:101).

Petrographers usually take one thin section per sample, although Quinn (2013:21-23) notes that more sections are better for interpreting forming or manufacturing techniques, and vertical sections are necessary, if petrographers want information for formation techniques as well as provenance data (Quinn 2013:23). Quinn and Burton (2009) examined micro-structural evidence for technological processes through the orientation of voids and inclusions with some success. Though one of the biggest proponents of examining forming and manufacture using thin sections, Quinn also notes that it is rare for thin sections to really show an alignment of inclusions (Quinn 2013:83).

3.3 Other Archaeometric Techniques

A diverse array of other archaeometric techniques can be used in conjunction with CT, X-radiography, petrography, and macroscopic examination. These include neutron activation analysis, X-ray diffraction, X-ray fluorescence, atomic absorption spectroscopy, Mossbauer spectroscopy, inductively coupled plasma mass spectrometry, and others. In materials science, such techniques fall into the category of characterization studies (Bronitsky 1986). They can inform us about the makeup of ceramic materials but do not typically add understanding to forming techniques. Archaeologists have been using these techniques since the pioneering work of Shepard (1995 [1956]; also see Matson 1952 for a review of earlier studies). These archaeometric techniques have been reviewed in detail elsewhere (e.g. Bishop et al. 1982; Goffer 1980; Harbottle 1982; Kilikoglou et al. 2002; Neff 1992; Peacock 1970; Wilson 1978). Of particular note are applications of backscattered scanning electron microscopy (SEM) in ceramic studies (e.g. Freestone and Middleton 1987; Froh 2004; Tite and Maniatis 1975; Tite et al. 1982). SEM is used in mineralogical investigations of archaeological problems, including the characterization and provenance of geological raw materials, as well as formation and post-depositional processes.

3.4 X-radiography of Archaeological Ceramics

X-radiation is a type of electromagnetic radiation that penetrates objects in reverse proportion to their atomic density. The energy is then captured as a greyscale image on a monitor or film in 2D (Berg 2011:57). Since its discovery in 1895 (Röntgen 1896), X-radiography has been used successfully to examine archaeological objects (see Lang and Middleton 2005 for a summary, and also Casali 2006; Morigi et al. 2010; Pantos 2005). X-radiography has been used for ceramic analysis by several archaeologists starting in the first half of the 20th century (Digby 1948; Titterington 1933; see also Berg 2009; Carmichael 1990; 1998; Glanzman and Flemming 1986; Laneri 2011; Magrill and Middleton 2001, 2004; Maniatis et al. 1984; Nenk and Walker 1991; Vandiver 1987). Notable here were the contributions in the 1990s of Carr and colleagues who conducted studies using radiographic methods that advanced the field and revealed the utility of radiography for determining vessel formation techniques and the potential for petrographic studies (Carr 1990, 1993; Carr and Komorowski 1995; Carr and Riddick 1990).

X-radiography has been used for the characterization of clay fabrics for composition and provenance studies and for identifying sherd to vessel matches (Adan-Bayewitz and Wieder 1992; Berg 2008, 2011; Blakely et al. 1992; Braun 1982; Carr 1990, 1993; Ellingson et al. 1998; Foster 1985; Maniatis et al. 1984; Middleton 2005; Rye 1977, 1981). There has also been extensive work seeking to identify primary forming techniques used in vessel construction (Berg 2008, 2009; Pierret et al. 1996; Rye 1977; Tite 1999), attachments of handles, spouts or straps (Digby 1948; Foster 1983; Leonard et al. 1993), and identification of repairs and breaks (Middleton 2005). X-radiography analyses were found to be unable to effectively identify more subtle secondary forming techniques and surface treatments on vessel exteriors (Berg 2011:57). The one exception might be the paddle and anvil technique that obliterates primary forming technique traces but leaves its own distinctive pattern of inclusions (Rye 1981).

X-radiography can be easily used to identify the basic formation process of ceramic vessels. Tite (1999) suggested radiography could be used to explore formation techniques through void and inclusion orientation and to reveal joins between coils and slabs used to make a pot. Berg (2008) determined, using an experimental data set, that X-radiography could accurately determine the primary forming technique and in some cases secondary forming techniques, and that surface treatments had no effect on the X-radiographic visibility of the primary forming technique. The success of X-radiographic attempts to identify temper visibility was mixed, however: the voids left by organic temper proved to be visible, but some minerals with similar radiodensities to clay, like sand and quartz, proved difficult to see (Berg 2008). Carr (1990) also outlined the potential of X-radiography as a way to study hidden features (joins, voids and the size, type, density and orientation of inclusions) within ceramic materials, while Berg (2011) demonstrated the value of the technique to offer minute details such as coil height or hidden drying and firing cracks. Rye (1977) and others (Pierret and Moran 1996) have looked at X-rays to determine if the orientation of inclusions are related to the initial forming technique and found that even rather poor-quality images could provide information on of how vessels were formed based on void and inclusion orientation.

Pinching, ring and coil-building, slab-building, drawing, moulding and wheel-throwing through elongated void and temper orientations were established by Rye (1977, 1981) and further discussed by Berg (2008). Carr (1993) used radiographs to reveal the internal traits that differed from vessel to vessel including: temper fractional volume, temper size, temper distribution, temper material, void spaces and fracture systems, and noted that different minerals exhibit a wide range of specific gravities and lightness compared to clay.

Still other studies have suggested that X-radiography could be used to identify the mineralogy of temper and inclusions using traits similar to those used in petrography. For example, Carr and Komorowski (1995) conducted blind tests using X-radiographic techniques to identify minerals in a collection of 726 sherds of Ohio Woodland pottery. They found that people familiar with petrography could identify minerals from X-radiographs at a 75-85% success rate. This study outlined the advantages of radiography over thin sectioning: crystal faces are visualized, more sherds can be tested because the analysis is non-destructive, and as such, interpretations can be made from a more representative sample. Other research suggests that, while size, morphology, number and angularity of crystal faces might point to specific types of inclusions, similar radiodensities and morphologies in temper (such as those of chert, quartz and sandstone) may prevent more precise identification than classing into felsic, mafic and opaque minerals (Berg 2011:57). Inclusions must be greater than 0.5mm in size to potentially be identified, and as such mixed clays and grog, if they have differing densities, as well as organic inclusions such as straw, wood, insects, shell, and seeds, are recognizable (Berg 2011; Day et al. 2006; Foster 1985). Middleton (2005) also pointed out the potential for interpreting radiographic densities of different particles to gain insight into their mineralogical identity.

More recently, Alan Greene (2013) and colleagues (Greene et al. 2017) used X-radiography to examine ceramics and developed protocols for both established and new archaeometric methods. They incorporated qualitative data (related to production methods) as well as quantitative data such as the size and density of inclusions and voids. Green and Hartley (2009) employed post-processing tools that take advantage of the metric matrix qualities of digital imagery. By using statistical manipulation and applying algorithmic filters, Green et al. (2017) were able to identify features and matrix patterns in greyscale that were imperceptible to the human eye. They were able to identify four types of ceramic sub-structures, including inclusions and voids. They recorded the shape, size and radiodensity of these structures using a custom software routine written in Interactive Data Language entitled “Sherd Image Viewer and Analysis.” While they found digital radiography data useful for basic understandings of ceramic manufacture, they acknowledge that it compresses the full sample into a 2D view, which conflates overlapping sub-structures and gives little sense of the depth of these features. They encourage future research into 3D techniques such as CT scanning, but advocated for the pre-screening of ceramics with inexpensive and fast X-ray techniques before CT analysis is undertaken.

3.5 Summary

Most analysis on Ontario Late Woodland ceramics (with a few exceptions, e.g., Cheng 2012, Howie 2012, Braun 2012, 2015; Striker et al. 2018), and ceramics in general have been limited to examining macro exterior attributes. That approach to the analysis of ceramics served conventional archaeological classificatory and typological needs of practice through much of the twentieth century. More recently, the advent of material science studies on vessel manufacture, as well as on more nuanced theoretical frameworks for thinking about the craft of and artisans involved in manufacturing vessels, have invited researchers to think differently about the place of vessels and ceramics in the material lifeways of communities and makers. Many of these techniques have been successful in exploring the materials that were used to make ceramics, as well as determining if ceramics were made locally or not.

Most recently, X-radiographic analyses of ceramics have come to offer additional advantages to researchers. It is non-destructive. It can visualize larger sections of the sherd or vessel than other conventional microscopic methods and, as a result, provides more information on the orientation of voids and inclusions in the clay fabric and overall structure of the clay body (Laneri 2011). X-radiographic analyses can be completed relatively cheaply and quickly (Berg 2011:57; Greene et al. 2017). However, X-radiography is best considered a complementary tool rather than a replacement for petrography and chemical analyses. In the examination of the characterization of fabrics, thin section analysis is considered better than traditional radiographs because of the greater magnification and the recognizable optical properties of minerals that are lost when represented in greyscale. Visual examination, petrography, X-radiography, and other material science techniques have added to our understanding of ceramic manufacture over time, but in Ontario archaeology there are still more assumptions than certainties. Micro-CT analysis has the potential to further advance our understandings of ceramics by building from these material science advancements.

Chapter 4

4 The Use of Computed Tomography (CT) and Micro-Computed Tomography in Archaeological Ceramic Analysis

This chapter provides a summary of how computed tomography and micro-computed tomography have been used as research tools to advance a material science in archaeology, with a focus on ceramic analysis. Micro-CT and CT studies related to archaeological ceramics are reviewed based on their focus on either the manufacturing techniques used to build ceramics or the mineralogy of inclusions and temper. These two areas are the main contributions of micro-CT and CT ceramic analysis to date.

4.1 Micro-CT and CT Analysis in Archaeology

Though primarily used in bioarchaeological applications (e.g. Friedman et al. 2012; Kaick and Delorme 2005; Lieverse et al. 2017; Longato et al. 2015; Mays et al. 2014; McErlain et al. 2004; Morgan 2014; Nicklisch et al. 2012; Smith et al. 2016; Swanston et al. 2013; Wade et al. 2011; Xing et al. 2016), the use of micro-CT and CT analysis holds promise for most classes of archeological materials and is a rapidly growing field (e.g. Barron et al. 2017; Baum et al. 2017; Bettuzzi et al. 2015; Bertini et al. 2014; Bird et al. 2008; Bradfield et al. 2016; Conlogue et al. 2010; Conlogue et al. 2020; Ellis et al. 2019; Makovicky et al. 2015; Miles et al. 2016; Morigi et al. 2010; Stelzner & Million 2015; Stelzner et al. 2016; Suda et al. 2017; Tuniz et al. 2013; Tuniz and Zanini 2014; Tourigny et al. 2016; VanLoon et al. 2019; Van der Linden et al. 2010). The range of applications in archaeology has quickly grown over the last decade and I offer here only a survey of the range of archaeology-related research that has emerged in recent years through CT and micro-CT imaging applications.

Indeed, CT and micro-CT technology have a wide application across a diverse range of digital imaging science fields of research and industrial applications, and long history of development (see for example Boyd 2009; Hoffman and deBeer 2012; Hsieh 2009; Morgan 2014; Ritman 2004; Rudolph et al. 2012; Stock 1999, 2009). Other material sciences fields have also begun using micro-CT and CT technologies, notably in meteorite studies (e.g. Griffin et al 2012; Hsu et al. 2008), and cultural heritage and museum studies (e.g. Able et al. 2011; Ball et al. 2011; Casali 2006; Séguin 1990). For the purpose of this dissertation, I will focus more on the outcome and potentials of micro-CT in archaeology generally, and in ceramic analysis, in particular, and how this application compares to other methods.

Micro-CT is a non-invasive, high-resolution imaging technique (Boyd 2009:3; Conlogue et al. 2020; Stock 2009). The fundamental components of any CT system include an X-ray source, the object stage, and the detector (Boyd 2009; Ritman 2004). The system used for this research is operated by Western University. It operates as an in vitro system, where the object is placed on a rotating stage, rather than in vivo where the source and detector are rotated (like most systems used in hospitals) (Boyd 2009:5; Hoffman & deBeer 2012; Figure 4.1).

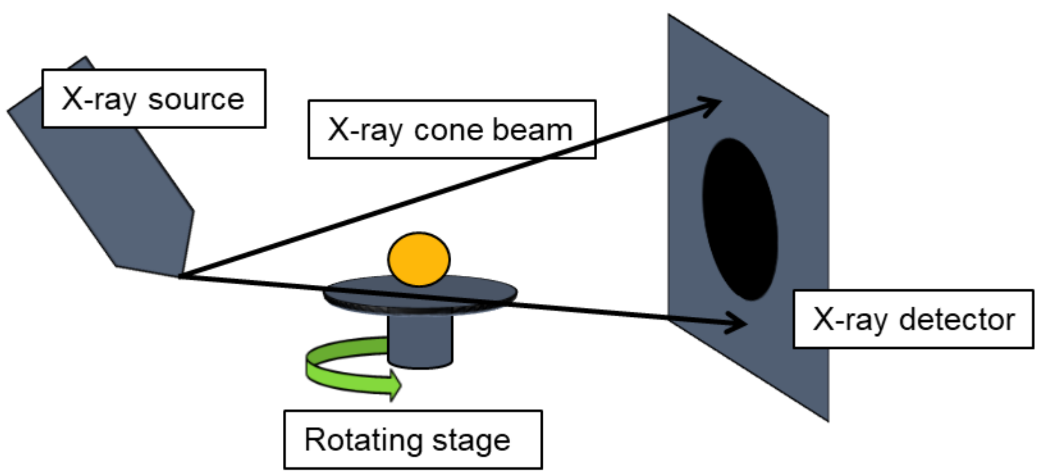

Figure 4.1: Components of in vitro micro-CT scanner system (after Stock 1999).

Micro-CT technology provides high resolution digital X-ray 3D images of the interior and exterior of archaeological artifacts through non-destructive volume data collection of CT scans that can be sliced in any direction (Conlogue et al. 2020; Stock 2009). A flat-panel detector eliminates the need for acquiring data slice by slice, thus allowing the acquisition of fully volumetric images (Pan et al. 2008). Stock (2009) emphasizes the importance of collecting volumetric data using a filtered back projection algorithm, as opposed to single slices/projection images. The volumetric data is made up of voxels, which are 3D pixels (Conlogue et al. 2020). Micro-CT is generally defined as “an X-ray unit with a small focal spot paired with a high-resolution detector that can produce a volumetric scan with voxel sizes in the 1 µm to 50 µm range” (Conlogue et al. 2020:165). In this chapter I use “micro-CT” to refer specifically to studies using micro-CT units and “CT” to refer to studies using clinical systems. The digital images provided by both CT and micro-CT applications illustrate features inside the object, positioned in 3D, and provide information on internal structure and density (Boyd 2009; Landis and Keane 2010).

4.2 Micro-CT and CT of Archaeological Ceramics

To date there has been limited application of CT and particularly micro-CT analysis of ceramics recovered from archaeological contexts. Studies undertaken include primarily preliminary projects, scanning small samples of three to ten ceramic sherds (e.g., Kahl & Ramminger 2012; Kahl et al. 2012; Machado et al. 2013; Machado et al. 2017; Sanger et al. 2013; Sobott et al. 2014), as well as a few larger scale studies of between 30-55 sherds (Kosastas et al. 2018; Sanger 2016; 2017). While most studies to date have been focused on manufacturing techniques (Kahl and Ramminger 2012; Kosastas et al. 2018; Machado et al. 2013; Sanger et al. 2013), some also explore inclusions in clay (Kahl and Ramminger 2012; Kahl et al. 2012; Machado et al. 2017; Sanger et al. 2013; Sobott et al. 2014) and potentially determining provenance for the inclusions in clay. These studies have all recorded different variables and present findings in different ways, both qualitatively and quantitatively, as a result of the differing aims and technologies used in this research. Indeed, an initial hope for this research consisted of trying to establish a methodology for large scale ceramic scanning, and to determine which variables should be recorded and how best to analyze these in 3D.

Studies that use clinical CT scanners for ceramic analysis are closely related to micro-CT studies in terms of techniques used and research foci. It is not surprising that these archaeological studies using CT and micro-CT are relatively recent, since CT scanning was invented by Hounsfield in the 1970s (Bates et al. 2012; Hounsfield 1973; Kalender 2006), and micro-CT scanning did not first emerge until the 1980s (Flannery et al. 1987). Most authors define micro-CT as CT that has results with at least 50-100μm of spatial resolution (Stock 2009:1), but others make the cut off for *micro* as “better than 1μm” (Landis and Keane 2010), or from 20μm-1μm (Ritman 2004:185). Though not as high in resolution as micro-CT or as widely used in ceramic studies as X-radiography, there have been studies that have used CT with success. Notably, CT scanning has been used to access bone fragments contained within ceramic cremation urns (Anderson and Fell 1995; Harvig et al. 2012; Minozzi 2010), and to examine ceramic museum objects or pottery sherds (e.g. Applebaum and Applebaum 2005; Jacobson et al. 2011; Vandiver et al. 1991), or to characterize ceramic groups based on their attenuation values using dual energy CT scanning (McKenzie-Clark and Magnussen 2014).

From this brief overview of micro-CT and CT studies, the potential of 3D imaging in ceramic analysis becomes evident. Multiple authors have emphasized the ability of CT scanning to provide valuable information non-destructively about formation techniques in ceramic materials without the overlap of structures seen in traditional radiography or the necessary destructive slicing of petrography (Applebaum and Applebaum 2005; Sobott et al. 2014). In sum, in the limited micro-CT and CT literature related to ceramics analysis all emphasize the value of seeing the whole exterior and interior of an archaeological object. Below I provide more detailed information across the range of studies that focused directly on archaeologically derived ceramics.

4.2.1 CT Studies that Focus on Manufacture

One of the largest CT ceramic studies published to date was conducted by Matthew Sanger (2016, 2017) on Late Archaic ceramics from the American Southeast. The study used radiography and computed tomography to explore these earliest ceramics from the region to see if insights into manufacture could aid in understanding past communities. Sanger (2016: 588) examined what he referred to as “micro techniques” and technological “fingerprints” to explore diversity in potting. Sanger also scanned experimental vessels and ceramic tiles in order to discover what different techniques look like within radiographic imaging. Sanger selected 316 archaeological sherds for analysis, however only 55 3D models were created. The other 261 examples were 2D modelled and viewed in 3D in real-time, while in the machine. Sanger's (2016:592) work focused on determining the directionality of aplastics and voids as well as characterizing disjunctures and layering on both vertical and horizontal axis. Voids in Sanger's (2016:595-6) sample were determined to have been left by vegetal temper and were easily characterized in image analysis. Use of radiographic techniques also showed the non-random distribution of formation techniques from the two archaeological sites sampled, potentially indicating differing potting communities. Further work led Sanger (2017:103) to argue that the formation, techno-functional and decorative attributes of vessels possibly correlated between formation techniques and decorative elements, which he sorted into four distinct groups. These groups appear non-randomly at the two sites Sanger (2017) sampled, suggesting differing communities of potters and social groups represented by differing ways of making pots.

An earlier study led by Sanger (Sanger et al. 2013:830) examined a sample of 10 fibre tempered ceramics to identify possible manufacturing techniques. That work used ImageJ software to identify the qualitative traits in ceramic vessel interiors, including the presence and alignment of voids, the spatial arrangement of fabric and temper, and the recognition of the constituent components of the fabric. They also undertook quantification of inclusions in terms of volume, shape, diversity and distribution (Sanger et al 2013:831). They also examined the possibility of void angularity as a determinant of vessel construction techniques and identified layers of clay. Similarly, in a preliminary study, four samples of ceramics from the Macacú Archeological Site, located in Itaboraí, Rio de Janeiro, were analyzed by Machado and colleagues (2013). They examined the manufacturing techniques of these archaeological ceramic pieces as interpreted by the direction of pores or voids.

Sobott and colleagues (2014) scanned three macroscopically different ceramic sherds from varying archaeological contexts, and compared micro-CT to X-ray diffractomometry and energy dispersive X-ray fluorescence spectroscopy as methods to use for examining porosity. They found that it was difficult to obtain accurate percentages of matrix and porosity density in micro-CT analysis but noted that the strength of micro-CT lay in the presentation of 3D images indicating the orientation of pores and not necessarily quantification of voids and inclusions.

Kahl and Ramminger (2012) used high resolution X-ray micro-CT to scan five ceramic fragments from an Endmesolithic-Neolithic site in Northern Germany. This proof of concept study outlined how micro-CT scanning could be used for quantification and shape analysis of ceramic vessel fabric components that could allow for quantitative and qualitative analysis of different temper materials and voids, to study vessel forming techniques. They suggested that the distribution analysis of heavy minerals in the clay matrix may allow for the identification of clay sources without destructive techniques. They were also able to determine the nature of organic temper by the shape of the voids left in the ceramic. They compared the results of 2D slices and 3D images in determining percentages of temper in a sherd, and illustrated the impact of sampling position in thin section selection.

More recently, Kosastas and colleagues (Kosastas et al. 2018) used micro-CT analyses to examine primary forming techniques in a Middle Neolithic pottery assemblage from the archaeological site of Sesklo in Greece. They used micro-CT to allow for the detection and measurement of coils, slabs and other construction units and joins, as well as the orientation of voids and inclusions. Beyond just primary forming techniques, they recognized the potential for micro-CT to identify "even the most individualized craft behaviors" (Kosastas et al. 2018:104). They analyzed a sample of 33 potsherds from House A of Sesko B, in which five vessel shapes were represented. This study began to establish protocols for describing ceramic fabric's features (morphology of the construction units, morphology of joins, and orientation of voids and inclusions) and how these relate to ceramic forming operations (Kostasas et al. 2018:104). By looking at the morphology of the construction units (slabs, coils etc.) and the morphology of the joins (noting differences between undulate and smooth joins and whether those were smooth or rough) between construction units, they were able to tease out different steps in the *chaîne opératoire* of ceramic making (Kostasas et al. 2018:107-108). They also examined the orientation of voids and inclusions, and found that these could vary between regions of a vessel, responding to quite localized pressure potters exerted while potting (Kostasas et al. 2018: 109-110). They observed coiling, slab-building and moulding, and variations within these categories, and were able to illustrate how these were differentially used on different vessel forms and across different regions of the vessels (2018:110-111). Techniques varied within vessels, and even within one region of a vessel. They found a "technological pluralism" in the ceramics, indicating a "plethora of potters" formed technically distinct pots (Kostasas et al. 2018:115).

4.2.2 CT Studies that Focus on Minerology and 3D Petrography

As discussed in Chapter 3, X-radiography analyses of archaeological ceramics, amongst a range of other applications, have been employed in attempts to image, identify and source mineralogy of temper inclusions in vessel fabrics (e.g., Carr and Komorowski 1995; McKenzie-Clark and Magnussen 2013; Middleton 2005:82-83). While micro-CT scanning has the potential to be used for this kind of analysis, preliminary studies have concentrated on vegetative fibre temper and only mentioned the potential to recognize mineral temper in passing (Kahl and Ramminger 2012; Latini et al. 2013; Sanger et al. 2013; Sanger 2017).

Several authors note that the use of 2D images, including petrographs, of vessel fabric interiors to classify the size, shape, distribution and frequency of inclusions in ceramics is limited, because of the sampling bias inherent by only looking at one slice of a sherd (Adan-Bayewitz and Wieder 1992; Applebaum and Applebaum 2005; Jacboson et al. 2011). Traditional X-radiography confounds wall thickness and density in ceramic sherds by collapsing 3D structures into a 2D image (Pierret et al. 1996). Kahl and Ramminger's (2012:2212) research illustrated the advantages of 3D over 2D images in determining the percentages of temper in a sherd. Moreover, a CT scan versus a radiograph offers greater access to otherwise obscured data; since CT scans provide images of the crystal faces of temper or inclusions (Sanger et al. 2013:837). Further advantages micro-CT scanning offers include the use of software to provide filtering, and the ability to select images on any plane (Applebaum and Applebaum 2005). However, magnification of x25, x40, x100 and up to x400 for small inclusions can be used in thin section petrography (Quinn 2013), geometric magnification on the images resulting from micro-CT scans of ceramics are generally not as high as thin section magnification

Using micro-CT, researchers are able to non-destructively gain information on internal structure: the proportions, spatial distribution and relative orientation of components (Griffin et al. 2012). These factors are essential in the study of archaeological ceramics, and the non-invasive nature of micro-CT allows for examination of specimens that have previously been off-limits in many scientific fields. More broadly, micro-CT is also being used to scan geological samples at the University of Texas High Resolution X-ray CT Facility (UTCT 2013). This research has the potential to contribute to an understanding of 3D ceramic petrology because they are scanning materials that are often included in ceramics as temper or inclusions. At high or low energies, different minerals have different attenuation coefficients and can be differentiated through setting adjustments. For example, quartz and orthoclase feldspar are similar in mass density and have similar attenuation coefficients at high (around and above 125kV) energy while at low energy the high Z-potassium in the orthoclase causes them to attenuate differently (UTCT 2013). The XCOM photon cross-section database managed by NIST (National Institute of Standards and Technology) provides attenuation coefficients that may be used as a starting point for determining these values (Berger et al. 2011). Knowing these attenuation values for different minerals may aid in identifying the mineralogy of temper and inclusions within ceramic sherds as revealed through micro-CT scanning. With such dual-energy techniques, we may be able to differentiate between a greater number of minerals (Friedman et al. 2012; McKenzie-Clark and Magnussen 2014). And, as noted previously, micro-CT has already proven useful for visualizing and even identifying plant species used by potters based on voids left by vegetative fibre temper, and also the presence of human hair in ceramic sherds (Kahl and Ramminger 2012; Sanger et al. 2013).

The potential and limitations of applying micro-CT-based analyses to ceramic petrography are not yet fully understood. It has not been used as a complementary approach to archaeological ceramic petrographic analysis and it only just beginning to be used in other fields. We may be able to answer some of the same questions as those posed through destructive 2D petrography, but research needs to include ground truthing the information gained from 3D scans with 2D petrography (Linda Howie, personal communication 2013; Phil McCausland, personal communication 2013). I do not think micro-CT analysis will be able to examine clay mixing in the same way as ceramic petrography since most of the identification of different clays is based on colour and reflective properties (Quinn 2013), and most types of clay have a similar density to one another. Micro-CT analysis is likely more suited to examining voids and inclusions, rather than the clay matrix itself, since micro-CT presents density differences in greyscale. It is also possible that many inclusions typical of Ontario ceramics may have densities that are too close to be separated based on greyscale values, although dual-energy techniques may address this problem in the future.

There is promise for 3D petrography in the field of soil science where micro CT has been used to study bulk radio densities, aggregate densities and the spatial variability of soil structures (Tiana et al. 2008; Winstone et al. 2019). Studies of soil structure, examining the nature, shape and arrangement of dominant mineral grains in soil (Tiana et al. 2008) may inform 3D petrographic studies of ceramics in the future. Various studies in soil science have used different methods: scanning at low energy levels (Carlson et al. 2003; Ruiz de Argandoña et al. 2003), combining scans from varying energy levels (Van Geet et al. 2000; Ketcham 2005) or simply examining the attenuation levels of given minerals at different energy levels (Heck and Elliot 2006), to differentiate and identify mineral grains in soils. However, no standard methods or guidelines have been developed (Tiana et al. 2008).

Temper choices can be seen as a technological trend in pottery production and can be linked to functional differences in pottery (Carr 1990); although there is not always a link between temper type and vessel type (Dickson et al. 2013). Braun (2012:1) argued temper size and mineralogy is also determined “through the negotiation of various constraints” including tradition, social organization, intended function and the availability of raw materials, and may also be related to access to resources (Roddick and Klarich 2013) . Howie (2012) also used petrographic techniques to examine the choices that potters were making and linked these to local and non-local traditions. Indeed, temper additions to clay body is the additive of an ingredient within artisan production recipes, so it may be possible to determine through temper size and mineralogy, as revealed through CT scans, what sort of choices potters were making in the early preparation stage of production.

4.3 Summary

Previous studies using micro-CT and CT to study archaeological ceramics have underscored the strength of these methods for revealing ceramic manufacturing techniques, and otherwise earlier stages in vessel production, and the potential for future work in mineral identification and 3D petrography. These studies use of CT and micro-CT technologies to examine ceramics allows archaeologists to see elements of the manufacturing process that cannot be viewed through macroscopic exterior examinations and that could only previously be seen through destructive petrographic work. Almost all of these previous studies suggest that the real strength of micro-CT analysis is the ability to see the orientation and shape of voids and not in the quantification or identification of various components of the ceramic matrix. Void shape and structure relate to choices potters were making when they were manipulating clay to form a pot; choices that relate to the communities of practice artisans were participating in.

Chapter 5

5 Micro-CT Methods and Protocols Adopted for Scanning the Arkona Collections

In this chapter I will review the approach to scanning ceramic vessel sections and sherds from the Arkona Cluster of Late Woodland archaeological sites. This review will include reviewing the methodological protocols adopted for conducting the scans and how I collected the data. It will conclude with what these protocols will allow me to explore from the results of the scans, and what the limits to these protocols are for advancing a material science of interior vessel architecture, including the hardware, software, and object limitations encountered.

5.1 Sample Selection

All materials used in this study were available through the Museum of Ontario Archaeology and the Ministry of Heritage, Sport, Tourism and Culture Industries. In all, I conducted an analysis of 106 artifact specimen scans (Appendix A). This analysis included 67 vessel scans from seven Arkona Cluster sites (Table 5.1). The 67 vessel scans included 62 rim portions of vessels, which also included a limited or variable length of the lower neck sections present on those sherds. I also scanned five neck sections without completely intact rims (Table 5.2).

The selection of ceramic sherds from the Arkona Cluster sites was an iterative process. At the beginning of the study, I did not know how long scanning, reconstruction and analysis would take per sherd so the sample number remained somewhat flexible. At the end of this project, my experiences suggested that it took, on average, roughly four hours to complete each scan and all subsequent analysis.

Originally I imagined I would scan somewhere between 50-75 sherds, which at the time (I was selecting samples in 2014-2015) would have represented a larger number of ceramic scans than any existing micro-CT study. Usually budget would dictate the number of scans undertaken for a study[2], but access to the scanner was facilitated and funded for this study through Dr. Ferris' SSHRC research grant related to studies on the Arkona Cluster of sites.

Table 5.6: Arkona Cluster Vessels included in analysis.

Borden Number and Site Name	**Number of Scans included in analysis**
AgHk-56 Inland West Loc. 6	1
AgHk-40 Bingo Pit Loc. 3	5
AgHk-54 Inland West Loc. 3	9
AgHk-32 Van Bree	10
AgHk-52 Figura	15
AgHk-42 Bingo Pit Village Loc. 10	20
AgHk-58 Inland West Loc. 9	7
Total Arkona Vessels	67

Table 5.7 Arkona vessel portions scanned and included in analysis.

Part of Vessel scanned for Arkona Sample	**Frequency**
Rim	22
Rim and neck	28
Rim, neck and shoulder	10
Neck	5
Complete profile	2
Total	67

[2] Micro-CT scanner user fees for the machine operated by Western University in 2018 for a Western University Graduste Student: $50/hour, for a SA Research Associate/ Accredited Researher/ External Graduste Student: $150/hour and for a Non-Collaborator: $300/hour. (Sustainable Archaeology SA Ancient Images Laboratory Equipment User Agreement 2018).

I originally selected a group of 35 ceramic specimens containing both rim only and rim and neck sections of a vessel, scanned them, and then completed a preliminary analysis on the scans. This first sample group was selected based on my examination of the collection itself, first by pulling all rim sherds from their boxes and setting aside those that I felt were of a suitable size and that appeared to me were unlike one another. I also reviewed the consultant's analysis in their reports sorting ceramic rims into distinct vessels (Archaeologix Inc. 1998; Golder 2012a, Golder 2012b). The aim of this preliminary selection process was to identify and ensure there was a representative sample of the morphological and decorative variety within the ceramic assemblages from the Arkona sites captured in the scans, in hopes of addressing questions related to communities of practice and the borderlands context of the Arkona cluster. Samples were also selected to ensure coverage from most of the sites in the cluster. While not directly proportional, I did take a larger number of specimens from sites that had larger collections.

I then selected a second group of 32 rim sherd specimens based on further consultation of the decorative variability represented in the consultant report catalogues. These specimens were selected to give more insight into the original 35 specimens. I was aiming to fill gaps in terms of decorative variety that I had failed to achieve across the first group of specimens selected, endeavoring to select more specimens that had typical "Western Basin" decorative traits. I also wanted to provide repetition and confirmation of my initial analysis, selecting specimens that had thicker rims or pseudo collars. In initial analysis different manufacturing gestures were recognized and I wanted to test if these techniques were repeated or not on similar looking rims. Though 67 may seem a random number, I felt at this point in the study that I had captured a substantial amount of the variability and representativeness in the sample of sherds scanned.

The other scans I undertook included ten scans of additional sherds from Arkona vessels already scanned, three learner vessels from Arkona, five clay pipes from Arkona, and eight lumps of clay recovered from the Arkona sites (Table 5.3). These latter specimens were scanned with the intent to investigate local clay signatures and potential manufacturing evidence.

Table 5.8: Comparative scans included in analysis.

Type of sample	Number of Scans included in analysis
Arkona Vessels	77 (including 10 duplicate vessel scans)
Arkona Clay Pipes	5
Arkona Clay lumps	8
Inland West Pit Loc. 3 Miniature Vessels	3
Comparative Ontario Late Woodland Tradition Vessels	6
Comparative Western Basin Tradition Vessels	7
Total scans in analysis:	106

Additionally, I also scanned seven Western Basin Tradition "type" rims from Bruner-Colasanti, Dymock, Cherry Lane and Robson Road, all sites beyond the Arkona Cluster. I also scanned six vessels from various other Ontario Late Woodland Tradition contexts (Table 5.4). These scans of ceramic vessels from elsewhere were intended to be more instructive than representative of variations in pot making, and of variations in sherds from other places and other times. In the end, these additional scans were not included in analysis, but they were useful for confirming that micro-CT scanning could be a valuable tool for research beyond the Arkona vessels.

An important dimension to the initial 35 scans was gaining experience and familiarity with the resultant data. These preliminary findings helped confirm the best steps, or refinements, to follow for additional scans. For example, the initial scans clearly demonstrated that the rim portion of vessels were a useful unit for analysis, since I was readily able to visually observe differences in construction methods in the analysis of the scans. I also was able to confirm that a sample size of minimally 10 cm x 10 cm in length and width gave voxel sizes of around 40-50 µm while still providing a large enough sample area to observe those construction methods. To some extent these initial impressions reinforced my preferences, encouraging me to select sherds based on size and rim representation. However, I did scan many larger sherds, and two near-complete vessel sections in an attempt to view manufacturing methods across a larger extent of vessels.

Table 5.9: Comparative Ontario Late Woodland Tradition and Western Basin Tradition specimens by site

Site Name	**Number of Specimens scanned**
Lawson (OLWT)	2
Praying Mantis (OLWT)	3
McKeown (OLWT)	1
Robson Road (WBT)	1
Bruner-Colasanti (WBT)	2
Dymock (WBT)	3
Cherry Lane (WBT)	1

At the conclusion of a specimen scan I ensured that the sherd was bagged separately within their original bags, with tags that noted they had been micro-CT scanned, the date of the scan, and the scan number of this study, which will alert future researchers to the existence of these scans. They were then returned to their original boxes.

5.2 The Micro-CT Scanner Used for this Study

The scanner used exclusively for this research is a Nikon XTH 225 ST micro-focus X-ray tomography system, which is a cone beam projection system with a four-megapixel Perkin Elmer XRD 1621 AN3 HS detector panel (Figure 5.1). As outlined in Section 4.1, it operates as an in vitro system, where the object is placed on a rotating stage (or turntable) between a stationary X-ray source and detector panel (Figure 5.2).

Volumes are captured using a program called Inspect-X version 4.1(Metris X-Tek). They are then reconstructed using CT 3D PRO (Metris X-Tek) and visualized using VGStudio

Figure 5.1: The scanner at the Museum of Ontario Archaeology operated by Western University, showing the chamber from the exterior with the door closed and the two acquisition computer screens to the left.

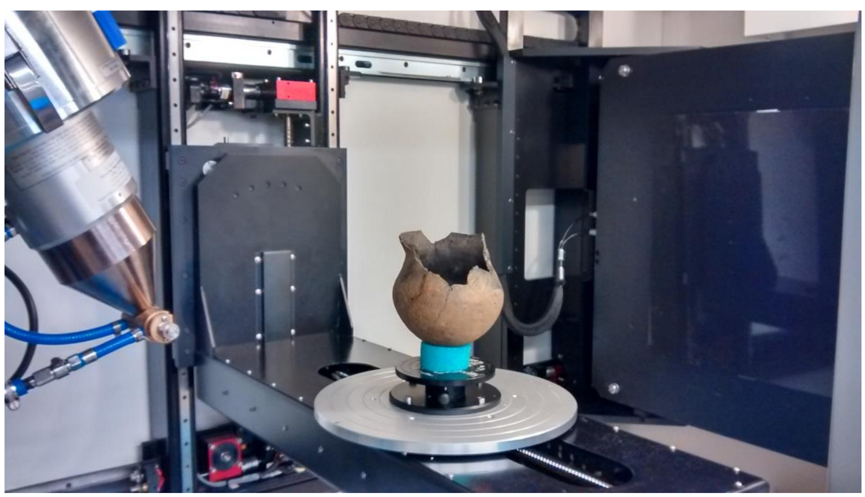

Figure 5.2 Left to right: the X-ray source, a ceramic vessel specimen mounted on the rotating stage and the detector panel inside the scanner chamber.

MAX (Volume Graphics) version 2.2. This system can provide for geometric magnification of up to 150x between the object and the detector, and the resolution of scans can be up to 3 micron voxels, although as mentioned above, achieving this resolution depends on the size and positioning of the sample, among other factors. Actual scan resolution for any given object is the result of several variables, including voxel size, focal spot size, noise, the contrast in the image, scattering, the movement of the object, the number of projections taken, and the reconstruction algorithms employed (Conlogue et al. 2020).

As used for this research, the scanner was configured with a reflection target that has a maximum power of 225W, a maximum voltage of 225kVp, a maximum current of 1000µA, an exposure range of 0.25-5.6 frames per second, and geometric magnification up to 160x (Hoffman and deBeer 2012; Morgan 2014). Most scans in this study had voxel sizes between 20-120 microns. The resulting images were used to take measurements, and identify the shape, size and densities of internal structures for each specimen scanned.

5.3 Operational Approaches to Scanning

This section outlines the steps involved in running a micro-CT scan of a ceramic specimen using the scanner at SA from placing the specimen in the scanner to the acquisition and reconstruction of projection images. This includes mounting, positioning and filtering a specimen, determining the best settings using Inspect-X software to use for each particular scan, and then reconstructing the projection images created by scanning using CT 3D Pro software. The recording of variables is also discussed. Though not discussed in detail, before these steps can proceed, the operator must also adjust (to the home position) the manipulator table within the chamber of the machine and run auto conditioning to stabilize X-rays prior to running a shading correction or scan.

Not all CT scans are perfect, in fact most are not, and many of the adjustments made during scanning were in an effort to reduce artifacts in the CT data. “Artifacts” can be broadly defined as any discrepancy between the reconstructed values in an image and the true attenuation coefficients of the object (Hsieh 2009:209). In effect, they are blemishes that prohibit analysis of the scan, and are usually categorized as noise, streaking, shading, rings and bands, motion and miscellaneous defects (Conlogue et al. 2020; Hsieh

2009:209; Nikon 2015:50; Stock 2009). Three artifacts I encountered frequently were random noise, ring artifacts, and beam hardening. Noise “appears as speckle in the slice images” and ring artifacts “appear as rings in the axial slice images” (Nikon 2015:50). Beam hardening artifacts are caused by the object differentially filtering the X-ray beam, leading to uneven exposure (Nikon 2015:41-43). To reduce the effects of artifacts in scans the operator can: increase the number of photons penetrating an object (by increasing exposure time, number of projections, frames to average or kV), run improved shading corrections, use software corrections (such as the minimize rings function), add filtering, or use corrections in reconstruction (Boas and Fleischmann 2012; Nikon 2015:52). This section walks through the steps involved in the roughly hour-and-a-half to two-hour process of setting up, running, and reconstructing a micro-CT scan for analysis.

5.3.1 Recording Protocols

All variables (e.g. kV, µa, filters, mounting material, positioning notes) of all scans were recorded in both the paper scanning record forms that are kept for all scans conducted at the facility, and in an excel spreadsheet of all scans generated for this project (see Appendix B). All specimens were also photographed from several angles. I recorded values or notes for each of the categories listed in Table 5.5 in my spreadsheet. Most of these categories were taken from the standard scanning forms used for this lab, but some were added for my reference. Variables related to the archaeological site, unit or feature, vessel, or catalogue number and description of specimens helped place and sort the scan data by context. Recording voxel size was valuable in analysis, allowing me to make a quick assessment as to whether my results or lack of results for any given category were related to resolution. I tracked the duration of scanning and reconstruction in an attempt to track how long each scan was taking in terms of technician hours. Many of these variables will be discussed in more detail as I review the steps involved in scanning. Overall the summary data from these scanning variables helped me in establishing the protocols I suggest for scanning ceramics using the Nikon XTH 225 ST micro-focus X-ray tomography system.

Table 10.5: Values recorded when scanning. Those with * are values duplicated in the equipment recording sheet.

St. John Spreadsheet column heading	**Notes or example**
Sample ID or File name*	StJohnCT001
Will this scan be used for analysis?	Many scans were conducted that failed altogether or were not of high enough quality to use in analysis; a yes/no in this column helped in sorting these for analysis
Site Name	Figura
Borden Number	AgHk-52
Context within site	Unit and/or Feature #
Vessel number and Catalogue number	Many had both, but often only one of these was available
Specimen or Object	Rim, neck, body, pipe etc.
Observable Specimen Characteristics	A quick visual analysis: notes on temper, decoration, residue, thickness, presence of coil breaks etc.
Scan date*	Day/month/year
Duration of scan	Time from opening the chamber to acquisition: affected by minimize rings function, duration/difficulty of positioning the sample, and setting KV and micro amp values, and complexity of shading corrections. Typically 15-20 minutes for set up and 53 mins for scanning, though scan time was 1 hour 45 minutes when minimize rings function was used.
Duration of reconstruction	Time spent in CT pro reconstructing the scan. Typically 15-20 mins.
Mounting method*	Mounted in clamp with foam, in box with foam peanuts, etc.
Filter*	Type and mm, e.g., 0.5 mm Cu
Gain	A detector parameter that influences level of noise in the resultant scan. A lower gain will produce less noise but result in a darker scan. Either 24dB or 30dB was used here.
Target*	All scans used the reflecting target.

KV*	Unit of electromotive force, or X-ray beam energy. e.g. 130. It affects the penetration of material.
µa/micro amps*	Unit of electrical current, or X-ray beam current, e.g., 60. It affects the quantity of X-rays used.
Exposure*	Exposure time in milliseconds: set at either 1 or 2 here.
Number of projections*	The number of projection images acquired- this was set using the "optimize" setting in Inspect-X. It was set at 3142 for all scans.
Frames/time* or frames per projection	An exposure parameter in frames per projection: set at 1 or 2 here.
Effective Pixel size	In µm-; depended on sample size and positioning, and other factors.
Operator name*	Amy St. John
Minimize rings*	Yes or no: Used to correct ring artifacts sometimes produced by the scanner.
Shading corrections	Used to reduce noise in scans. I recorded the number of images and frames to average, typically 3 images/150 frames to average.
Comments*	Used to note errors in scans or particularly high quality scans.
Scan successful?	Yes or no or a qualified yes or no.

5.3.2 Selecting Specimens

As noted above, 106 specimens in total were scanned for this project. The choices made for what objects were to be scanned were largely informed by dimensions of the ceramic assemblage from the Arkona Cluster of sites, and interpretive questions related to understanding the ceramic craft tradition reflected in that assemblage. This included an attempt at capturing the decorative variability present in the collections, which might relate to influences from both east and west of the Arkona cluster. I also attempted to select rims that both had and did not have incipient collars, and both rim sherds with and without castellations in an attempt to capture any differences in manufacturing techniques these features might relate to. This meant, however, that the physical characteristics of individual ceramic pieces selected to be scanned, and the issues for mounting these specimens in the scanner, were only tackled through the experience of trying to scan each object. In other words, ease and quality of scanning and the resultant scan did not frame the initial selection of specimens I chose to scan.

That specimen selection was initially based on archaeological interpretive priorities meant that there was a large variance in the size of specimens to be mounted into the scanner. For example, specimens scanned ranged from 5 cm in length to 40 cm in length. Most specimens also were not flat (i.e., interior/exterior curve of vessel shape), and typically weight was not evenly balanced across the specimen (e.g., variable thickness). This physical variability meant, simply, that it was not possible to just place a specimen loose on the rotating stage, since the specimen would be constantly shifting during the scan. Further, to readily separate the scanned object from the rotating stage during analysis it aids greatly if a medium is placed between the specimen and rotating stage that has a lower density material. So mounting strategies for the Arkona ceramics had to be devised that would both provide a fixed, stable position for each object by size and weight, and that would not interfere with my subsequent software analysis of the scan.

5.3.3 Mounting Specimens

Unfortunately, a dimension of available scanning protocols that does not often become part of published results (and is consequential to resulting output) is how to physically mount a specimen into the scanner. There are several priorities to mounting a specimen. First is to ensure the mounted specimen is secured and not susceptible to shifting as the stage rotates, since any movement will blur the resulting image. Second, the material used to hold the specimen in place needs to be low-density so that it can be easily distinguished from the specimen in subsequent digital analyses.

A wide range of materials were experimented with to serve as a mounting medium, providing stability and relative invisibility in the resultant scans. Mounting material needed to be malleable but sturdy enough to hold relatively heavy objects like large ceramic vessel sections and sherds. There were no protocols for mounting but Dr.

Andrew Nelson (supervisor of the CT machine at Western) and various Nikon technicians suggested using foam containers or platforms to mount specimens because its low density makes it easy to isolate from most other materials.

I experimented with various types of foam, including pool noodles (which I found generated too much rebound), various types of packing foam (which often contained too much glue), and floral foam (which created too much fine dust). In the end, the most effective material I found to use as a mounting material was expanded polystyrene foam (EPF). In particular, large cell white foam, typically used in the manufacture of objects such as picnic coolers, proved the most effective for providing stability and a low density. I also found that adding low density green or white packing peanuts around a specimen held in a white foam container provided more support for larger objects.

After much trial and error, the standardized method I used for mounting ceramic specimens in the micro-CT unit chamber consisted of the following variations:

1: Clamp and EPF: the most successful. For these mounts, I cut a slit a bit wider than the ceramic's thickness in a piece of white EPF, wedging the ceramic into the slit and holding it in place, adding small EPF packing peanuts, if needed. This entire piece of foam and ceramic was then firmly but not too tightly clamped into the clamp apparatus Nikon had provided for use with this micro-CT scanner. As seen in Figure 5.3, the clamp consisted of two rubber pads that could be tightened together using a simple rotating handle. This method seemed to hold things steady unless the ceramic was too top-heavy, in which case the specimen rocked while it rotated.

2: Secondary Clamp and EPF: This system used a clamp meant to hold a cellphone (not provided by Nikon_ with pieces of EPF held between the specimen and the clamp. This whole apparatus was then placed within the Nikon provided clamp. This system worked well, but only for lighter and smaller specimens that could be suspended between two pieces of EPF by the strength of the smaller clamp (Figure 5.4).

3: Specimens placed in an EPF box with peanuts. Most large specimens were mounted this way by placing them in a small EPF box, which I then filled with packing peanuts and foam wedges, and then placed onto the scanner turntable (Figure 5.5).

4: Using a stacked mount, with specimens wedged into the side of a piece of EPF. I used this method when scanning multiple small specimens together. Holes were cut into the EPF and specimens were wedged into a vertical alignment (see Figure 5.6). The EPF was then placed on the turntable and secured with double-sided tape.

Additionally, some scans were mounted less successfully. These included placing a specimen in a shallow EPF box and using a section of a polyethylene foam noodle wedged in around the object. Unlike EPF material, the polyethylene material tended to rebound, disrupting the unit's stability during scanning. As well, for smaller specimens I tried placing the item in an EPF cup and using peanuts for support. The high center of gravity and the small base of this mount meant the specimen was not very stable (Figure 5.7).

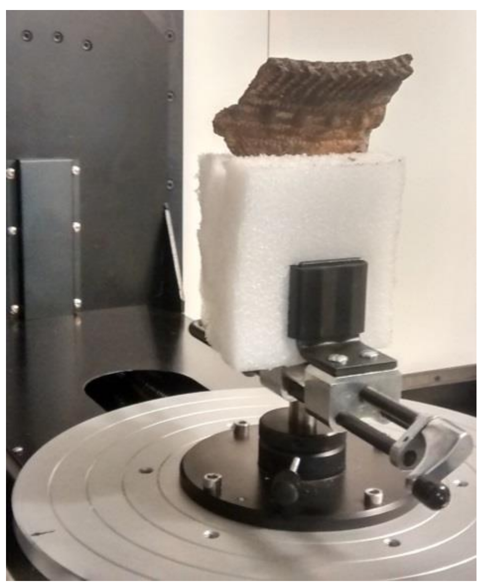

Figure 5.3: Combination clamp and EFP mount.

Figure 5.4: Secondary (cellphone) clamp with EPF. A water phantom is included in this scan. Water phantoms were used to run calibrated scans (see Section 6.2.4). They were created by placing distilled water in a clear plastic tube with caps on each end and mounted by creating a hole in the EPF next to the ceramic specimens.

Figure 5.5: Ceramic mounted in EPF box surrounded by EPF peanuts.

Figure 5.6: A stacked mounting method used to scan multiple small specimens at once, in the case scanning multiple clay lumps.

Figure 5.7: An example of a mounting method for small specimens that was not successful due to instability.

5.3.4 Positioning Specimens

An additional consideration I had to account for was positioning the specimen in the chamber relative to the X-ray source and detector panel. Part of this included determining the distance between the X-ray source and the specimen. Intuitively, I assumed it would be best to zoom in as far as possible on the specimen (creating a scan that encompassed just the limits of the ceramic specimen). However, what I subsequently learned was that it is better, when setting up a scan, to avoid the top of the screen and bottom of the field of view when possible since there is more noise further from the center plane of the X-rays. Positioning relative to the left or right of the X-ray source and detector panel could be adjusted by manually moving the sample left or right on the rotating stage to center it, or by moving the stage itself to the left or right. Positioning was completed by looking at and adjusting the X-ray image on the image window of the Inspect-X interface, using a series of joysticks (see Figure 5.8).

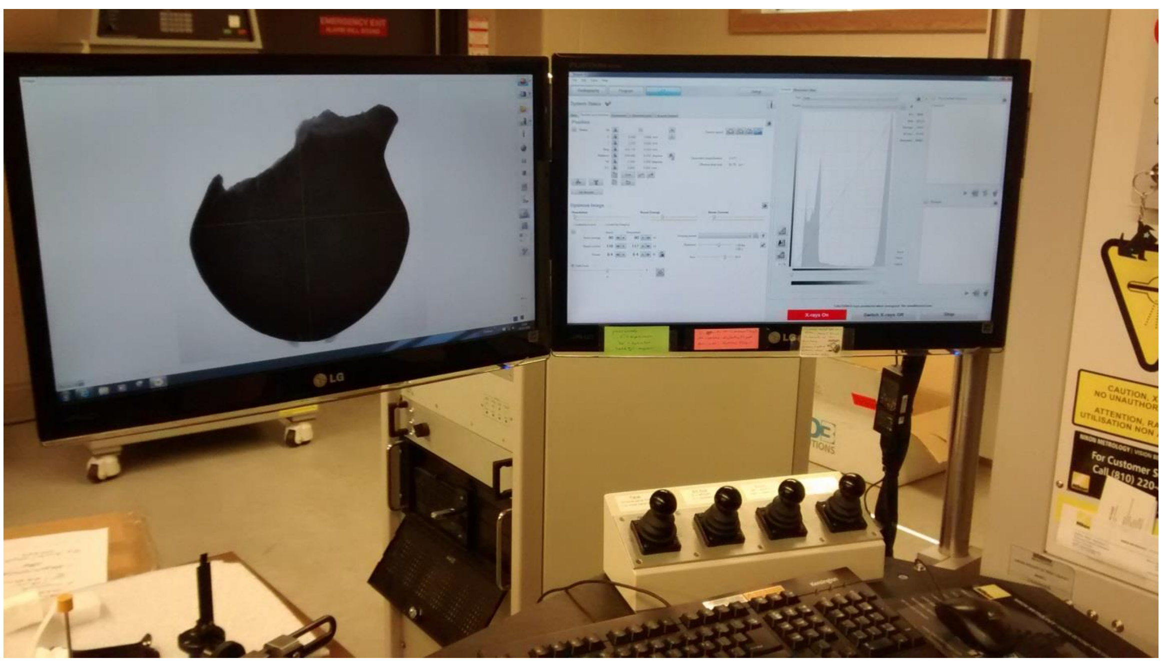

Figure 5.8: Inspect-X interface with the image window showing a specimen on the left screen. This live view screen and the joysticks at the lower right were used to move the specimen to an appropriate position before scanning. The right screen shows the control window where variables such as KV and micro amps are set.

When positioning a specimen, it was also important to place it to ensure the "longest path length." In other words, to make sure the X-ray penetration would be through the thickest part of the specimen. This alignment ensures that when setting KV and micro amp values they are high enough to penetrate the thickest part of the specimen in its rotation (see Figures 5.9 and 5.10). My first batch of scans was not set up this way, and it was only through discussion with a Nikon technician that I learned to account for these characteristics of the machine in subsequent scans.

Once the specimen was set in the desired position, I could then move on to the next steps in scanning.

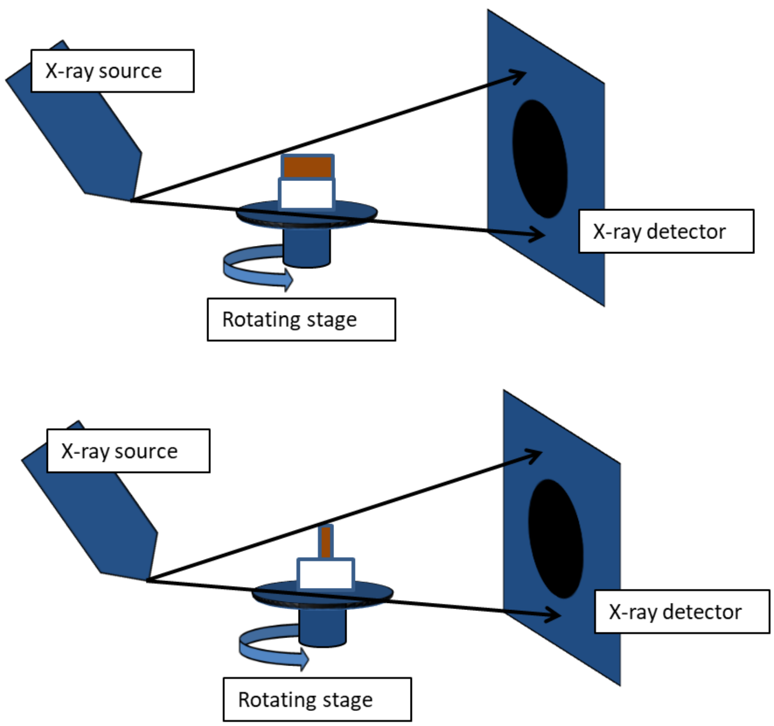

Figure 5.9: Illustrating "longest path length" set up in upper image. Ceramics should be positioned as pictured in the upper image, not the lower image.

Figure 5.10: Correct positioning to obtain "longest path length", indicated by the white arrow at the ceramic sherd's rim.

5.3.5 Filtering

One more step that can be completed prior to closing the Nikon XT 255 chamber is ensuring a physical filter is attached to the X-ray source, if filtering is required. Physical filters mounted to the head of the projection target are made of metal and are used to filter out low-energy X-rays. The Nikon system came with a selection of filters of different metals and in different thicknesses. The choice of physical filters depends on the material scanned and the X-rays generated (Conlogue et al. 2020). For example, a metal coin could require more filtering than bone. In effect, the higher the atomic number of the filter material, the more low energy X-rays are filtered out, raising the mean energy level of the beam. Filtering the X-ray beam helps optimize exposure settings and reduces beam hardening artifacts in the final image (Nikon 2015). This filtering is important because it results in clearer images from which to conduct analysis.

For this project I experimented with no filter, as well as copper filters of 1 mm, 0.5 mm, 0.1 mm and 0.25 mm in thickness. While scans completed with no filter often gave good results, the best results, with the clearest images, were obtained using a thin copper filter of either 0.25 mm or 0.1 mm, which dampened some of the beam hardening. Filters of greater thickness did not provide noticeably better results and required higher KV and/or micro amp inputs to obtain similar results (Figure 5.11).

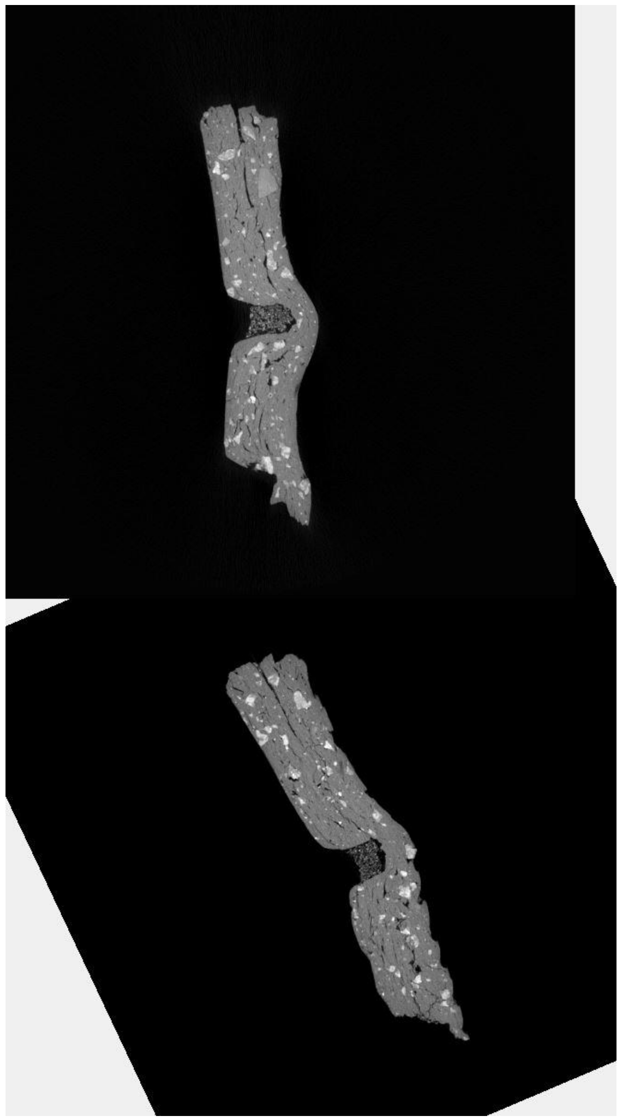

Figure 5.11: A filter of 0.5mm copper used in the top image and a filter of 0.1mm copper used in the lower image. Similar results were obtained, but the 0.5mm copper filter scan required settings of 205kV and 75µa and the 0.1mm copper filter scan settings of 175kV and 45µa.

5.3.6 Setting Scanning Parameters

After mounting and positioning was completed, and chamber door closed, I turned to setting the scanning parameters for the individual scan, using the Inspect X 4.1 operational software for the Nikon XT 225 scanner. A number of various X-ray settings could be adjusted, including the beam energy (kV), beam current (µa), power (W), shading corrections, frames to average, number of projections, exposure and gain. These variables can considerably affect the resultant quality of the scan and the researcher's ability to analyze the data compiled for an individual specimen, and I found it took many scans before I was able to determine the preferred settings for scanning ceramic specimens.

Several critical variables to account for during a scan were guided by an image histogram on the Inspect-X control window (Figure 5.12). This histogram detailed the grey values being read by the detector panel (Figure 5.13), which allows the operator to judge how light or dark the resulting scan will be, based on the variables selected for that particular scan. Filters, beam energy (kV), beam current (µa), and power (W) were all adjusted to manipulate the histogram. Power, in this study, was a function of the energy and current used in most cases, and not typically adjusted on its own. The resting grey value (when X-rays are off) of the Nikon XT 225 is usually at about 5000, which simply reflects background noise. Ideally, the operator aims to ensure a minimum 2x signal to background noise ratio, which means ideally getting the darkest areas of individual scans at a minimum grey value of 10000. At the high end of the histogram, the aim is to get the brightest areas of individual scans to a maximum grey value of up to 60000. As the grey value range of the detector is between 0-65000, the goal is to leave some of the range open at either end as a buffer. The minimum grey value of 10000 ensures penetration of the object, while the maximum of 600000 maximizes contrast without over saturating the image (Nikon 2015). Trying to obtain these detector values on the histogram in Inspect-X determined both beam energy and current for any given scan. Critically, these adjustments effectively ensured adequate X-ray penetration of the object without saturating the detector panel, thereby maximizing contrast and resolution in the resulting scans.

There are several other variables that can be accounted for before starting a scan. For example, shading corrections were another step in image acquisition used on all scans. Shading corrections are used to compensate for the drop-off of X-ray flux due to the inverse square law. Notably, as X-rays are generated out from a point source, X-rays that fall on the corners of the imaging device have had to travel further than those that fall on the middle of the imaging device (Nikon 2015:6). Shading corrections also account for small variations internally within the imaging device's pixel array (Nikon 2015:6). Mostly, shading corrections are a means of eliminating faults or defects in the imaging system by recognizing and eliminating them from the live CT scan. Longer shading corrections with an increased number of frames take longer to run, but eliminate more noise. After some experimentation with shading corrections, I determined that three corrections at 30 seconds per frame and 150 frames to average produced a good quality scan.

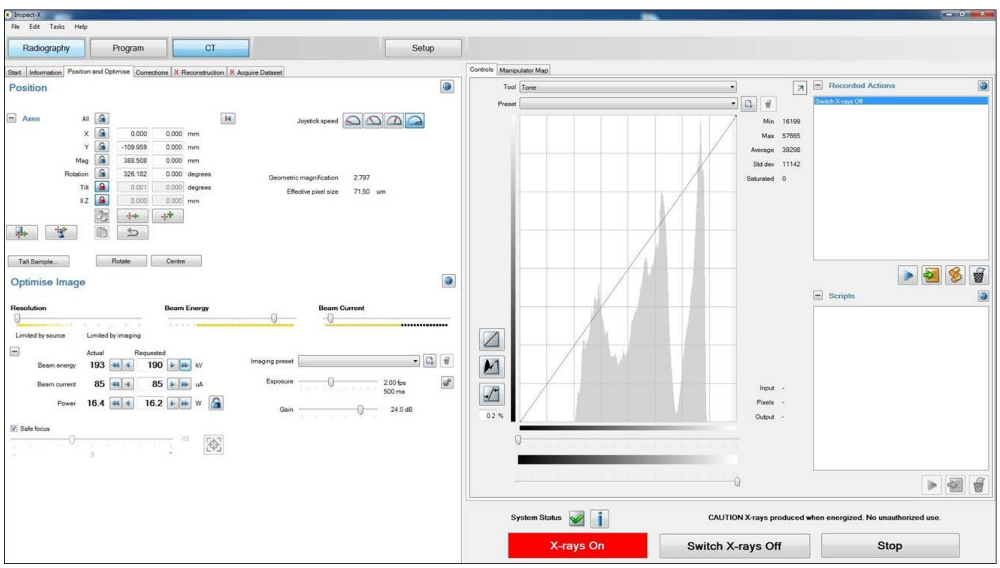

Figure 5.12: Inspect-X control window with image histogram to the right.

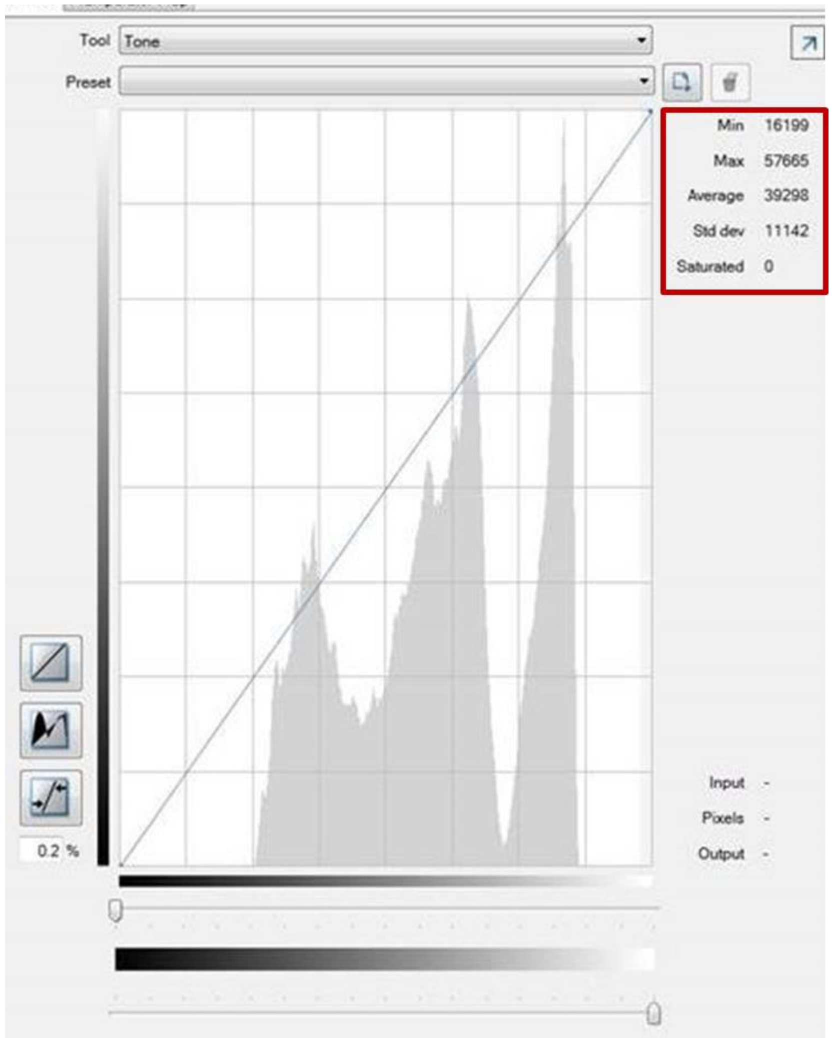

Figure 5.13: Image histogram in Inspect X with Minimum and Maximum Grey Values within an appropriate range at the top right. Ideally these values would be 10000 and 60000.

One other variable an operator can adjust prior to scanning is gain. Gain also controls noise on the resulting scan, but causes the resulting image to be darker, unless the operator sets a longer exposure time at a higher power level. Higher gain amplifies the signal, which increases both the signal and results in more noise in scans (Nikon 2015). I usually did not adjust this variable: gain was typically set at 24dB.

The operator can also choose the number of frames per projection to average and the number of projections per scan (the number of projection images taken). Frame averaging takes more projections at the same angular position in an attempt to eliminate fluctuations in projections (Stolfi et al. 2018:163), and the more frames per projection increases the resolution of resulting images (Nikon 2015:48). By manipulating frames per projection the operator can maximize the signal to noise ratio, increasing resolution by eliminating noise. Exposure time in milliseconds is one way to regulate the quantity of X-rays used and the contrast of an image (Nikon 2015). The adjustment of these variables affects scan time length and quality. Given the large number of scans I undertook for this project, I attempted to keep scan time down per specimen. Generally, I tended to adjust these settings so that: a) frames per projection was either 1 or 2 frames; b) the exposure was either 1 or 2 milliseconds; and 3) the number of projections was set at 3142. The number of projections in this study was not chosen by myself but was always set using the "optimize projections" setting in Inspect-X, to ensure enough projections were being used (Nikon 2015:47-48). These settings which were used for scans, unless I was using the minimize rings function (see Section 5.5), resulted in a 53 minute scan time per specimen.

5.3.7 Reconstruction

Assembling and reconstructing the projection images acquired during the scan into fully volumetric data was undertaken using CT 3D Pro. It is only once volumes are reconstructed that analysis of particular interior and exterior attributes of a specimen can take place. For this project, the number of TIFF image files (the projection images) to be reconstructed for one specimen was 3142, and generally, reconstruction took 15 to 20 minutes to complete after the scan.

Reconstruction using CT 3D Pro is a simple process on the operator's part. It involves ensuring there was no movement in the scan, choosing reconstruction corrections and selecting the volume of material to be reconstructed. Examining the first and last projection images (which are taken from the same angle) determines if there was movement of the specimen during the scan. If there was only a small amount of movement, I would proceed with reconstruction. But if there was a large variation between the first and last images, indicating significant movement of the specimen, the scan could not be reconstructed with any success.

Reconstruction correction entails adjusting a variety of digital filters and other image processing tools. For this project, only beam hardening correction and a median noise reduction filter were ever changed. Selecting the beam hardening and noise reduction corrections is a judgment call, but essentially the operator is looking for a reduction in noise in the image. Only infrequently did the use of the lowest correction settings for either noise or beam hardening assist in slightly cleaning up the reconstructions. Finally, the volume for reconstruction is simply a tool to select the specimen area to be reconstructed so that as much of the empty space around the object is eliminated from the final volume. This tool decreases the overall file size, making analysis slightly faster.

5.4 Analysis of the Resulting Object Reconstruction

The result of the scan process is a compilation of thousands of individual X-ray projection images into a three dimensional, fully volumetric reconstruction of the specimen. Since CT data uses X-rays to create this volume, variation in density is reflected in greyscale. The various features within a ceramic fabric, including the clay itself, inclusions (both intentional temper and natural), and voids (pockets of air within the clay), can all be isolated based on their grey values. The volume of the specimen can also be isolated from the surrounding air and mounting material based on grey values. A grey value in a CT reconstruction simply indicates the brightness of a voxel (3D pixel), which reflects the density of the material located within that voxel. This distinction is vital for analysis since differing grey values allows the operator to identify and quantify the internal architecture of the sherd, as well as the physical features of the exterior surfaces of the sherd.

5.4.1 Analysis Software

While there are a number of CT analytical software programs that can be used to analyze CT reconstructions, the one I used included VG Studio MAX 2.2 (VG), which allows the researcher to examine a large number of interior and exterior attributes as well as characteristics of material and volume in three dimensions across the entirety of the specimen. These analytical tools meant that I could use the software to explore ceramic manufacture, morphology and decoration.

The file sizes of reconstructions were extremely large, ranging from roughly 10GB to 25GB in size. Greyscale was captured in 32bit, but to conduct analysis, I opened all my files in 16bit resolution, which allowed the computer to run significantly faster than opening images in 32bit. I also found that files opened in 16bit did not sacrifice image quality, as the human eye cannot see that many shades of grey. The basic VG workspace includes windows for visualizing the data and the tools for analyzing these data. Though it can be reconfigured depending on the needs of the researcher, the typical set up includes three 2D windows that show slices through the X, Y, and Z planes of a volume, and one 3D window (referred to as the "scene" in VG manuals), showing the volumetric rendering of the specimen (see Figure 5.14).

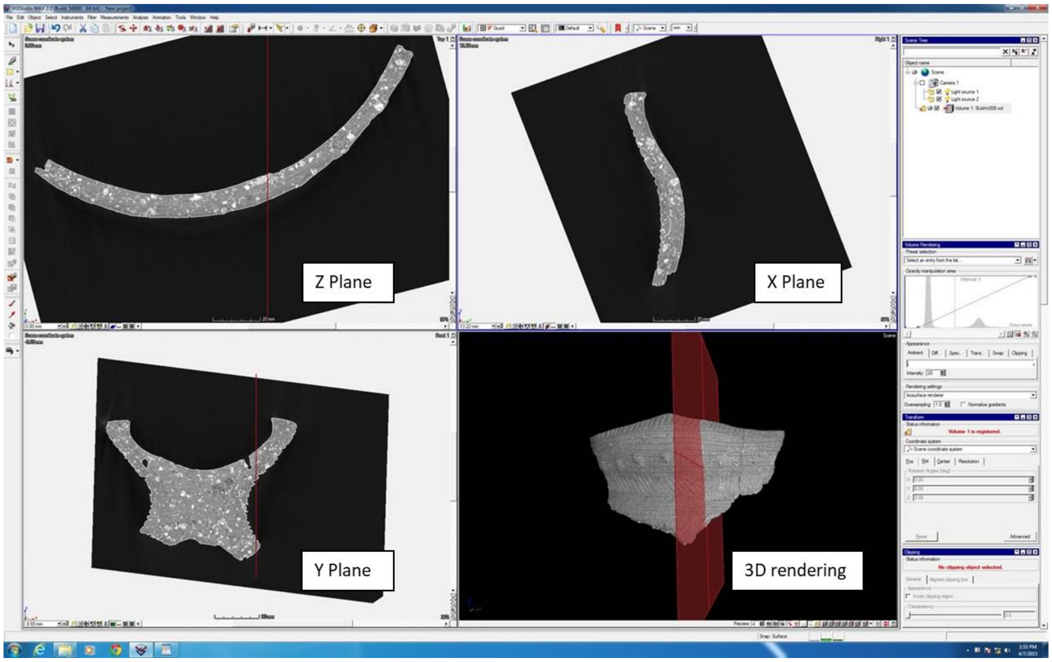

Figure 5.14: VG workspace with analysis tools at the top and right of the screen and X, Y and Z plane 2D windows and 3D rendering window at the center of the screen. The red slice through the 3D rendering illustrates the location of the X plane slice. Surface determination and simple registration have both been completed on this volume.

Before I could analyze the reconstruction, it was necessary to refine further the surface of the specimen from the air in the volume surrounding it. VG provides an automatic surface determination feature for this purpose, which allows for the creation of a region of interest from the surface of the specimen. All ceramic specimens were also registered using the "simple registration" function in VG. Registering an object changes its position in the scene, which allowed the specimen to be aligned in an upright position (see Figure 5.14). In effect, registration in this case provides a 3D orientation to the specimen so that I could work from orthogonal vertical (X plane), horizontal (Z plane) and "front on" (Y plane) cross-section views.

5.4.2 Analytical Methods: Thresholding and Segmentation

Many researchers (e.g. Sanger 2017; Kosaztos et al. 2018) use thresholding or segmentation based on attenuation coefficients (density) to digitally divide ceramics into their components, including inclusions, voids, and the clay matrix. Thresholding was completed in VG, which "creates a selection of voxels with gray values within the selected gray value interval" (Volume Graphics 2016:164). Thresholding uses voxel intensity histograms that allow for three-dimensional images to be segmented into different phases, which basically refers to a range of grey values. For example, in Specimen 008, inclusion grey values were set at a threshold of 39000-65535, and voids were 0-23000. For this research thresholding simply allowed my analysis to focus on distinct elements that make up a ceramic sherd. Segmentation of phases based on grey value thresholding allowed for the isolation of the clay matrix from different inclusions, as well as from void spaces, in the fabric (Landis and Keane 2010; Figure 5.15).

Using VG, I was able to create three separate Regions Of Interest (ROIs) for inclusions, clay, and voids by thresholding the different densities of these materials from one another. To isolate voids within the ceramic from the surrounding air in the volume, I had to create an inverted ROI from the ceramic's surface and subtract this from the ROI for voids (detailed steps can be found in Appendix C). Thresholding, in this case, was subjective, based on my best judgement call about what should be included in the ROI based on increasing or decreasing the threshold for grey values until most of the inclusions or voids were contained.

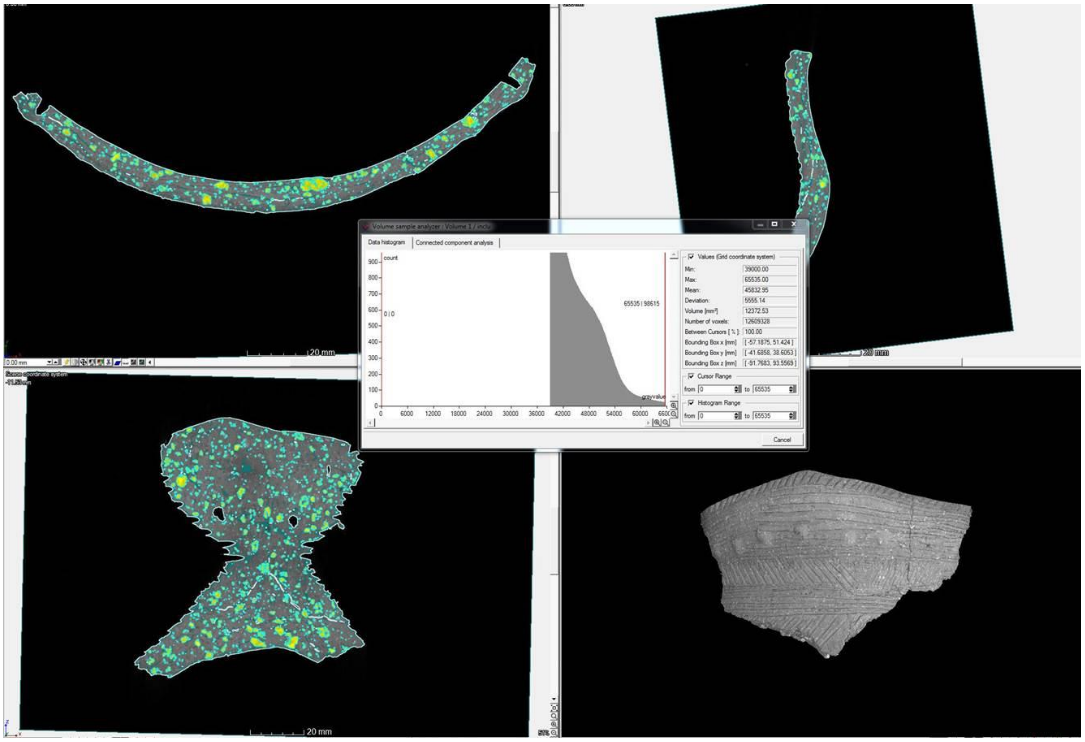

Figure 5.15: Using thresholding to segment out inclusions in VG. Note, because inclusions are higher in density than clay or voids, the higher end of the grey value histogram is selected.

Void and inclusion volume percentages were quantified based on the thresholding I completed, which were then compared to the volume of the entire ceramic sherd. This step gave me a percentage of the total volume that inclusions represented, and a percentage of the total volume that voids represented. Void and inclusion counts were obtained by splitting inclusion and void ROIs into their individual components and recording that value. Both volume percentage and counts for voids and inclusions were recorded for the entire volume of each specimen.

While entire volume measurements were useful, I also needed a method that allowed comparisons between scans of smaller rim sherds with larger vessel section scans, and that would eliminate variability caused by uneven sample sizes of specimens and the uneven distribution of voids and inclusions across a vessel (Figure 5.16). In visual examinations, it appeared as though there were typically more voids in the rim portion of a vessel than the body or neck, and sometimes different techniques or clays were used on the upper portion of the vessels. Also, the surface of volumes tended to have more noise than the centers of volumes, making it difficult in some cases to threshold inclusions and/or voids. To solve this problem, I created a rectangular 2 cm^3 prism ROI that was placed within each specimen. The prism was placed between 10-15 mm from the lip of the vessel and in the center of the specimen (Figure 5.17). Thresholding of voids and inclusions within this prism allowed for comparisons of volume percentages and counts between a consistent sample size and from the same position for each vessel scanned.

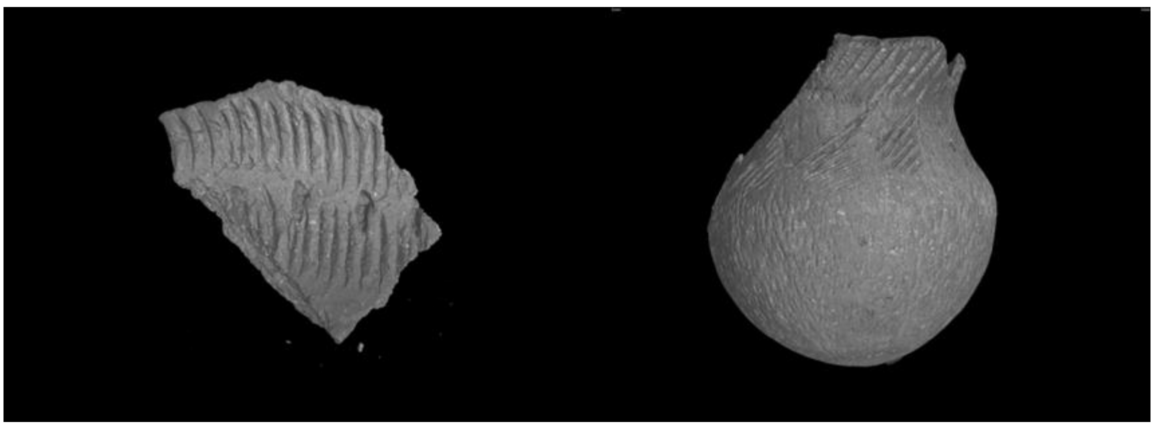

Figure 5.16: A 2 cm^3 prism was used to eliminate variability caused by uneven sample sizes and uneven distribution of voids and inclusions across a vessel. This method allowed for the comparison of very different specimens such as the rim sherd at the left and a near complete pot at the right.

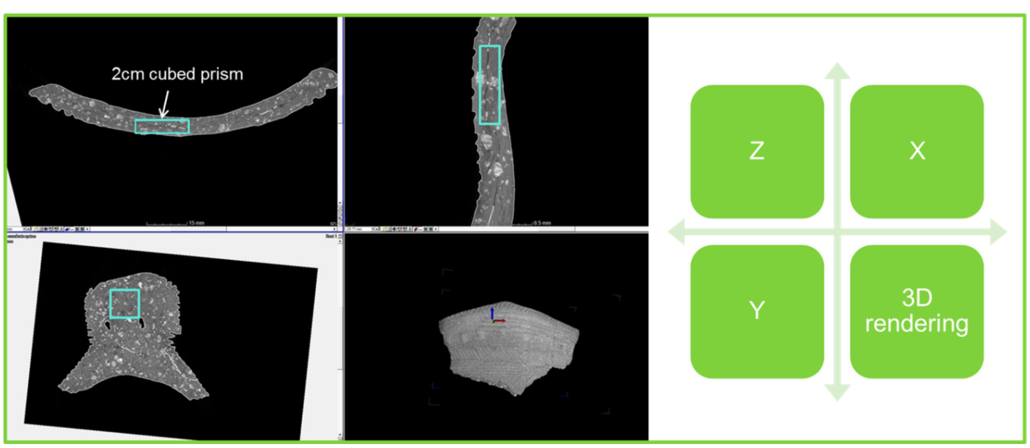

Figure 5.17: Placement of a 2 cm cubed prism.

Arguably the most important analytical insight from micro-CT volumes was the ability to conduct qualitative analysis of void structures. These void structures are a preserved record of where clay was manipulated and affected during manufacture, drying and firing, and where compression between and within pieces of clay are visible in both 3D images and by reviewing the thousands of individual X-ray slices recorded for the specimen (see example of a scroll through of slices here: https://youtu.be/Zpwy_tZSnHA). Three-dimensional renderings of voids often illustrated quite clearly where large voids were occurring across rim sherds in a way that 2D analysis simply could not present (Figures 5.18 and 5.19).

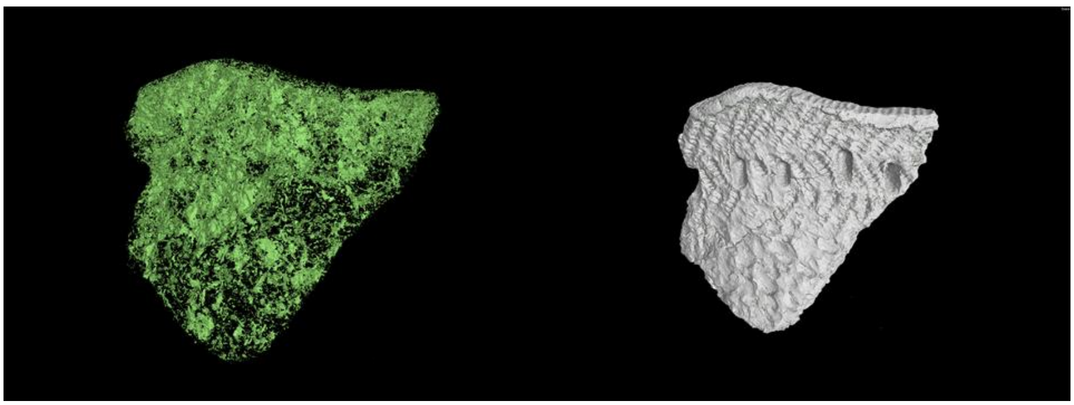

Figure 5.18: A 3D rendering of voids in Specimen 050 showing large voids near the rim and castellation where layers of clay have been imperfectly joined. At right is the exterior 3D rendering.

My analysis of voids recorded angles of larger voids relative to either the walls of the vessel or the Y plane (see Figure 5.20), described their shape and orientation (random or aligned), and inferred construction methods that might be associated with them. This data is presented in Appendix D. The most common shapes of voids in each sample was recorded based on categories found in petrographic literature, which in turn borrows from the characterization of voids in soil micromorphology (Quinn 2013:97-98). Quinn (2013:97) outlines four types of voids including vesicles (equant, spherical voids with smooth edges), planar voids and channel voids (both elongate with parallel walls; planer are usually straight and end in a point, while channels can be curved and have rounded ends), and vughs (irregularly shaped voids that are neither spherical nor have parallel sides which can be somewhat elongate or equant and can have smooth or irregular sides). Voids in micro-CT scans were sorted based on these categories in 2D slices, but I also noted when they formed larger structures in three dimensions.

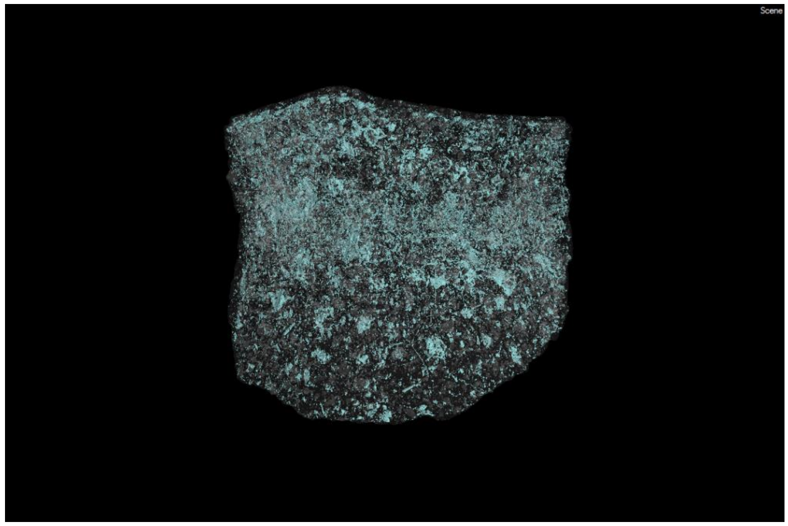

Figure 5.19: A 3D rendering of voids in Specimen 049, illustrating a band of large voids below the rim where the clay has been folded and voids near the lip where the clay has been added.

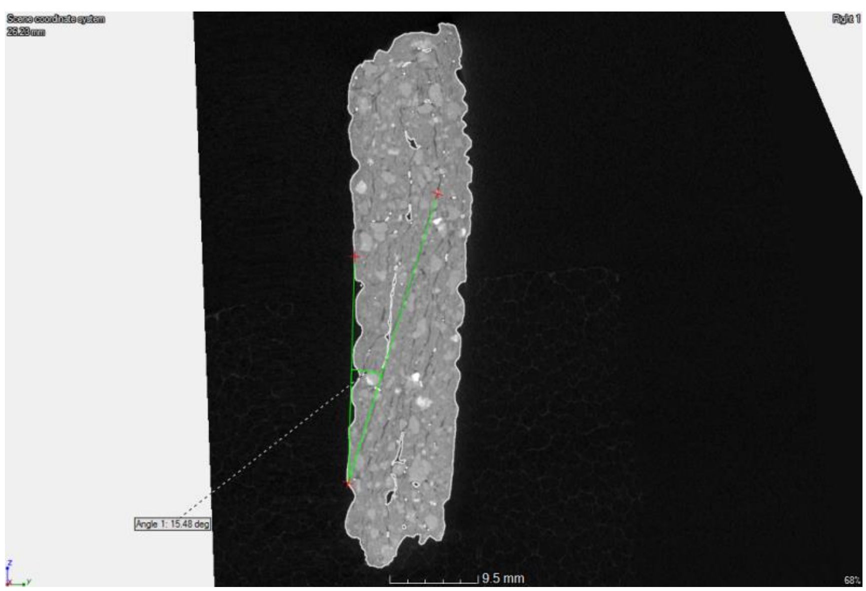

Figure 5.20: Angle of voids relative to the plane through the Y axis.

Finally, image analysis in VG also allowed me to examine more traditional ceramic morphological attributes, like rim form, neck profile, rim diameter and thickness of vessel walls. Some decorative attributes were also recorded following Watts (2006), using a simplified version of his decorative variability. Decorative and morphological variables are presented in Appendix E. Digital slices through the ceramic also allowed for an examination of features not normally visible, such as the depth and directionality of punctates, but generally most attributes present on the exterior surfaces of vessel sherds could also be seen through basic visual examination of the sherd.

It should also be mentioned that I was able to briefly employ a trial version of VG version 3.0, which included analytical modules not accessible through the VG version 2.2 I had available for most of this study. Through this trial version, I was able to explore the potential of porosity and inclusion modules, which allowed me to create threshold templates for voids and inclusions. These templates were based on typical grey values used for thresholding voids and inclusions, defined by the user, that could be applied and then adjusted as needed. As well, these modules provided not only total volume and quantities of both voids and inclusions, but also individual volumes for each inclusion and each void. In this way, these modules provided for grain-size distributions of inclusions, allowing for a qualitative categorization of inclusions from the finest natural inclusion to the largest temper inclusion. VG Studio MAX 3.0 also has a module that examines fibre orientation, but when used on these particular ceramics, the void structures were not fibre-like enough.

5.5 Methodological Challenges

As with any technique, micro-CT scanning has limitations and inherent problems that researchers must account for in their research. Notably, CT imaging can generate artifacts on the resulting reconstruction, impeding analysis (Boas and Fleischmann 2012). Indeed, complete avoidance of artifacts is impossible, but mechanical issues can accentuate the number and impact of artifacts on the quality of the resultant scans. For example, I had to contend with serious ring artifacts in many scans for a period of a few months (Figure 5.21), caused by undetected bad pixels in the detector (Conlogue et al. 2020). Minimizing these ring artifacts required running scans with the “minimize rings artifacts” software feature turned on in Inspect-X, which resulted in longer scans (130 or 105 minutes versus the usual 53 minutes). I used this feature to minimize rings since it was listed in the Inspect-X manual as the solution to ring artifacts. Overall, 22 of the 101 scans used in the final analysis in this study were run using the minimize rings feature, and no noticeable difference in scan quality was noted between these scans and the shorter ones without rings. Test scans running longer shading corrections, with more frames to average, was also used to combat ring artifacts in scans with some success, but also resulted in longer overall time spent on scans (Figure 5.22). Longer shading corrections did result in cleaner images and was one way to combat noise in scans.

Determining the settings to be used for any given scan depended on the mechanical state of the machine on any given day and within the machine's maintenance schedule. For example, at the end of a filament's life, I would acquire fairly dark images using 160kV and 65µa. But once the filament was replaced, images would be quite bright using 145-150kV and 60µa (Figure 5.23).

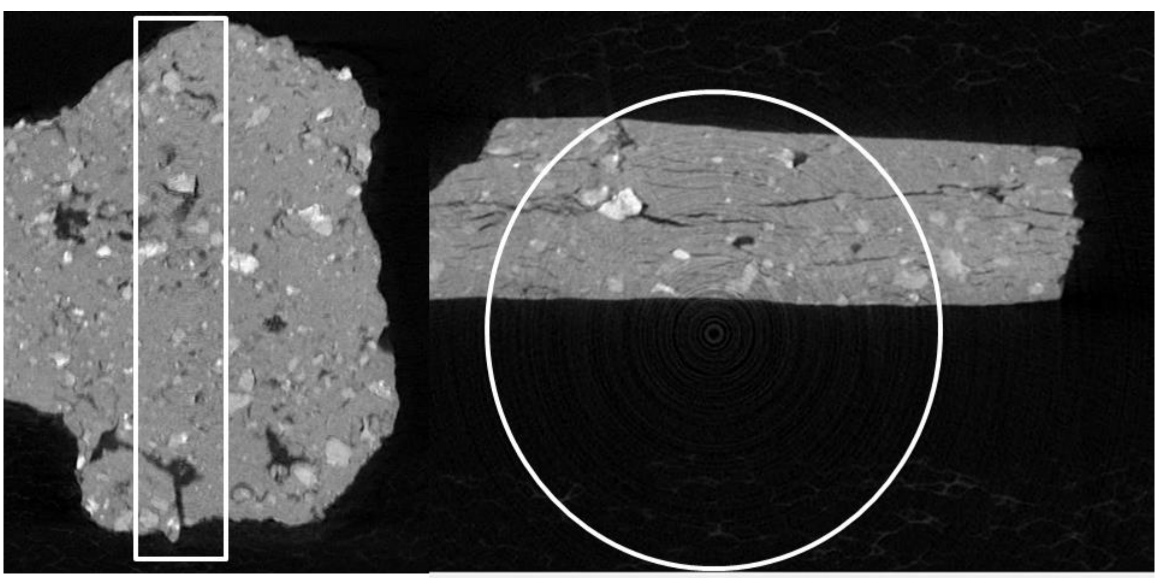

Figure 5.21: Scan of Specimen 010 from December 2014 with ring artifacts visible in slices through the Y and Z planes.

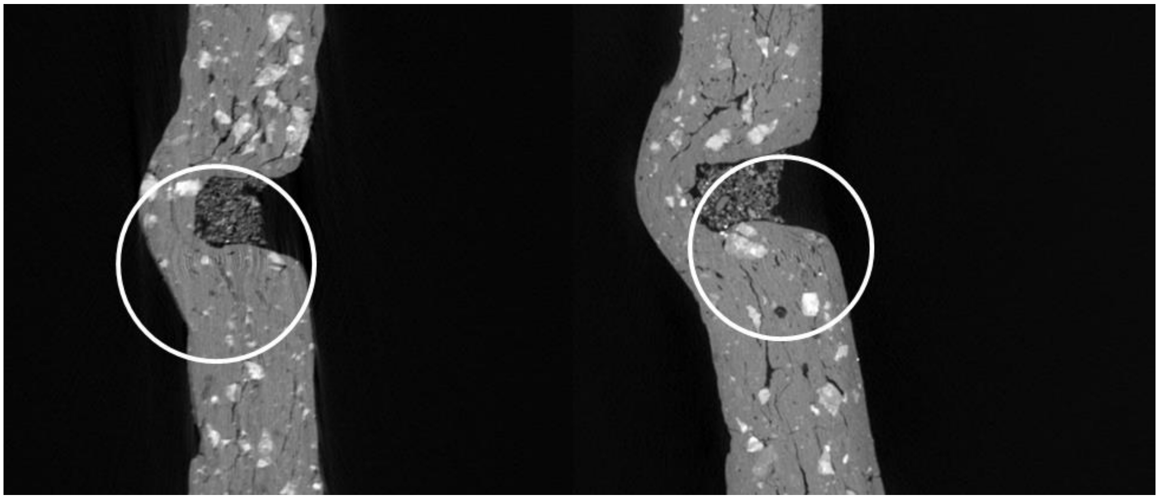

Figure 5.22: Testing shading corrections to eliminate rings. The image at the left had shading corrections set at five images, 250 frames to average, and the ring artifact is still prominent. The image at the right had shading corrections set at five images and 350 frames to average, and the ring artifact is still visible, but quite faint.

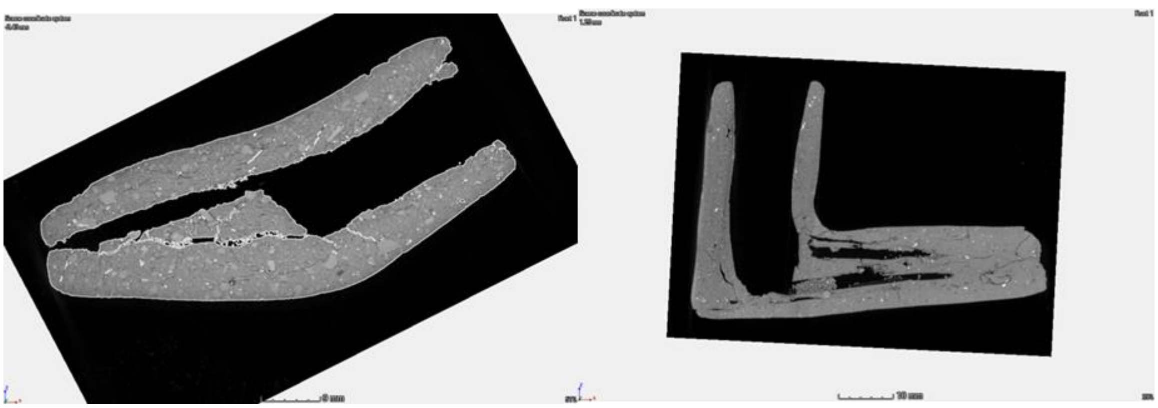

Figure 5.23: At left: Specimen 086 scanned at 165 kV and 65 µa. At right: Specimen 087 scanned at 150 kV and 60 µa. All other settings were the same, but the filament blew after scanning Specimen 086. These images illustrate how more beam energy and current were needed near the end of a filament life.

Early on in the scanning of specimens for this research, there was a slight misalignment with the tilt axis of the manipulator in the machine that controls the rotating stage, meaning that the position of samples was not perfect and leading to blurriness and double edges in scans. This issue is likely why some of my early scans are not as clear and crisp as they could have been. I also consistently had to deal with turntable rotation errors, since, the turntable would occasionally over-rotate, and sometimes it dropped frames, i.e., not all images were taken. At one point during the life of this research, the turntable would go about 40 degrees into a scan and then just start spinning and stop in a new, random spot. These errors with the machine created the need for longer scan times, and lots of instances of scans that had to be re-done. While I ended up conducting analysis on 106 scans, my total number of scans, including failed scans and test scans run that experimented with different settings in attempts to fix errors, was in fact 152. In other words, there were 46 scans that were tests that failed mid-scan, or were completed but gave results that were unusable.

I also discovered that specimen size affected the resolution and quality of the resultant scan greatly. Because the Nikon XT 255 uses cone-beam projection, the smaller the sample, the greater the geometric magnification can be, maximizing resolution. Thus very large vessel sections had to be scanned at a lower resolution than I could obtain for smaller rim sherds, and as a result the effective pixel size in scans used in this analysis varied from 21 to 120 µm, with an average pixel size of 72 µm. The only way to have made all scans the same resolution would have been to scan the largest specimen first and match that position and other settings for all subsequent scans, or to only scan portions of larger specimens. However, I chose to obtain the best resolution possible for each specimen. This decision may have made my scans less comparable objectively, but it meant that at least in the smaller samples, it was easier to visualize and isolate the smaller and less dense inclusions in the specimens. As well, as a key aim of this study was to examine the overall manufacturing method reflected in a vessel section, I was more interested in scanning the entirety of these larger specimens, in order to see manufacturing methods across a larger section of the vessel. For answering questions related to ceramic composition, smaller samples scanned at higher, consistent resolutions would have been more appropriate.

I also found thresholding was not a perfect method for isolating one material from another. Sometimes I missed some voids because the very edge of the ceramic was a similar density to some of the interior voids, so I had to set the threshold higher. As well, some of the lower density inclusions were too close to the density of clay to be isolated effectively. As a result, it always proved to be a bit of a judgement call where to choose the cut off for density. In general, I attempted to consistently include slightly fewer voids or inclusions rather than include material that was being misidentified as voids or inclusions. This practice meant that my percentages of voids and inclusions for specimens were generally slightly lower than reality, though it is worth noting that an average sherd generated 100,000's of inclusions and voids overall. Also worth noting is that, because the scans were not all done at the same settings, and were not all calibrated, and because there was so much variation between the ceramic specimens themselves, I could not just rely on the same threshold values for each specimen, but had to adjust them. Furthermore, as the resolution of micro-CT is finite, it is not always possible to determine with complete certainty where one material inclusion of clay texture ends, and the next begins (Wade at al. 2011:315). In future studies I would consider creating a cutoff point based on the voxel size for each scan and eliminate void and inclusion volumes smaller than that, considering them noise. Nonetheless, despite these limitations, various characteristics of internal ceramic architecture were documented across scans and were comparable.

Though improving rapidly, most software available for examining micro-CT images is designed for either medical or industrial applications. For example, the fibre module in VG was designed to pick up man-made fibres, not void structures in ceramics. Even in the porosity and inclusion module I had limited access to, the automatic algorithm tended to miss many voids, and the manual states it is not effective on multi-component and complex materials – which is what archaeological ceramics are (Volume Graphics 2016:439). Newer software such as Dragonfly, by Object Research Systems, offers deep learning options for segmentation that may represent the future of this type of analysis (Object Research Systems 2020).

Finally, sample selection of specimens was influenced by catalogue errors, to some degree. One box of large vessel fragments from the Figura site was mislabeled in the Museum box listing so these vessels were not included in my sample. Further complicating sample selection was the fact that some rim sherds listed and pictured in the reports were nowhere to be found in the collection; six banker's boxes of ceramics containing mostly rim sherds were found by the licensee's employer only after the completion of my analysis. Thus, to some extent the sample of specimens that makes up this study was based on the Arkona Cluster ceramics available to me at the time. I also learned that I should have attempted to select for unmended sherds (i.e., avoided vessel sections where multiple sherds have been glued together), as breaks in the ceramic that had been glued back together were impossible to isolate from voids created by manufacturing processes in my analysis, resulting in skewed void percentages in those cases.

5.6 Discussion

CT scanning is mostly science, but also a little bit arts and crafts. Each specimen required differing settings and was undertaken under slightly different conditions involving ingenuity, workarounds, and judgement calls. However, part of this project was concerned with determining the protocols for scanning ceramics through the micro-CT scanner. While issues with the technology, software and my research priorities preclude any universal standards being offered here, my experience did define preferred settings to be considered when scanning this material. Ideal beam energy (kV) and beam current (µa) settings generally ranged from about 130-140kV and µa of between 67-70, though this tended to be based on filament life at the time of any individual scan. In addition, a 0.25 mm or 0.1 mm Cu filter was preferred because it filtered out low energy X-rays without the need for a huge increase in kV. When the scanner was working properly, I used a 53 minute scan, which represented 3142 individual projections. For the purposes of this analysis, these scans were clear enough to see everything needed. Some of the scans in this analysis were completed using a longer setting to eliminate ring artifacts plaguing the machine for some time in fall 2015 and winter 2016. A timeline of the scanning and analysis process for this research is presented in Appendix F. However, the resulting scans were not of a higher quality than the shorter scans. While only offering my perspective as someone who has run a lot of scans, and not that of a trained CT technician, it is my hope that the overview of the methods used in this research and the flexible protocols developed here through trial and error will be of use for future ceramic studies.

Chapter 6

6 Results

This chapter presents the qualitative and quantitative data obtained from micro-CT scans relevant to my interpretations of this dataset. With these results, I make conclusions about how decisions potters were making during several steps in the *chaîne opératoire*, including clay preparation, vessel forming and vessel finishing. Results from micro-CT scans suggest connections between the potters in the Arkona Cluster, indicating a shared community of practice at these sites. There are many types of data that can be recorded from micro-CT images, but here the focus is on dimensions of ceramic artifacts that can be seen in a unique way through this innovative technique. Presented here are compiled results, not separate data from each scan undertaken, though I provide in Appendices D and E a range of information on individual scans.

Results from a series of experimental clay slabs are presented first in this chapter, as an example of the types of results that can be obtained, and to test the validity of results obtained from scans of archaeological samples. Results from the archaeological scans presented in this chapter are organized relating to multiple stages in the *chaîne opératoire*, or operational sequence of ceramic making (i.e., De La Fuente 2011; Dobres 2000; Edmonds 1990; Lemonnier 1992). Results will be presented according to these stages of manufacture, focusing specifically on the clay fabric preparation, vessel forming, and, to a limited extent, vessel finishing. Note that both earlier and later stages along the *chaîne opératoire*, including clay harvesting, and vessel acquisition, use and disposal, are not explored in this chapter. Many finishing attributes that are visible through micro-CT scans, such as shallow exterior decoration or vessel surface treatment, are not presented in detail here, as they can be explored just as effectively using traditional ceramic analysis methods. They are explored here as they relate to other attributes that are only analyzable through micro-CT analysis. Examining these steps in the *chaîne opératoire* through micro-CT analysis provides a new way to explore the craft of ceramic making and provides information on this craft from actual archaeological ceramic material. These results provide a starting point for the examination of generational transmissions, and social change as it might be visible in ceramic manufacture. The qualitative and quantitative data presented here permit ceramic researchers to begin to access the context of production and determine what this can tell us about communities of practice at Arkona.

For the purposes of discussion in this chapter, I will be referring to the internal architectural features of ceramics as oriented along one or more of the object's X, Y, or Z axis. To orient the reader to these axes, I am assuming a vessel sherd orientation where the top or lip of a vessel fragment is north (up), and lower down the vessel is south (down). See Figure 6.1 for the orientation of the axes for a hypothetical vessel fragment, in order to orient references to these alignments (see also section 5.4.1).

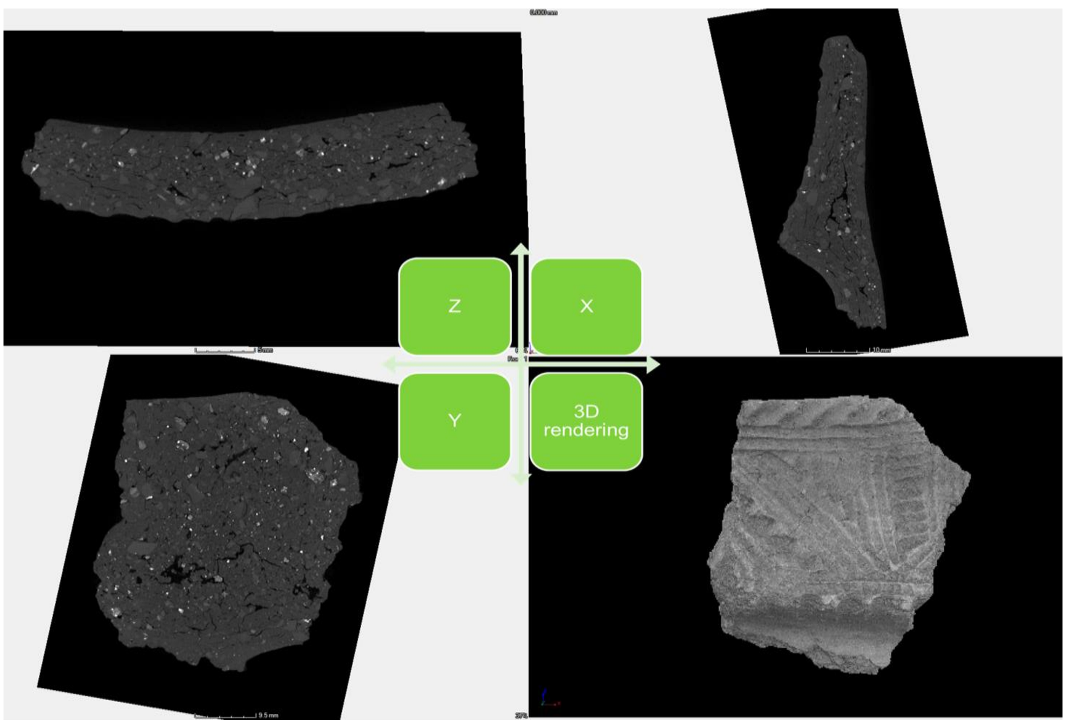

Figure 6.1: Figure illustrating slices through a ceramic along the Z, X and Y planes with vessel lip oriented upwards.

6.1 Test Scans with Experimental Clay Slabs

In order to better understand ceramic vessel scan results, I separately created 12 clay slabs and one small pinch pot using store-bought clay meant for wood firing, and temper collected in the Arkona area. The intent was to scan these prepared objects to provide a general sense of how "visible" my preparation of clay paste and manipulation of clay was in resulting scans of these slabs. These were not an exhaustive or particularly scientifically created sample, just an experimental exercise to explore how different ways of manipulating clay might appear in micro-CT scans. Some of the techniques and gestures used in this experiment, such as joining coils together and folding rims over were informed by the initial macroanalysis and micro-CT analysis of early test scans in an attempt to recognize techniques that appeared to be visible at Arkona.

I weighed the amount of clay and temper that I then mixed as a preparation to get a percentage temper by overall slab weight before firing. All clay preparations were then wedged/kneaded before forming. These slabs dried for ten days then were fired in an open hearth. Either because of my lack of ceramic experience or my material selection, all of the slabs exploded or cracked during firing. There were only seven that had large enough pieces left after firing that could be scanned. Due to a variety of factors, the scanning and analysis happened over two years later. I undertook the analysis blind to see if various forming methods could be detected without prior expectations. The results of the specimens that could be scanned are presented below.

6.1.1 Experimental Clay Slab Results

Specimen 072 Experimental Slab 7: made with 200g clay and 10.8g granitic temper (G2) from Rock Glen[3] (5.4% temper). This slab included an applied strip of clay attached at the rim, created with a flattened coil. The interior was smoothed, not scraped.

Scan Results (Figure 6.2): 4.3% inclusion volume, 0.5% void volume. Voids were primarily planar with some small vesicles, and some vughs around inclusions (see Section 5.4.2 for a discussion of void terminology). Voids ran parallel to the vessel wall, except at 20-22 mm from the lip of the vessel where there were horizontal voids. This horizontal void is readily visible, and correlates with the attached strip of clay creating the rim.

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[3] Rock Glen is a Conservation Area immediately to the north of the Arkona Cluster of sites, located along the Ausable River.

Specimen 074 Experimental Slab 9: made with 200g clay and 12.8g sand temper (6.4% temper). This object was created using two separate slabs that were flattened out by hand, then cut to shape and joined. The “rim” was created by applying a flattened coil to the top of the joined slab.

Scan Results (Figure 6.3): 4.8% inclusion volume, 0.4% void volume. Voids were primarily planar with some small vesicles. Voids ran parallel to vessel wall, except at approximately 20 mm from the lip of the vessel where there were horizontal voids. I was able to note some parallel voids between 7-10 mm from the lip, while at the lip I noted some voids at 22-25 degrees from the y plane (for void angle recording see Section 5.4.2). The patterns I noted in the scan suggested to me Slab 9 might include clay added to the exterior of the vessel, and that the whole rim might have been added.

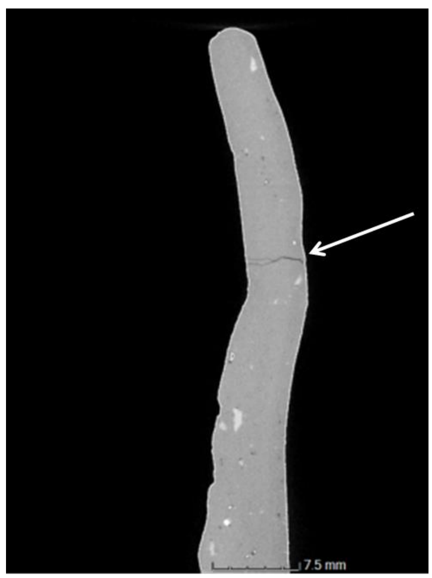

Figure 6.2: Specimen 072 with an arrow highlighting the horizontal void where the rim was added.

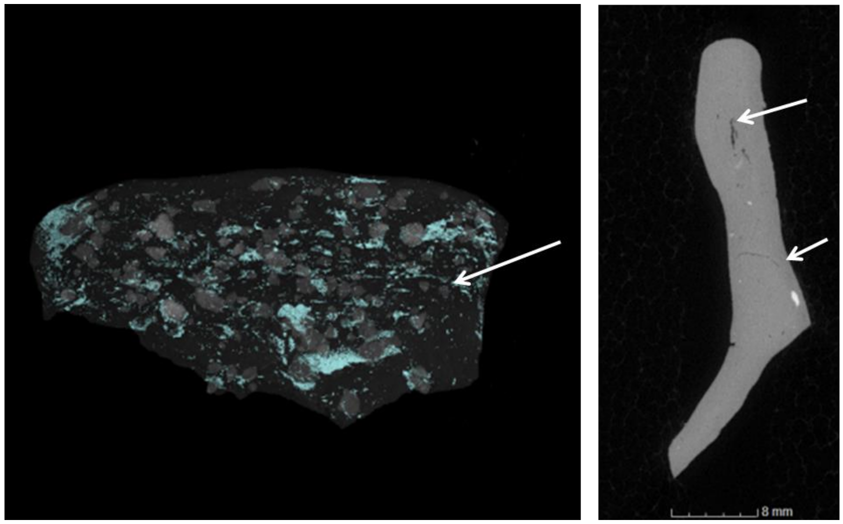

Figure 6.3: Specimen 074. Left: the arrow highlights the horizontal void running across where the rim was applied in this 3D representation of the voids in the specimen. Right: This is a 2D slice through the X plane, where a coil join (lower arrow), and a parallel (upper arrow) void can be seen.

Specimen 076 Experimental Slab 2: made with 200g clay and 9.9g quartzite temper (4.9% temper). This slab was created using six coils joined together, and then a paddle and anvil method (the anvil being a flat palm sized rock) was used to press the coils together and pound the resulting slab thinner.

Scan Results (Figure 6.4): 2.8% inclusion volume, 0.7% void volume. Voids are primarily planar with some vesicles. Rather than parallel to vessel walls, most voids run horizontal with large voids at 15, 28, and 45 mm from lip. These voids suggested to me that the specimen was a coiled vessel, with three joins visible.

Specimen 077 Experimental Slab 12: This slab was made with leftover clay from the other slab specimens I created, and contains a mix of all tempers. I formed the leftover clay together into a slab, which was then drawn upwards and thinned using the same paddle and anvil method I employed previously. It was then smoothed with a wooden tool, and I wiped the interior and exterior with a cloth. A castellation was pulled upwards by hand. After two hours of drying, this slab was decorated using a number of incising and impressing decorative treatments.

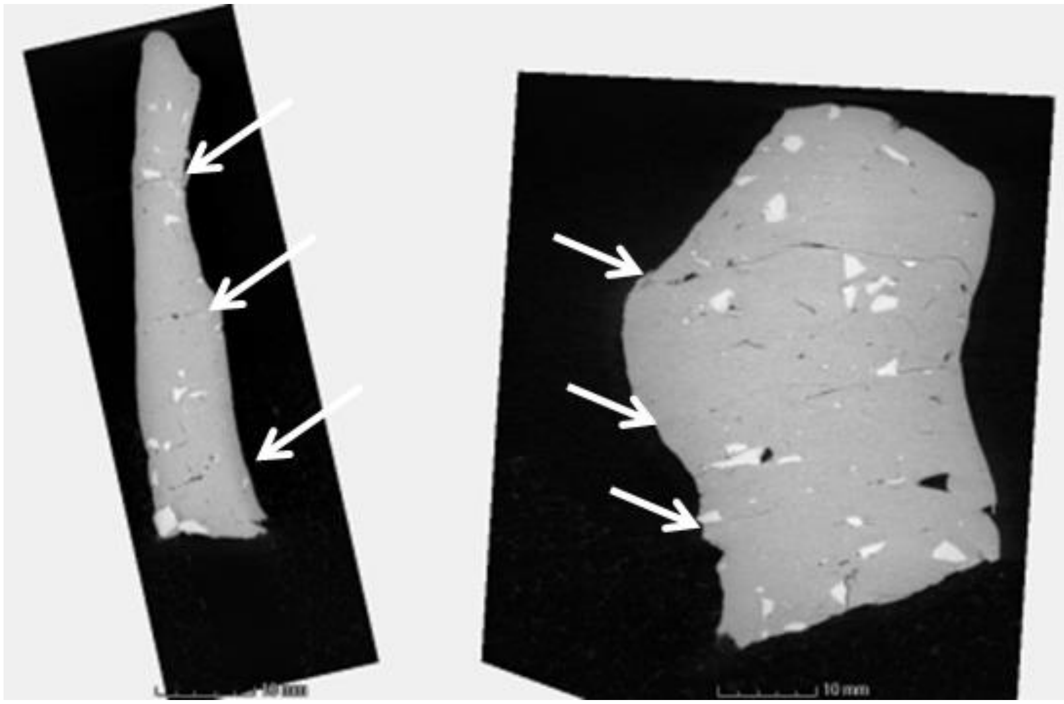

Figure 6.4: Specimen 076 with horizontal voids indicative of coil joins in slices through the X and Y planes.

Scan Results (Figure 6.5): There was not much of this slab left to analyze, with only one edge of the vessel surviving firing. It had 5.1% inclusion volume, 0.4% void volume. Voids are primarily planar with some vesicles. Voids are parallel to the vessel walls. At 22 mm from the lip, there is a large void that meets the interior wall at a 59-60 degree angle. In reviewing the scan, I noted that this void goes all the way to the lip, which suggested to me that the rim may have been added. While this observation is not reflective of how the slab was actually made, the fact that the scanned section of the slab was so small may have limited my ability to interpret the result.

Specimen 078 Experimental Slab 13: this small vessel was tempered with a small amount of granitic temper (G1) obtained near Rock Glen, but not weighed against the amount of clay used. This specimen was a small pot formed from a lump of clay that was pinched and then drawn upwards. I folded the rim of the vessel and created castellations by folding. After two hours of drying, it was decorated using a pointed wooden tool using right-handed motions.

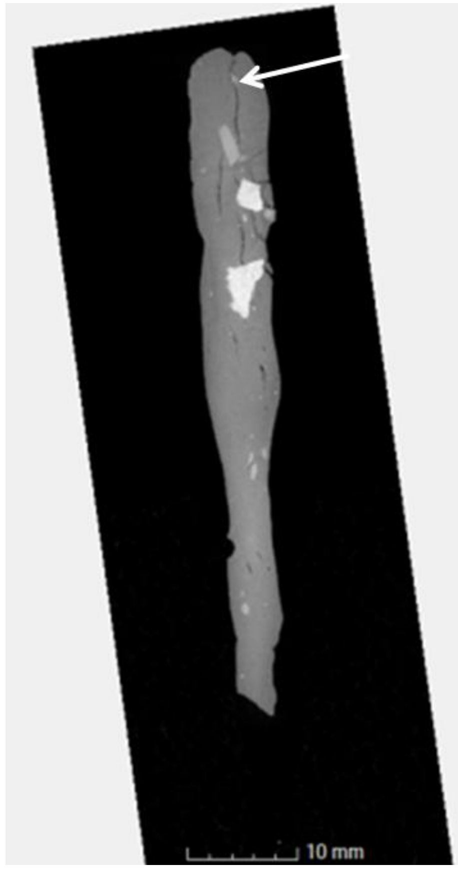

Figure 6.5: Specimen 077 2D slice through the X plane with a large void near the lip.

Scan Results (Figure 6.6): 3.7% inclusion volume, 0.6% void volume. Voids are primarily planar with some large vesicles. Voids are mostly parallel to the vessel walls with some very fine horizontal voids at about 28 mm from the lip. I noted that there were no obvious construction methods suggested by the scan, but perhaps the large vesicles reflected compression from pinch pot manufacture. I also thought I could see the folds in both the 3D and 2D images.

Specimen 095 and Specimen104 Experimental Slabs 3 and 4: These specimens were made with 200 g clay and 10.8 g limestone/fossil based temper (5.4% temper), and represent both halves of a pinch pot/bowl that was cut in half. The Slab 3 (Specimen 095) half was subjected to paddle and anvil forming, while Slab 4 (Specimen 104) was scraped smooth on the interior with a shell and had a rim applied.

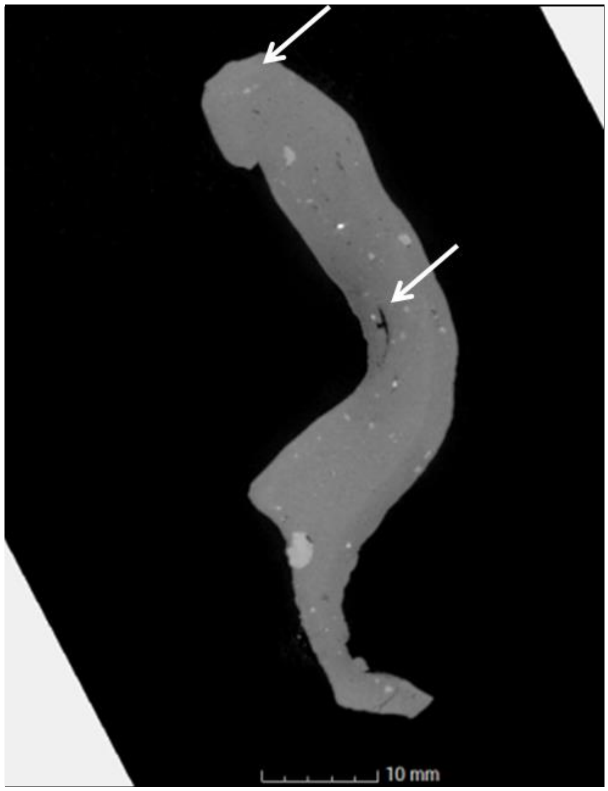

Figure 6.6: Specimen 078 2D slice through the X plane, illustrating large voids near the rim of the vessel.

Scan Results (Figures 6.7 and 6.8): Slab 3 (Specimen 095) - 5.1% inclusion volume, 0.9% void volume. Slab 4 (Specimen 104) - 5.4% inclusion volume, 0.5% void volume. Voids for both specimens were primarily planar with some vughs. Most voids were parallel, but there were some perpendicular to the walls close to the rim in Slab 3, while in Slab 4 the largest voids were non-parallel, and at 52-54 degrees from the y plane smaller voids were parallel to the vessel walls. I noted that it looked like the rim was added on, and maybe there was a fold visible lower down.

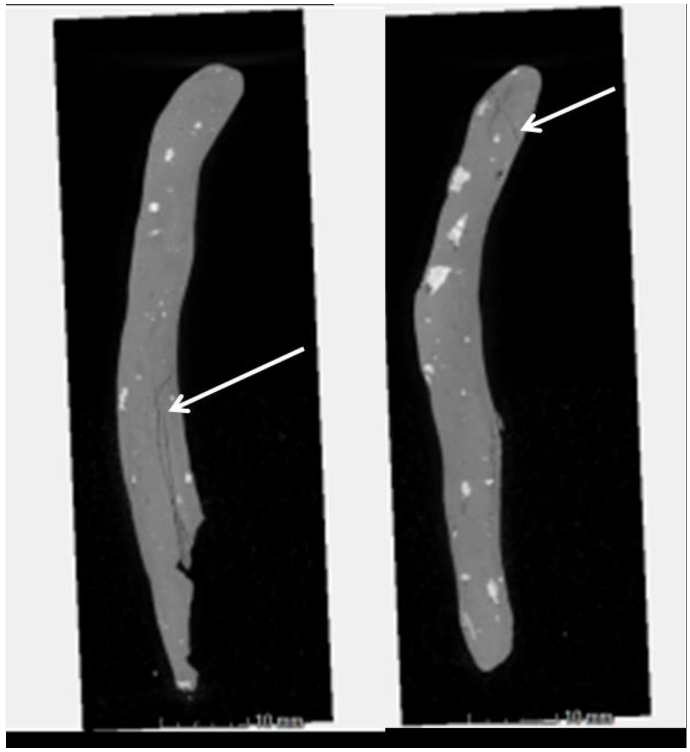

Figure 6.7: Specimen 095/Slab 3. Large voids are visible in 2D slices along the X plane. In the slice to the right, illustrates perpendicular void is seen near the rim.

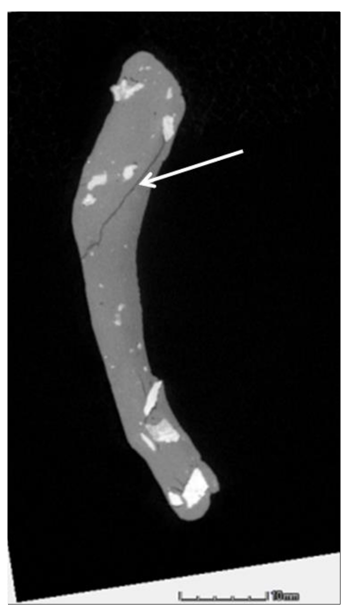

Figure 6.8: Specimen 104/Slab 4 with large perpendicular voids visible in the 2D slice through the X plane.

6.1.2 Summary of Test Scanning Experimental Slabs

Overall, my limited expertise in clay manipulation meant that these slabs were not well made enough to provide detailed insights into most clay preparation, forming, and finishing attributes in the micro-CT scans. Nonetheless, these experimental slabs did reflect major forming characteristics, notably joining and folding of clay, and a sense of void alignment related to the general drawing and thinning of clay that occurred during forming. Certainly, these samples reinforce the insights others have offered (Kahl and Ramminger 2102; Sanger 2013, 2017) that coils and joins in clay can be readily seen in micro-CT scans. Temper inclusions were visible in both 3D and 2D, but I was not able to detect the role these inclusions played in augmenting or interfering with void patterns. Volume percentages for inclusions ended up being generally lower than their weight percentages. This discrepancy makes sense since some of the granitic, quartzite and sand tempers might weigh more than clay by volume. Ultimately, while these slabs were not used directly in interpretation of the archaeological samples, the exercise did give me a general idea of some of the manufacturing techniques that might be visible in the archaeological samples scanned, and what might be more difficult to discern. Future material craft studies, such as tracking artisan vessel manufacture through each stage of production with a skilled artisan using a number of material variables, and scanning clay objects at each stage, does have the potential to further advance our understanding of vessel interior architecture revealed by micro-CT scans.

6.2 Analyzing Clay Fabric Preparation using Micro-CT

A range of internal ceramic fabric attributes could be identified and quantified through micro-CT scans as they relate to the clay used in pottery, and notably on the conversion of that clay body into a clay fabric for making ceramic vessels. These attributes provide information on the natural make-up of the clay and its inclusions, as well as the amount and characteristics of the tempering material that was added to the clay by the potter. After collecting clay, this adding of aplastic material into the sorted and prepared clay source is one of the first steps in the process of manufacturing a pot (Rye 1981). The ratio of temper to clay, and textural analysis are important aspects of in archaeological ceramic analysis because clay “recipes” are often learned, taught and passed down from one potter to another and the choices potters make about the amount and type of temper they use are related to social factors (Braun 2015). Similarities in the way potters were preparing their clay at Arkona may indicate belonging in a community.

It should be pointed out that micro-CT scan data related to clay fabric recipes and internal structure of ceramic vessels complement data that is typically obtained through petrographic thin sections of ceramic vessel specimens. However, there are distinct differences between these two types of data generated and their resulting analyses. These distinctions will be noted when discussing particular attributes of fabric preparation below.

6.2.1 Comparing Total Volumes to 2 cm^3 Prisms

One notable distinction between petrographic thin sections and a complete 3D scan of a ceramic sherd or vessel section is the scale of raw data obtained in each scan of inclusions and void spaces, and the tremendous variability of that data from specimen to specimen, based on the size difference of individual sherds. As noted previously, I was interested in exploring evidence of vessel formation, so I wanted scans that encompassed the entire sherd, but this proved a challenge to then adequately compare ratios of inclusions, for example, between specimens, and at different resolutions.

Given this challenge, I undertook to explore whether an arbitrary portion of each specimen scan could be analyzed to provide meaningful, comparative results across all vessels. This approach would allow me to adequately compare inclusions and other internal features, regardless of whether I was dealing with a small rim sherd or a much larger section of a vessel that included the rim, neck and shoulder. Note that I generally have relied on overall internal feature volume percentages for inclusions and voids, rather than frequency counts, given the size variation between sherds.

To obtain an arbitrary comparator, I established a 2 cm^3 rectangular prism for 67 of the Arkona specimen scans, located at a set place below the lip of the sherd (see Section 5.4.2), to allow comparisons between rim sections of sherds that are different sizes and sherds that encompass rims only, with sherds that encompass additional portions of a vessel (i.e., neck, shoulder, body). When positioning prisms on five neck sherds, which did not have an intact lip, I used a best estimate of where the lip would have terminated based on the remaining profile of the vessel wall.

With only two independent variables for each prism/whole specimen, it was difficult to assess how effectively prisms can serve as proxies for an entire scanned specimen. I first thought to run a chi-square test to test inclusion and void volume percentages, and to determine the degree to which the prism-derived percentages are a close match to whole specimen percentages for each of these attributes. But chi square tests on void and prism volume percentages for individual sherds would be of very limited utility, since all I could compare would be two expected numbers against two actual numbers: void percentages and inclusion percentages between the full sherd and its arbitrary prism. As such, I would be working with only one degree of freedom for each p value. Moreover, the two percentages for each sherd reflect separate things: inclusion percent variation, for example, may be entirely independent or even anti-dependent of void percent variation. Given these constraints, I felt running chi square tests would be of no utility in this context.

As an alternative approach, I simply grouped prism-derived percentages by their variation to the percentages obtained for their associated specimen (Table 6.1). For whole sherds, the range of variation noted for inclusion volume percentages was between 1.9% and 19.9%; a relatively broad range. This scale of variation is also reflected in the prism findings, with only 34.3% proving to be either equal to or within 1% of their whole specimen counterparts when it came to inclusions volumes. At a 2% variation, 52.2% of all prisms were found to be within their full sherd volumes, increasing to 67.2% at a 3% variation or less. That still leaves 32.9% of prism inclusion volumes falling at a more than 3% variation difference from their whole specimen counterparts.

For void volumes, whole sherd variation was much mess extreme, with the range of variation across whole sherds scanned for this study ranging from 0.4% - 5.4%. Likewise, the void variation in prism-derived values was also relatively narrow, with 74.6% of all prism-derived values being equal to or within 1% of their whole specimen, and fully

Table 6.1: A Comparison of Prism Inclusion and Void Volume Percentages to whole specimens (WS). Individual Prism volume percentages are compared with their individual whole specimen volume percentages to tabulate the percentage difference.

	Inclusion Volume Percentage Difference	**Frequency**	**% of 67 prisms**
More inclusions in WS than prism	Prism is greater than 5% less than WS	0	0.0
	Prism is within 5% less than WS	0	0.0
	Prism is within 4% less than WS	2	3.0
	Prism is within 3% less than WS	4	6.0
	Prism is within 2% less than WS	4	6.0
	Prism is within 1% less than WS	11	16.4
	Prism is equal to WS	1	1.5
More inclusions in prism than WS	Prism is within 1% more than WS	11	16.4
	Prism is within 2% more than WS	8	11.9
	Prism is within 3% more than WS	6	9.0
	Prism is within 4% more than WS	7	10.4
	Prism is within 5% more than WS	7	10.4
	Prism is greater than 5% more than WS	6	9.0
	Void Volume Percentage Difference		
More voids in WS than prism	Prism is greater than 5% less than WS	0	0.0
	Prism is within 5% greater than WS	0	0.0
	Prism is within 4% less than WS	0	0.0
	Prism is within 3% less than WS	0	0.0
	Prism is within 2% less than WS	3	4.5
	Prism has within 1% less than WS	22	32.8
	Prism is equal to WS	4	6.0
More voids in prism than WS	Prism is within 1% more than WS	24	35.8
	Prism is within 2% more than WS	7	10.4
	Prism is within 3% more than WS	3	4.5
	Prism is within 4% more than WS	2	3.0
	Prism is within 5% more than WS	0	0.0
	Prism is greater than 5% more than WS	2	3.0

89.6% of all prisms fell within 2% of whole specimen values. The difference in variability between these two internal attributes underscore that these do indeed represent independent variables.

I did not originally intend for prisms to serve as one to one proxies for whole specimen volumes. The intention was simply to allow comparison of the rim portion of a specimen to other rim portions of scanned specimens in an attempt to eliminate variability caused by morphological variation. For example, by varying size and extent of intact vessel rims, necks, shoulders, and bodies across the specimens scanned. Furthermore, I hoped the prisms could equalize differences in scan quality by eliminating noise that occurred at the surface of some of the scanned specimens. This noise had made segmenting voids and inclusions from specimen surfaces more difficult than from specimen centres. That being said, overall prisms generally turned out to be relatively representative of the whole specimens they were located within.

The range of prism inclusion volume percentage variation to whole specimens suggest the confidence of prisms as proxies for this attribute is limited, given a third of prisms were more than 3% variable to whole sherd percentages. Only 6% of prism void volume percentages varied beyond 3% of whole sherd percentages, suggesting perhaps that this attribute is more effectively represented in prisms.

An important factor to consider is whether the differences noted between the prism and whole specimen volumes were positive or negative; i.e., was there more or less void and inclusion volumes being captured in the prisms vs the whole specimen? As it turns out, 42 of 67 prisms (62.7%) had a void volume that was equal to or greater than their whole specimens and 46 of 67 prisms (68.7%) had an inclusion volume that was equal to or greater than their whole specimen counterparts. This suggests that either there were higher inclusion volumes in rims than other portions of vessels, or that the elimination of noise at the edges of scans might have made an important difference in the ability to isolate inclusion volumes.

All inclusion volume percentages that had a 5% or higher difference (13 in all) between the prism and whole specimen-derived values were instances where inclusion volume percentages in the prisms were higher than those in the whole specimens. Of those, seven of the 13 vessels were rim sherds, five were rim and neck sherds, and one was a rim, neck and shoulder sherd. Given that inclusion variation between prisms and whole sherds included rim-only specimens, difference in vessel sections does not appear to be the source of variation between prisms and whole specimens for inclusions. Ease of segmentation of inclusions in the centre of the volume might have been a factor.

The four prisms where void volumes fell above 3% difference included two rim and neck sherds, a neck and shoulder sherd, and one rim, neck, shoulder and body portion of the vessel, but notably no stand-alone rim sherds. The prism-derived void volumes for all stand-alone rim sherd specimens fell within 2% of their whole specimen volumes. In the case of void volume inclusions, then, notable prism variation from complete sherd volumes might well be due to specimens that include elements of the vessel beyond the rim. This makes sense given that the rim portion of vessels is where the largest void structures were recorded, suggesting these prisms may provide some utility, however minor, in eliminating void volume discrepancies between rim-only specimens and specimens that encompass other portions of the vessel. These results allow me to make a case that prisms placed in the same location in each sample can offer some broad proxy comparisons for specimen scans, though cautiously, since rim portion values are not *always* the same as total sample volumes.

In the end, the prisms helped eliminate variation between sections of a particular vessel, or noise within the edges of particular scans. As such, the use of prisms does offer a means of comparing specimens, eliminating wider noise and variation across the sample of sherds, to create values that are more easily comparable between vessels. Moreover, as an object lesson, these prisms also provide 3D insight into a similar, arbitrary limitation that thin section analysis grapples with when understanding internal vessel fabric variables. As such, I will provide a comparison of overall specimen and prism patterns in the discussion below, recognizing that the prisms are a distinct analytical tool for examining frequencies of inclusions and voids in particular, rather than serving as a direct proxy for the vessel specimens overall.

6.2.2 Inclusion Volumes in Clay Fabric

Woodland ceramics throughout the Northeast are made of clay fabrics that have been prepared by potters prior to vessel forming. Clay preparation includes the addition of temper into the clay, typically stone grit (Watts 2006). Natural inclusions in the clay and tempering materials are the focus of many material science studies that consider material and frequencies to explore ceramic provenance, petrographic signatures for identifying distinct clay sources, technological improvements of the clay body, and dimensions of distinct craft tradition and enculturation reflected in particular fabric recipes by temper type, size and frequency (e.g. Braun 2015; Reedy 2008; Quinn 2013).

Textural analysis of inclusions is one of the main aspects of petrographic studies of ceramic fabrics. These analyses are based on the 2D surface of a thin section cut exposing the internal fabric of a particular ceramic specimen. In data collection to determine grain-size distributions, diameters of inclusions are recorded, most commonly based on a point-counting technique (Quinn 2013:109). Measurements or counts of 100-300 inclusions per thin section are normally considered a statistically significant sample in petrography to provide an accurate and detailed picture of the texture or composition of a sample fabric. Usually, the total number of inclusions is also measured per thin section where possible (Quinn 2013:109). Some petrographers have also used inclusion surface area as a proxy for volume, in order to develop a sense of 3D volume, which is considered more accurate than inclusion counts, but still not perfect (Braun 2015:57). As Braun notes, potters would not have been counting out temper inclusions. Instead, they would have been mixing temper and clay by feel until a perceived consistency was reached. If this was the case, measures of volume and mass, rather than counts of inclusions, are probably more in tune with the practices of potters.

Given the limitations of a thin section face to fully represent the textural dimension of recipes, further insights into ceramic fabrics could be gained through micro-CT scans. These scans have the potential to provide a 3D profile of all inclusions, allowing for complete frequency and volume measurements across a scanned specimen, and not extrapolated from a limited 2D surface.

The scale of the inclusions that can be recorded differs between micro-CT and petrographic results, however, depending on the resolution and goals of the micro-CT scan. For example, the volume data obtained from the VG inclusion and porosity module sorts the smallest inclusions into either 0.00 mm^3 or 0.01 mm^3 particle size categories, whereas petrographic analyses typically measures and counts surface particles visible in a 2D thin section that have a visible planar diameter of 0.01 mm or greater in size (anything less than 0.01 mm is assumed to be part of the ceramic matrix; Quinn 2013:42). If I convert that 2D diameter measurement of 0.01 mm into a 3D volume, such particles would have a far smaller volume than 0.01 mm^3. Thus, the inclusions on the small end of the petrographic spectrum are more accurately measured than those in micro-CT scans, at least when using VG software. In effect, volumes less than 0.01 mm^3 recorded in micro-CT scans are all lumped into a single 0.00 mm^3 category. In other words, micro-CT scans, measuring the presence and size of 3D particles, generate frequency and volume percent data that are not directly comparable to petrographic findings. While micro-CT identifies tens of thousands of individual inclusions in a single sherd that may measure as small as 0.01 mm in cross section, all those inclusions smaller than that volume are only counted. Further methodological differences between micro-CT and petrography are discussed in Section 6.6.

My first effort in approaching the quantification of inclusions was to generate a gross volume percentage of inclusions for each specimen and for each 2 cm^3 prism. To do so, I could not easily separate intentionally added temper from naturally occurring inclusions in the clay; thus, these volume percentage frequencies included anything in the sample that was not clay or air. Sorting temper from natural inclusions can be a difficult task even when examining only a small sample of a specimen and is based on a number of identifying factors (Quinn 2013) that were not accessible for all the scans, because some specimens contained very large numbers of inclusions. For example, across 53 specimen scans run though the VG porosity and inclusion module, numbers of inclusions recorded ranged from 9411 to 200479. Of these 53 examples, 57% contained less than 50,000 inclusions, 32% included 50,000-100,000 inclusions, and 11% included more than 100,000 inclusions. While I will explore questions involving temper versus natural inclusions when discussing grain-size distributions and textural analysis below, for determining inclusion volume percentages across all sherds I could not tease out intentionality for any given set of inclusions.

Despite being unable to discriminate between natural and introduced inclusions in scans, I could still generate an overall percent of inclusions in specimens generally, and from 2 cm^3 prisms. I separated inclusion percentages into 5% increments to summarize results, rounding when needed (e.g., a result of 10.79087 % would fall within the 10-15% category, while a value of 10.01087% would fall within the 5-10% category). These frequency percent categories align with those that tend to be used when presenting petrographic findings of inclusion volume percentages (e.g. Quinn 2013:82). The difference between the two analytical approaches is that inclusion volume percentages are calculated by visual estimation or computer generated results based on the 2D area of inclusions (e.g. Braun 2015) from a thin section, while they are calculated by their actual, 3D volume from a micro-CT scan.

Inclusion volume percentages within a specimen clustered fairly tightly across the Arkona sample. For whole sherds, 51 of 67 or 77% of vessel scans fell within the two categories that make up the 5-15% inclusion volume (Figure 6.9, Table 6.2). In the rectangle prism percentages grouped similarly, with 53 of 67 or 79% of Arkona vessels falling in the 5-15% inclusion volume range (Figure 6.10, Table 6.3). In other words, including both naturally occurring inclusions and added temper, the clay fabric contained 10%, plus or minus 5%, of non-clay material. This concentration of inclusion volume in specimens suggests that the combination of natural and introduced inclusions in Arkona Cluster vessels did not deviate greatly. This observation may suggest most vessels manufactured for use at these sites were made from generally similar clay sources by artisans adhering to a generally consistent paste preparation recipe. This regularity of practice that is indicated by these similarities in inclusion volume percentages throughout the Arkona Cluster suggests that these potters were working within a community of practice that was sharing knowledge about how clay should be prepared.

It is worth noting a slight increase in inclusion volumes in the 2 cm^3 prisms. Given that they derive solely from rim portions of a vessel, this may reflect a slight tendency for larger volume inclusions to be less abundant in the typically thinner sections of a vessel below the rim. Alternately, this higher volume percentage could simply be a result of more effective inclusion thresholding in prisms, due to the elimination of surface noise. There was no patterning of inclusion volume percentages noted for different sites or in conjunction other attributes. Further interpretive implications of these findings are considered in Chapter 7.

The deviation of some specimens from the 5-15% inclusion volume appears to have more to do with limitations in image analysis and user error than actual material differences within specimens. While a few specimens (see Specimens 102 and 040 in Appendix A), appear to have fewer inclusions, most specimens with less than 5% inclusion volume are either scans with a lot of noise that impeded the ability to threshold inclusions (see Specimens 096 and 100 in Appendix A), or specimens that have lower density inclusions (see Specimen 062 in Appendix A) that were more difficult to threshold from the clay matrix. Both noise in scans, and lower density inclusions made it more difficult to isolate inclusions in these specimens, resulting in lower volumes. The vessels with higher than 15% inclusion volume typically have larger/coarser inclusions, making them easier to pick up in the scans (see Specimens 079 and 021 in Appendix A), or have particularly high-density inclusions which made them easier to threshold (see Specimen 009 in Appendix A).

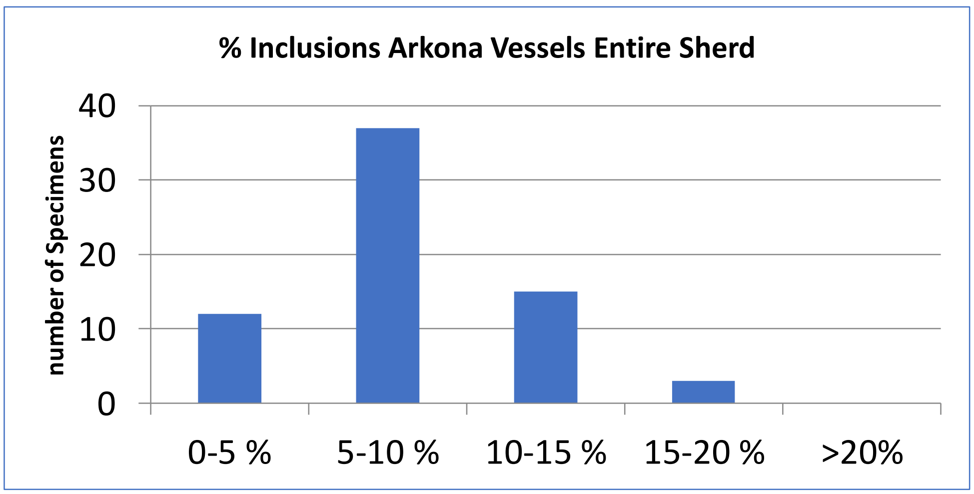

Figure 6.9: Graph for inclusion volume percentages for Arkona vessels whole sherds, n=67.

Table 6.2: Percentage of inclusion within whole specimens for Arkona vessels.

% Inclusions	Number of Vessels	% of Vessels
0-5 %	12	18
5-10 %	37	55
10-15 %	15	22
15-20 %	3	4
Total	67	100

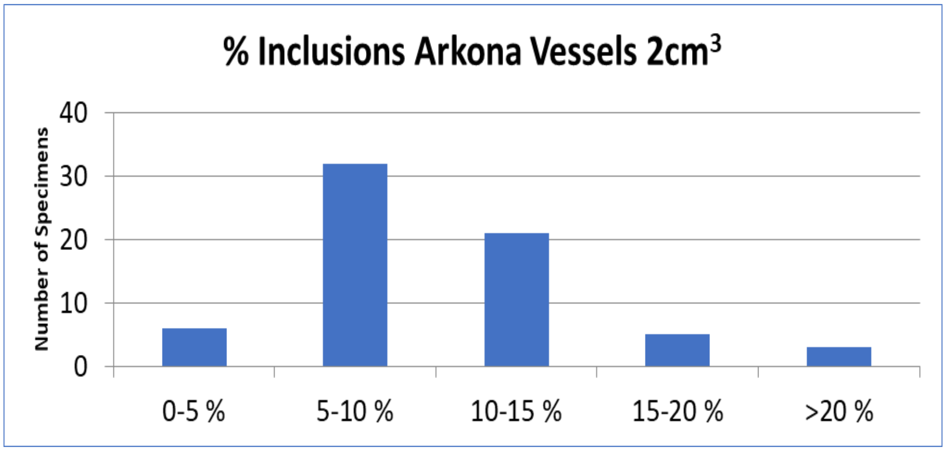

Figure 6.10: Graph for inclusion volume percentages from Arkona Vessels 2 cm^3 rectangular prism, n=67.

Table 6.3: Percentage of inclusions within 2 cm^3 prisms for Arkona vessels

% Inclusions	**Number of Vessels**	**% of Vessels**
0-5%	6	9
5-10%	32	48
10-15%	21	31
15-20%	5	7
>20%	3	4
Total	67	100

6.2.3 Sampled Scans for Textural Analysis and Grain-size Distributions

Working with the very large data sets of inclusion counts and volumes generated from the micro-CT scans was a challenge for conducting detailed textual analyses of specimens, and a full grain-size analysis on all 67 Arkona vessel scans represented a far greater time investment than could be afforded to this one dimension of the current study. As such, I opted to examine a sample of specimen scans in order to explore what analysis could be conducted from these very large datasets. The sample size I chose to work from was a little more than 10% of Arkona vessel scans (i.e., n = 7). The sample included scans from five of the seven Arkona sites that made up the larger collections (Table 6.4), including two samples from each of AgHk-42 and AgHk-52. I also ensured that I selected vessels exhibiting variation in exterior and manufacturing attributes. I then conducted textural analysis, grain-size distributions, and measures of sphericity for this sample using the VG 3.0 porosity and inclusion module.

Table 6.4: Scans used for textural analysis and grain-size distributions.

Specimen number	Site	Total number of inclusions identified in scan	Voxel Size (μm)
024	AgHk-52 Figura	47566	62.17
038	AgHk-42 Bingo Pit Village Loc. 10	34906	47.90
042	AgHk-42 Bingo Pit Village Loc. 10	29343	44.30
050	AgHk-40 Bingo Pit Loc. 3	51413	64.22
061	AgHk-32 Van Bree	47301	72.57
070	AgHk-52 Figura	47011	74.83
011	AgHk-54 Inland West Loc. 3	9411	113.01

6.2.3.1 Textural Analysis

As illustrated in Table 6.4, the spreadsheets generated for the sample specimens included anywhere from around 10000 to 50000 data points; each generating a volume measurement. As such, these datasets needed to be sorted into categories of volume size to begin to see patterns and make interpretations. The resulting information I had to work with was vastly different from petrographic studies where textural analysis data points (gathered using point-counting, line counting, area counting or ribbon counting) of 100-300 data points are often considered a statistically significant sample (Quinn 2013:109). More data may be gathered from thin sections when digital image analysis is used (e.g., Braun 2015; Quinn 2013:111), but the counts are entirely of a different order than the volume data in a micro-CT scan. The challenge for this study, then, was to explore the inclusion volume datasets I could generate to see how textural analysis of vessel fabrics have the potential to complement or interrogate conventional thin section analyses.

It became clear immediately from the sample specimen data that most of the inclusions the VGStudio MAX inclusion and porosity module registered fell into extremely low volume categories. The software sorts data by volume categories of 0.00, 0.01, 0.02 mm^3, and so on. In all the specimens examined, the vast majority of inclusions fell into the 0.00, 0.01 and 0.02 mm^3 volume categories. It was difficult to graphically represent the raw data for all specimens, since percentages of inclusions that fell into differing volume categories was variable, as seen in the following discussion.

Specimens 070 & 024: 83% of inclusions for these specimens were less than or equal to 0.03 mm^3, while 90% of inclusions were less than or equal to 0.07 mm^3.

Specimen 038: 83% of inclusions were less than or equal to 0.02 mm^3, while 90% of inclusions were less than or equal to 0.06 mm^3.

Specimen 042: 85% of inclusions were less than or equal to 0.02 mm^3, while 90% of inclusions were less than or equal to 0.04 mm^3.

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Specimen 050: 81% of inclusions were less than or equal to 0.06 mm^3, while 90% of inclusions were less than or equal to 0.14 mm^3.

Specimen 061: 81% of inclusions were less than or equal to 0.07 mm^3, while 90% of inclusions were less than or equal to 0.18 mm^3.

Specimen 011: 80% of inclusions were less than or equal to 0.53 mm^3, while 90% of inclusions were less than or equal to 1.82 mm^3.

To attempt to understand inclusion volume size frequencies from the perspective of what the potter might have been seeing and feeling and how they might have been interacting with materials, I found it useful to group this data using geological categories. Also informative was looking up the size of something like a grain of table salt, which is about 0.03 mm^3, to visualize exactly what these volumes physically represent, in terms of size. In petrography, typically clay particles and all other material less than 10 µm (0.01 mm) in diameter are referred to as part of the “matrix” of the clay (Quinn 2013:42) since they are too small to be studied in detail given the optical resolution of microscopes used for thin section analyses (e.g., Rice 1987; Smith 2008). When converted to 3D volumes, particles with a diameter of 0.01 mm would normally have a volume smaller than 0.01 mm^3 (e.g., a sphere with a diameter of 10 µm would have a volume of 523.6 μm^3 or 5.236e-7 mm^3). In other words, typical thin section analyses examine these smaller inclusions in more detail than micro-CT scans at the resolution I was able to obtain for this study. Given this distinction, a significant percentage of inclusions identified using the porosity and inclusion module that fall into the 0.00 mm^3 category could be either particles that would be included in petrographic analysis, or may be part of the clay matrix, or at least would be considered so in petrographic analyses.

It is worth noting that I was simply working with the data that the porosity and inclusion module provided at face value, as a first attempt at micro-CT textural analysis of ceramic fabrics. There are problems that emerged that were not corrected for in this preliminary analysis but should accounted for in future research, including the incorporation of a cut off point for inclusions that fall below the voxel size for a given scan, as these likely cannot be effectively recognized by the software. In the sampled scans here, voxel sizes ranged from 44.33 µm to 74.83 µm (Table 6.4), with the exception of Specimen 011 which has a lower resolution and higher voxel size of 113.01 µm. I believe working through this analysis again with scans of higher resolution would prove a valuable exercise, but was beyond the scope of this research.

As petrographic and geological data is presented in 2D measurements, either the diameter or radius of the inclusion, often using the Udden-Wentworth scale (Krumbein 1934; Udden 1914; Wentworth 1922), I converted these diameter measurements to mm^3 to adequately compare geological categories with the 3D volumes obtained in the micro-CT data. I arbitrarily used a sphere as the standard measure of volume when converting the 2D categories into 3D volume of grain types. This choice is not a perfect system, as not all inclusions are spherical, and the diameter measurements obtained in petrography are themselves somewhat arbitrary because a mineral sliced on different planes will generate different diameter measurements. Nonetheless, because geology and petrography can only generate measurements of diameter to classify inclusions, making an arbitrary assumption of volume shape provided me with a standard means of converting geological categories to 3D. Thus, while an arbitrary exercise, this conversion at least provided me with a means of understanding and exploring vast amounts of volume data in a way that was translatable to other ceramic textural studies, and in a way that allowed me to think about potting practice and potters' recipes. There are a growing number of geological and soil sciences studies that rely on CT and micro-CT methods to present geological data in 3D (Tiana et al. 2008), which should be consulted for future work in this area.

Table 6.5 provides a classification scheme used to categorize inclusion volume. Because of the way that the software presented volume data, a large portion of the inclusions that the software picked up fell into a "lumped" 0.00 mm^3 category (i.e., below 0.01 mm^3). This lack of distinction between volumes below 0.01 mm^3 meant I could not sort volume data for inclusions identified in the micro-CT scans to align them within the Udden-Wentworth based categories of very fine, fine and medium sand, because all of the inclusions in the 0.00mm^3 category could fall into any of these three categories. Rather than somehow force the micro-CT volume data to fit these distinct categories, for this study I placed all inclusions with a volume less than 0.01 mm^3 into a class named "very fine/fine sand" which, in reality, may include some particles from 0.008-0.01mm^3 that might otherwise belong in the medium sand category. The volume measurement category for medium sand encompasses values of 0.01 mm^3 through 0.06 mm^3, while the coarse sand volume values encompass 0.07 mm^3 through 0.52 mm^3.

Table 6.5: 3D Volume Categories based on 2D Udden-Wentworth (U-W) Classification Scale and Modified Categories based on Micro-CT Data Constraints

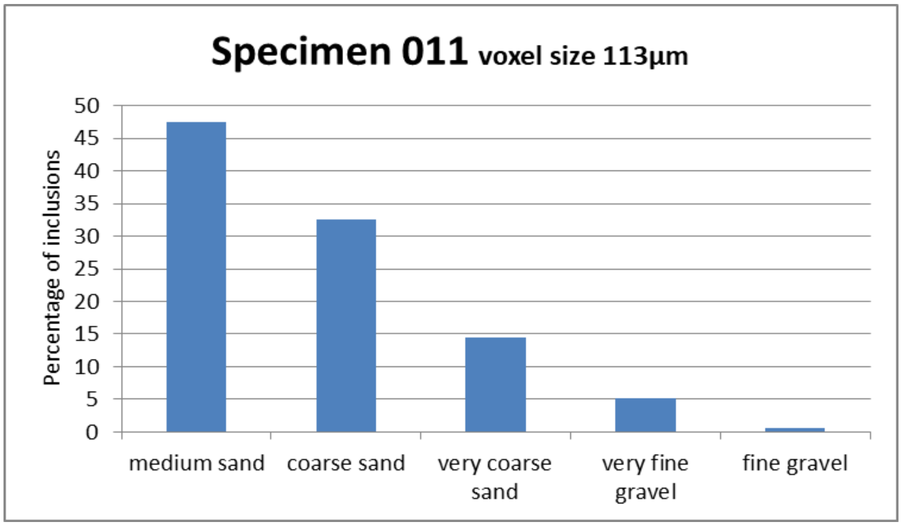
U-W Categories	2D diameter	3D volume calculated from 2D diameters	Adjusted Volume Categories	Volume categories for micro-CT Data
Very fine sand	62.5-125µm	0.000128-0.00102 mm^3	0.000128-0.00999mm^3	Very fine/Fine sand
Fine sand	125-250µm	0.00102-0.008mm^3		
Medium sand	0.25-0.5mm	0.008-0.0654mm^3	0.01-0654mm^3	Medium sand
Coarse sand	0.5-1mm	0.0654-0.524mm^3	0.0654-0.524mm^3	Coarse sand
Very coarse sand	1-2mm	0.524-4.19mm^3	0.524-4.19mm^3	Very coarse sand
Very fine gravel	2-4mm	4.19mm-33.51mm^3	4.19mm-33.51mm^3	Very fine gravel
Fine gravel	4-8mm	33.51-268.08mm^3	33.51-268.08mm^3	Fine gravel

. I should also note that I found the very fine gravel category, while encompassing volumes sizes for inclusions between 4.19-33.51 mm^3, problematic as a useful category for the micro-CT data. The vast majority of the inclusions that fit in the category fell in the lower end of this group, and very few had volume sizes above 6.00 mm^3 (see Figure 6.11). While I considered creating sub-categories to better reflect the micro-CT data obtained across my sample of seven sherds, in the end, because there were so few inclusions in this category at all, and because they were likely all intentional inclusions, I did not break down the category. Lastly, I should also note that Specimen 011 did not conform to the other scans, since the smallest inclusions below 0.00 mm^3 appear to have been missed (i.e., not counted), and so values only started to be recorded at 0.01 mm^3.

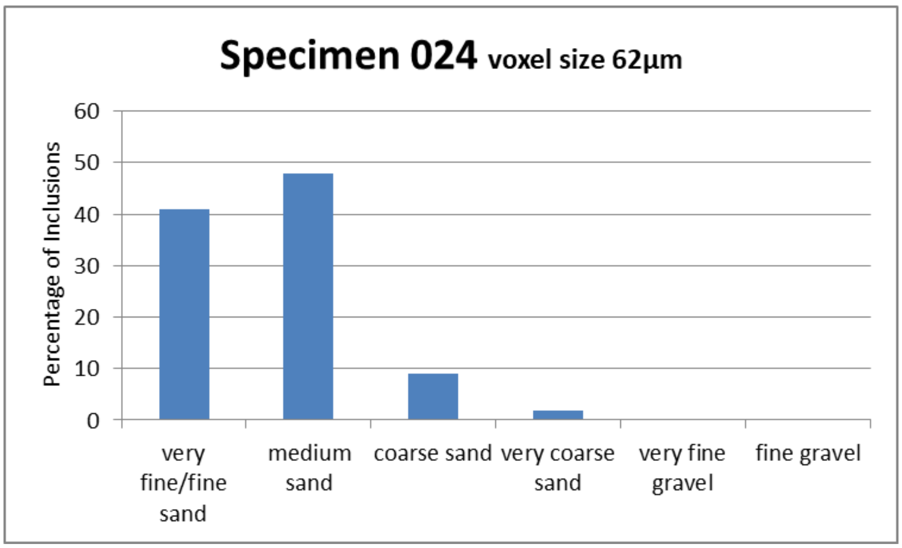
Overall, medium sand is the largest volume category for the four scans with complete inclusion volumes (Specimens 024, 050, 061, 070), ranging between 48% and 64% of all inclusions by volume. For two specimens (038, 042) the largest category is the very fine/fine sand category, at around 60%. In all six cases, these two volume categories are the most abundant, combining to range from just below 80% of all inclusions to around 90% (see Figure 6.11).

Specimen 011 is the only vessel where the coarse sand and above categories constitute more than 50% of all inclusions. This difference is likely due to scan resolution, which was affected by the large size of this specimen (see Specimen 011 in Appendix A). The software appears to have not picked up smaller inclusions at this resolution. Specimen 011 comes from AgHk-54 Inland West Location 3 (Suko 2017a), which, by radiocarbon dating falls between the later stages of the Figura site occupation and the Bingo site occupation (Neal Ferris, personal communication 2018). It has a typical rim shape and decoration for the Arkona Cluster, with stamped bands of linear, left obliques, interior punctates and external bosses, so both temporally and stylistically the vessel fits within the heart of the Arkona Cluster period of settlement and ceramic craft practiced among its potters. So there is nothing remarkable about the vessel to otherwise suggest the inclusion frequency discrepancy is anything other than an artifact of scanning resolution. That being said, I should note that the ratio of coarse and very coarse sand to medium sand for Specimen 011 is more substantial than seen for the other samples. As well, when examining the fabric visually, there appears to be more large inclusions present (see as an example Figure 6.12). As a contrast, Specimen 038 has more small inclusions visible and coarse inclusions make up a lower percentage of the inclusions in this vessel (see Figure 6.13). At this point, however, only scanning at a similar resolution would resolve whether this discrepancy is real or a product of variable scanning resolutions.

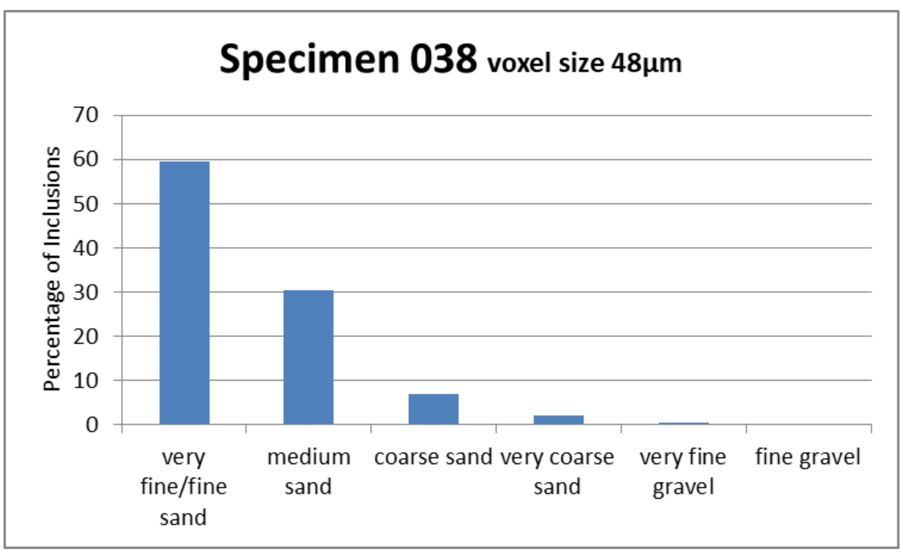
While these geology-derived volume categories for inclusions are broad, they do underscore that the majority of inclusions are extremely small. Inclusions within the very fine/fine sand and medium sand categories in particular likely encompass a spectrum of particles that may be part of the clay matrix, a spectrum of accidental inclusions incorporated into the clay matrix during preparation stages, and perhaps the smaller end of the spectrum of intentionally added tempering material. Thus, it is challenging to say from the micro-CT data, at this lower end of the spectrum, what percent of these inclusions might reflect differences in clay sources or clay preparation techniques across



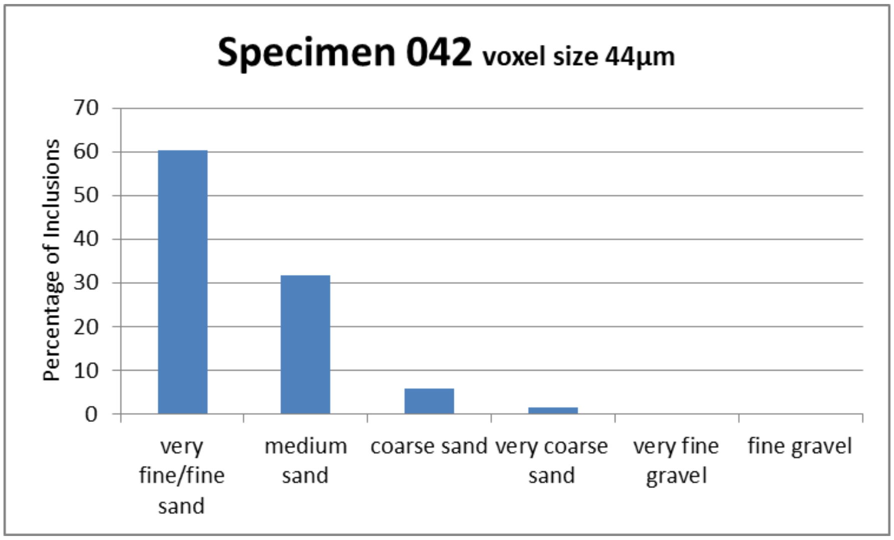
Specimen 011 voxel size 113µm
Percentage of inclusions
50
45
40
35
30
25
20
15
10
5
0
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel

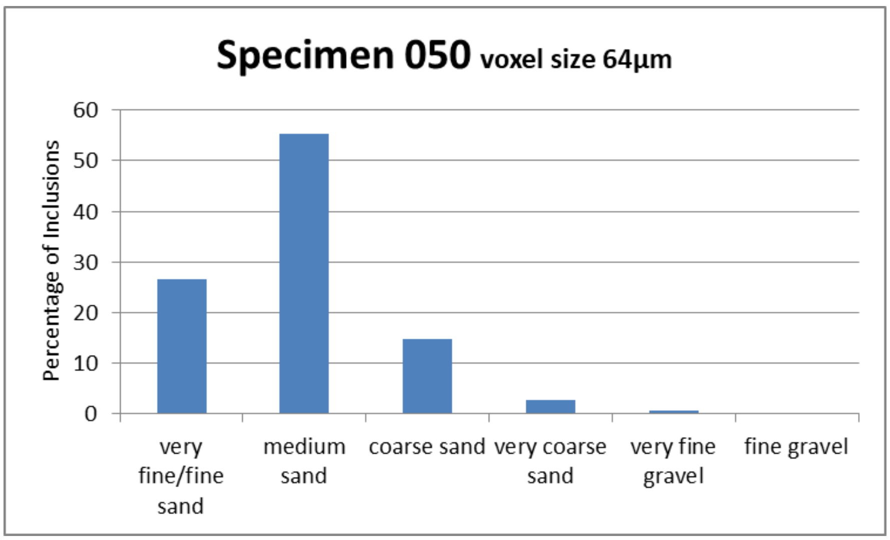


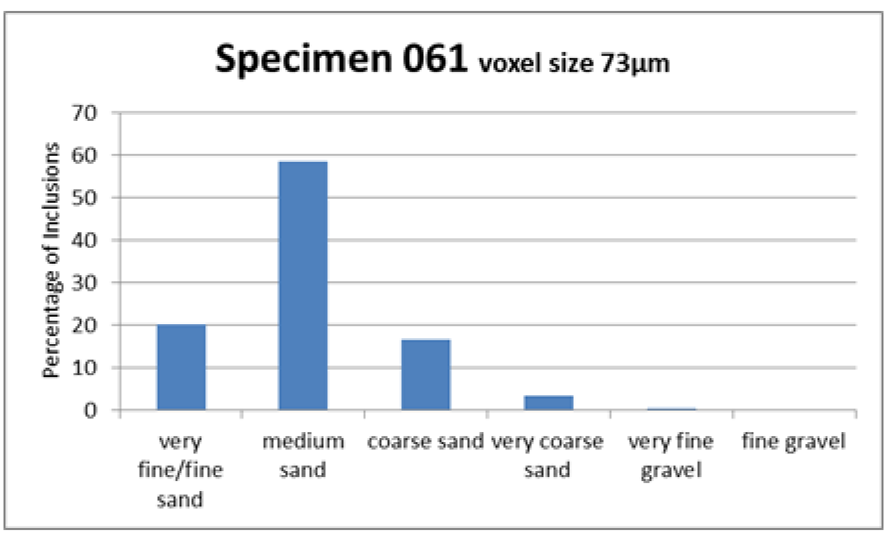
Specimen 024 voxel size 62µm
Percentage of Inclusions
60
50
40
30
20
10
0
very fine/fine sand
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel



Specimen 038 voxel size 48µm
Percentage of Inclusions
70
60
50
40
30
20
10
0
very fine/fine sand
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel


Specimen 042 voxel size 44µm
Percentage of Inclusions
70
60
50
40
30
20
10
0
very fine/fine sand
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel


Specimen 050 voxel size 64µm
Percentage of Inclusions
60
50
40
30
20
10
0
very fine/fine sand
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel


Specimen 061 voxel size 73µm
Percentage of Inclusions
70
60
50
40
30
20
10
0
very fine/fine sand
medium sand
coarse sand
very coarse sand
very fine gravel
fine gravel

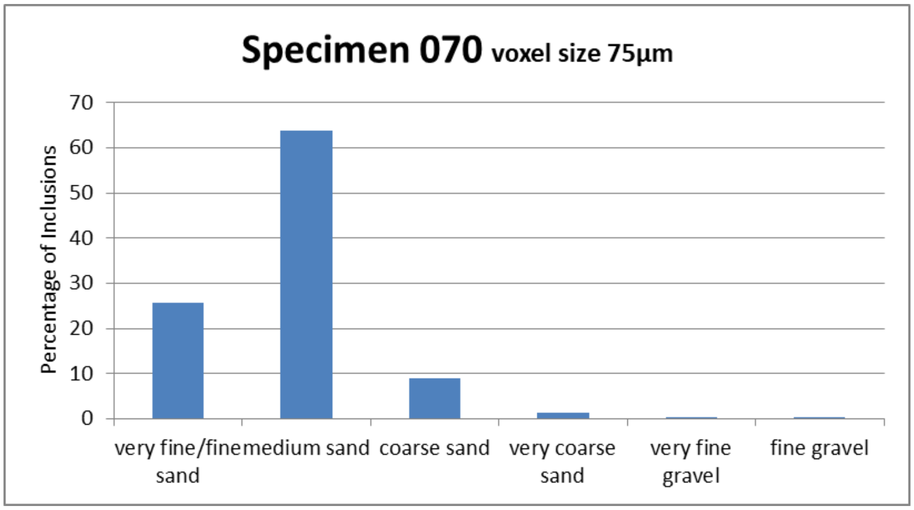


Figure 6.11: Graphs indicating the percentage of inclusions that fall into each volume category for each specimen.

the seven samples. Nonetheless, it is also readily evident that these volume categories do vary between vessels, which begins to suggest the possibility of some degree of variability in preparation and fabric recipes. I will explore this notion further in Chapter 7.

Ceramic fabric texture (coarse or fine) is a straightforward way for archaeologists to describe ceramics based on the frequency and size of inclusions in the fabric. These distinctions in fabric texture allow us to access the recipes potters were using and what steps they were taking in clay preparation. Quinn (2013:44) notes for petrographic studies of clay fabrics that fine-grained ceramics have an inclusion modal grain-size of 0.0625-0.125 mm or less, and coarse-grained ceramics have a modal grain-size of 0.5-1.0 mm, though these measurements are based on diameter. When compared to my conversion of these 2D measurements into volume using the Udden-Wentworth scale (Table 6.5; see also Quinn 2013:44), Quinn's "coarse-grained ceramics" would encompass the coarse sand category, while the medium sand category (with diameters of 0.25-0.5 mm) falls between fine grained and coarse grained ceramic categories, though closer to the coarse grained end of that spectrum. The very fine/fine sand category (with

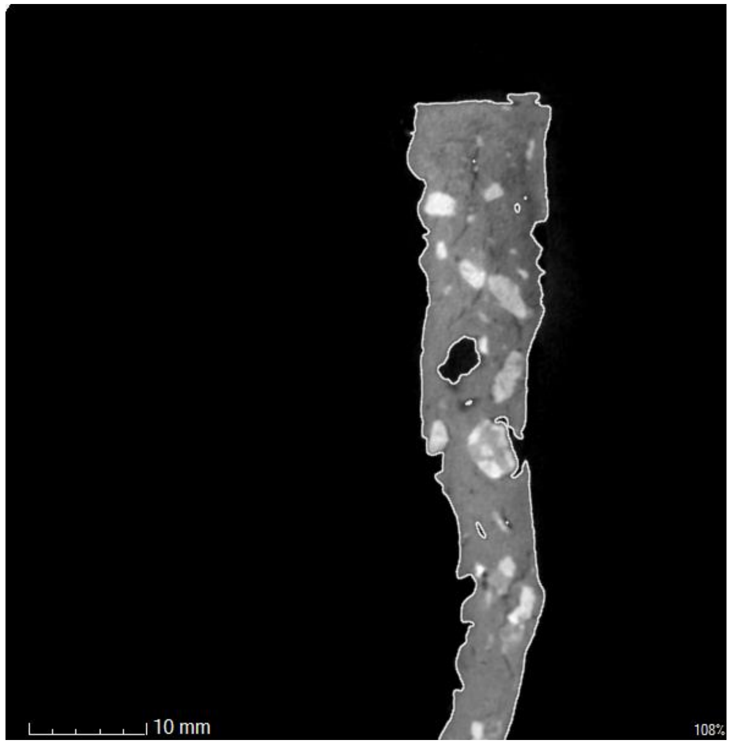


Figure 6.12: Image of inclusions in Specimen 011.

Figure 6.13: Image of inclusions in Specimen 038.

diameters of 0.0625-0.25 mm), fits into the fine-grained ceramic category. In this study, since micro-CT scan analyses do not distinguish inclusion volumes below 0.00 mm^3, it is difficult to determine what percent of inclusions would fall into Quinn's "fine-grained ceramic" category.

If I were to apply Quinn's classification scheme based solely on a direct application of 2D categories into 3D, all of the ceramics in the Arkona collections would have a modal grain-size that place them into a coarse-grained ceramics category. Certainly, the coarse sand and larger categories of inclusions would have been noticeable by potters, and these inclusions likely represent intentional temper additives, rather than natural inclusions in the clay fabric, since such large inclusions likely would have been sieved or picked out of the clay during preparation, otherwise (Rye 1981:17). I would also suggest that at least some of the smaller, medium sand category of inclusions were also visible to the potter, intentionally selected for or otherwise representing finer material generated while crushing temper in preparation for its addition into the clay. It is also likely that some percent of the medium sand inclusions are accidental additions into the clay from the potting environment or during the processing of the clay. In other words, there is a spectrum or gradient to inclusion volumes that defy easy categorization from 2D diameter measurements into 3D volume distribution, suggesting that micro-CT data on inclusion volumes and grain-size distributions needs to be thought about distinctly from 2D interpretive frameworks.

6.2.3.2 Grain-size Distributions

Grain-size distributions provide an opportunity to consider inclusion volumes obtained from the micro-CT data directly. Notably, given the abundance of very small inclusions recorded for these ceramics, grain-size distributions do not reflect the bimodal distribution petrographers tend to point to (e.g., Quinn 2013:103-105) as distinguishing intentionally added temper from natural inclusions. Rather, the bulk of grain-size distributions in my sample generally fall below 0.1 mm^3, followed by a steep drop off in frequencies. For example: in Specimen 024, 43571 of 47566 inclusions, or 91.6%, fell within the 0.00-0.09 mm^3 range (see Figure 6.14). This pattern is similar for all the seven specimens sampled (Figure 6.15).

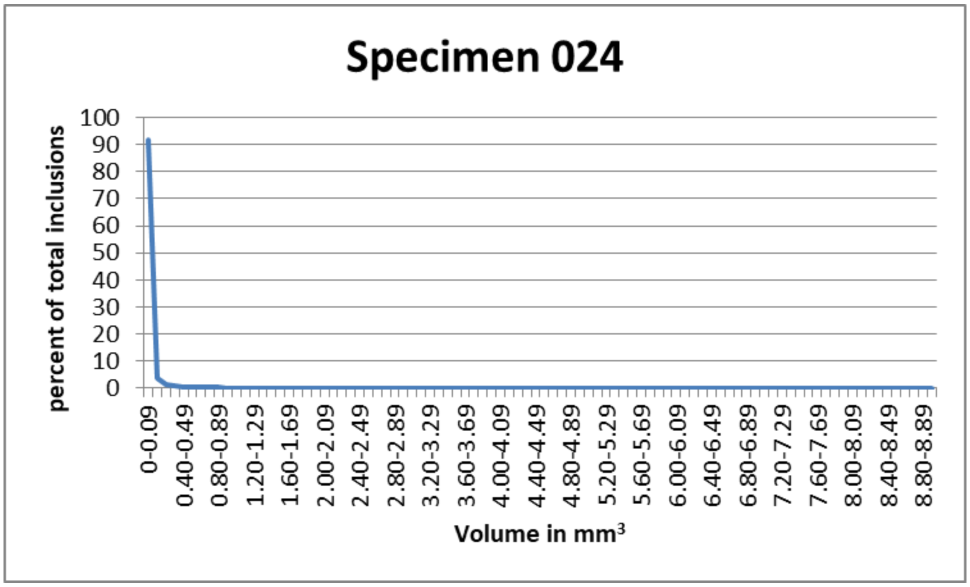


Figure 6.14: Total distribution of inclusions by volume for Specimen 024.

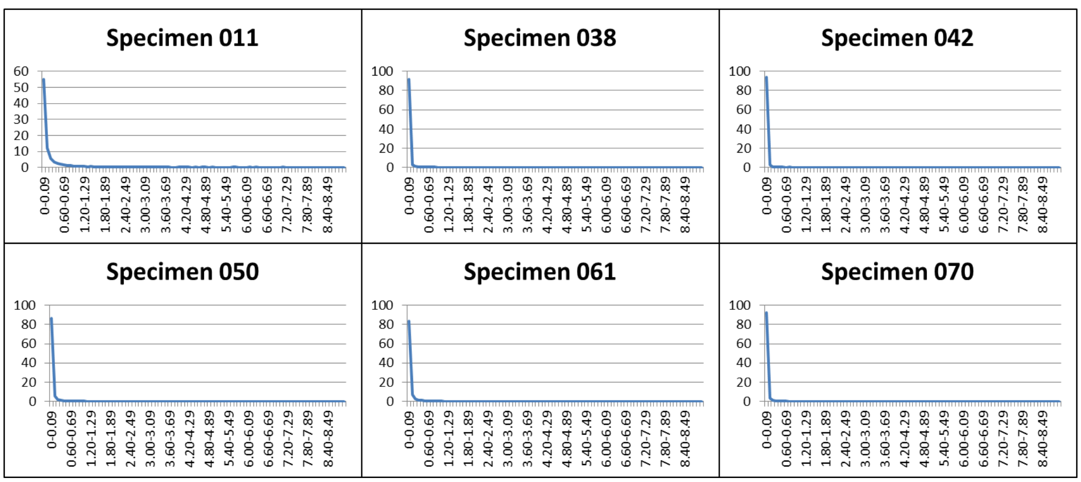


Figure 6.15: Total distribution of inclusions by volume for all other specimens sampled. Y axis for all represents the percent of total inclusions. The X axis represents volume of inclusions in mm^3. All specimens exhibit a sharp drop as inclusion volume increases.

This steep drop off may suggest that the bimodal pattern sometimes seen in petrographic analysis is masked by the micro-CT data not distinguishing volumes below 0.01 mm^3, and by the sheer number of inclusions that fall into the lowest volume categories in micro-CT results. If the differences between intentional temper and natural inclusions falls somewhere in the volume range below 0.01 mm^3 (e.g. if some of the "medium sand" category was intentional temper and some of it was natural inclusions) the micro-CT data obtained from the VGStudio MAX porosity module would mask that bimodal distribution; petrography is currently better suited to determining the intentionality of inclusions.

Though not a perfect comparator for the Arkona Cluster samples, Braun's (2015:77) findings suggest that grain-size distributions are problematic using traditional point-counting techniques. The issue is that over 80% of grains in the Ontario Tradition Late Woodland ceramics he analyzed measured below 60µm (which would fall into the 0.00 mm^3 category), and only a few dozen grains per slice measured above the 125 µm mark (Braun 2015:78). Braun used digital imagery to measure the area of inclusions and to obtain grain-size distributions, and plotted these using a logarithmic scale on the x axis, following geologic conventions that account for the abundance of smaller grains in samples (Braun 2015:56). Although micro-CT scans can examine a far greater number of inclusions than can be examined in a thin section, current software limitations prevented grain-size distributions from being a valuable method for determining which of those inclusions were intentional. Future work with higher resolution scans and advanced image analysis software that allows for volume analysis of high frequencies of very small particles will be needed to explore grain-size distributions for that part of the inclusion spectrum in clay fabrics.

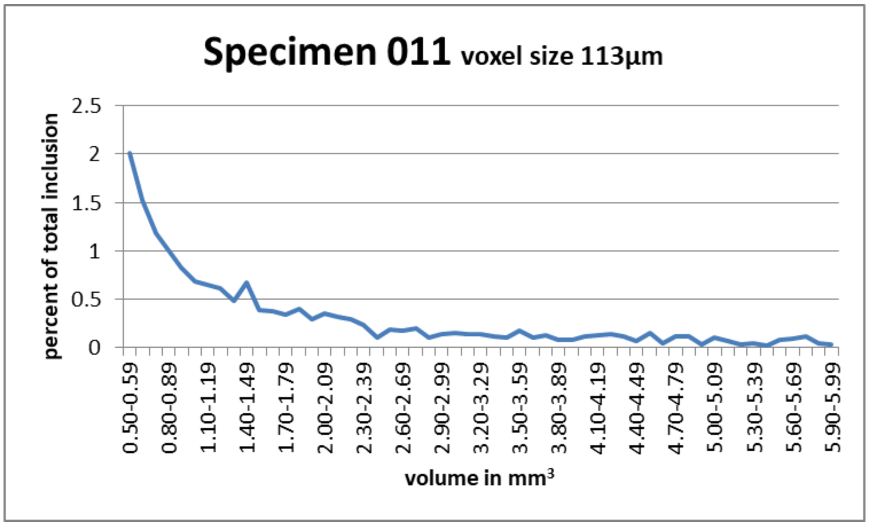
Such high numbers of small inclusions also made it difficult to appreciate inclusion distributions at the higher end of the grain-size spectrum for the samples examined here. To do so, I grouped inclusions into volume categories of 0.10 frequency groupings. When grouped, it became clear that the frequency of inclusions drops off drastically below 1 mm^3. Indeed, most of the samples tested drop off to less than one percent of the total number of inclusions measuring between 0.02 and 0.49 mm^3, with Specimen 011 being the exception (see Table 6.6). The relationship between voxel size and grain size may have been a factor here, with the larger voxel size in Specimen 011 affecting the software's ability to measure smaller grain sizes.

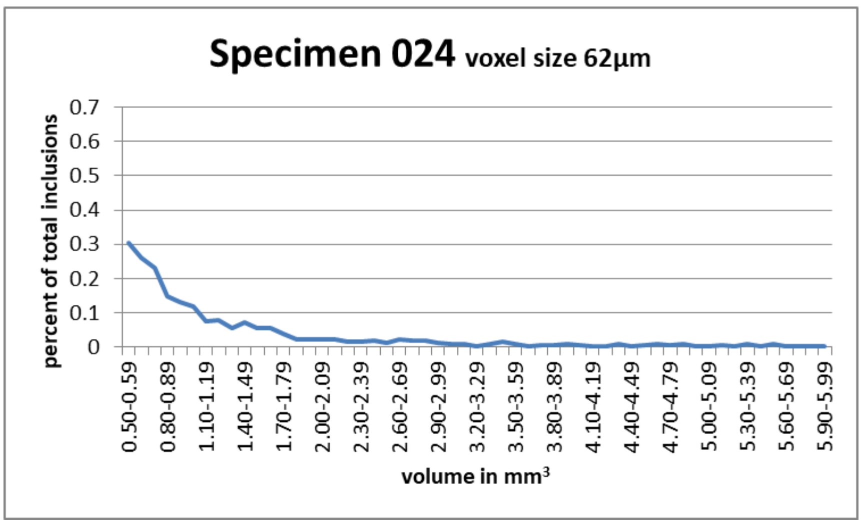
I eliminated the lower end of the grain-size distributions (below 0.50 mm^3), to provide better clarity where this decrease in inclusions happens, while retaining overall volume percent. By examining 0.50 mm^3 to 6 mm^3, the graphs in Figure 6.16 are focusing on part of the coarse sand category, defined above, through to the very fine gravel category. While these graphs illustrate where inclusion frequencies decrease significantly, it is worth noting that they represent a small portion of the inclusions, as indicated by the small percentage values on the Y axes. Additionally, the graphs illustrate that inclusions level off to minimal levels (lower than 0.05 percent of all inclusions) between the 1.30 mm^3 and 2.5 mm^3 categories.

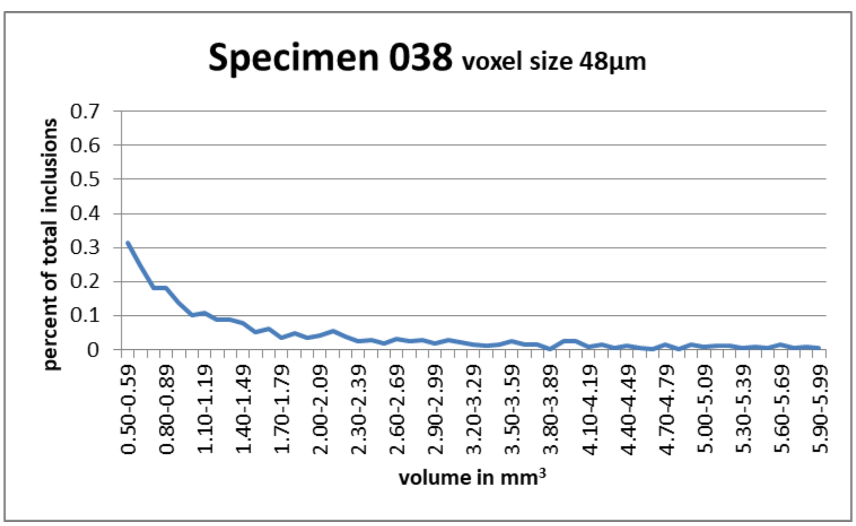
Table 6.6: Frequencies of inclusions drop to less than 1% of the total within the volume range indicated for the specimens examined.

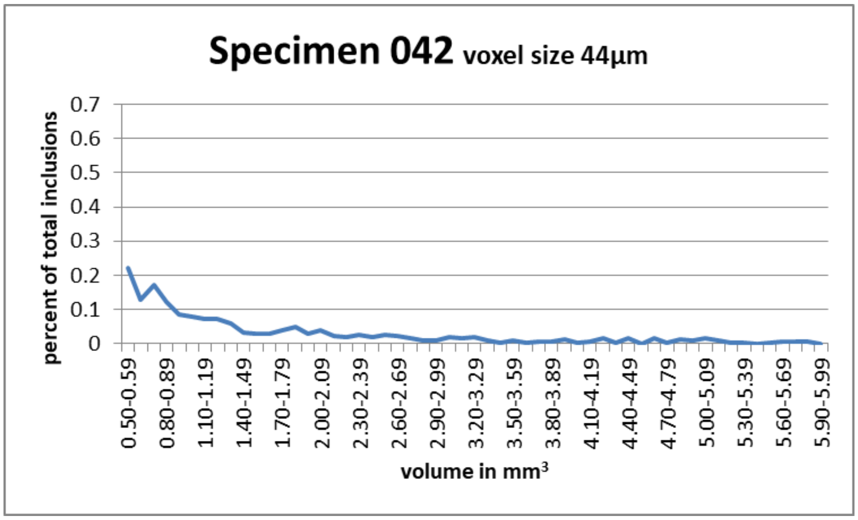
Specimen Number	Volume range in which inclusions start to represent less than 1% of total
011	0.90-0.99 mm^3
024	0.3-0.39 mm^3
038	0.30-0.39 mm^3
042	0.20-0.29 mm^3
050	0.40-0.49 mm^3
061	0.40-0.49 mm^3
070	0.30-0.39 mm^3

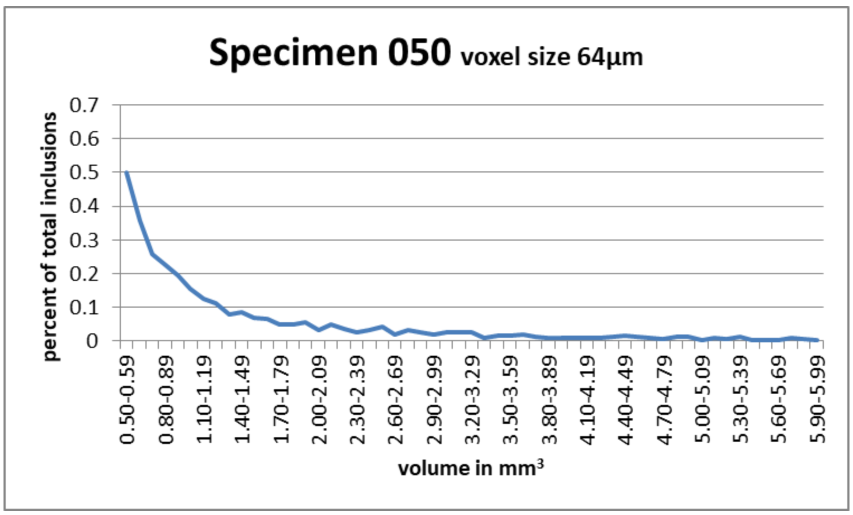
The point at which grain-sizes drop off in frequency is within the coarse sand range, suggesting that perhaps the ideal temper size that potters were adding was smaller than or within this coarse sand category. It also may be possible that a very modest bimodal pattern is visible in some of the charts. Notably, in Specimen 042 it is clear the steep and relatively even drop of frequencies is interrupted between 0.70-0.79 mm^3 units. Similar, very slight deviations, well below any disruption to the overall curves for each sample, can also be detected. But these blips are at such a discrete and small scale that they do not

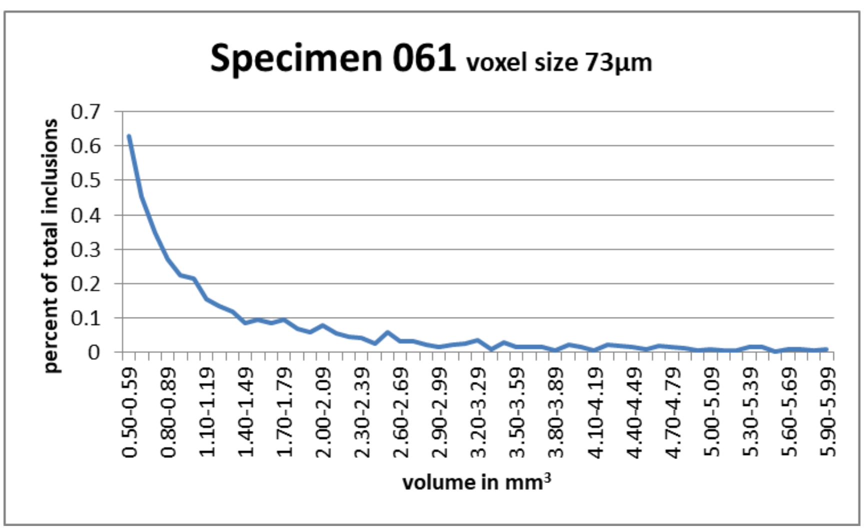

Specimen 011 voxel size 113µm
percent of total inclusion
2.5
2
1.5
1
0.5
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³


Specimen 024 voxel size 62µm
percent of total inclusions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³


Specimen 038 voxel size 48µm
percent of total inclusions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³


Specimen 042 voxel size 44µm
percent of total inclusions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³


Specimen 050 voxel size 64µm
percent of total inclusions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³


Specimen 061 voxel size 73µm
percent of total inclusions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.50-0.59
0.80-0.89
1.10-1.19
1.40-1.49
1.70-1.79
2.00-2.09
2.30-2.39
2.60-2.69
2.90-2.99
3.20-3.29
3.50-3.59
3.80-3.89
4.10-4.19
4.40-4.49
4.70-4.79
5.00-5.09
5.30-5.39
5.60-5.69
5.90-5.99
volume in mm³

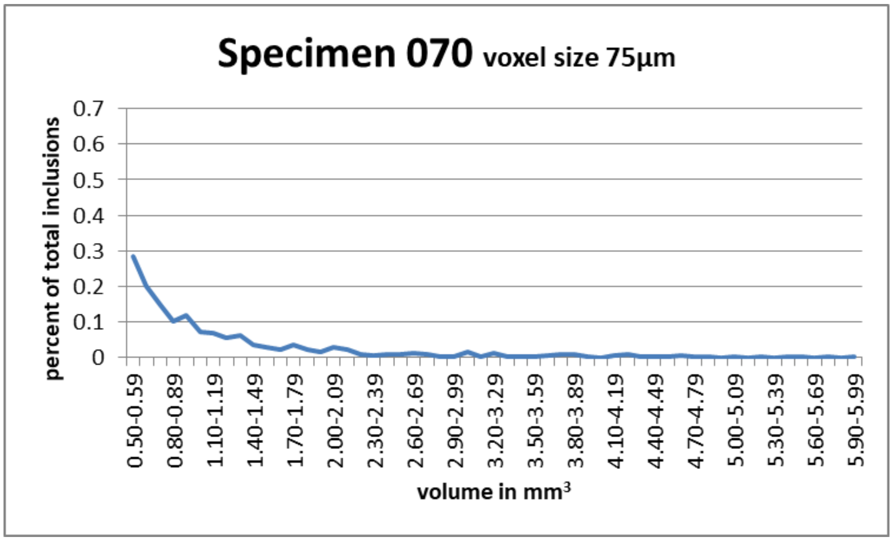


Figure 6.16: Distribution of inclusions from 0.05 to 6 mm^3 in specimens 011, 024, 038, 042, 050, 061 and 070. Note the Y axis is different for Specimen 011.

logically offer a distinction between natural and introduced inclusions. More speculatively, the pattern of drop off likely captures the upper spectrum and limit of what potters might have preferred, in terms of temper size range. Further interpretations of these findings are explored in Chapter 7.

6.2.3.3 Sphericity

Sphericity is a three-dimensional morphological measure of how closely the shape of an object approaches that of a mathematically perfect sphere (Wadell 1932). The manual for VGStudio MAX 3.0 (2016: 478) defines it as “a measure for the ratio between the surface of a sphere with the same volume as the defect and the surface of the defect”. Sphericity values range from 0 (non-spherical) to 1 (perfect sphere). For example: the value of a tetrahedron is 0.671, the value of a cube is 0.806, and a dodecahedron (a 12 sided polyhedron) is 0.910 (Krumbien 1941; Wadell 1932). Sphericity is a value the porosity and inclusion module in VGStudio MAX 3.0 provided, and so is considered here for the seven specimens sampled. Sphericity has the potential to be a useful measurement when examining ceramic manufacture and potters’ choices since the shape of temper can be a result of potters actions, like crushing rocks for temper, and the shape of temper and inclusions in clay affect the workability of clay and the mechanical properties of resulting pots (Müller et al. 2010).

When I began exploring sphericity values provided by VGStudio MAX, I was hoping that these values could allow me to eliminate some of the smaller volumes as natural inclusions in the clay, and not intentional temper, because I anticipated smaller inclusions would be more spherical, while prepared temper would be noticeably less spherical. But in geological terms, the value of sphericity is a morphological reflection of elongation, and typically in geology sphericity of particles is augmented by a measure of roundness, which more properly measures convexities and concavities on the particle (e.g., Wadell 1932; see also Ulusoy 2019; Zheng and Hryciw 2015). In other words, while sphericity can offer some insight into the properties of inclusions, it does not, on its own, offer a geological particle classification or provide a sense of how angular or rounded inclusions are, which presumably is a characteristic of tempering materials. Moreover, most sedimentary particles fall within the sphericity range between 0.3 to 0.9 (Powers 1953), and most of the inclusions in my samples fell into a 0.2 to 0.7 range of sphericity, confirming that the majority of inclusions align with expectations of sedimentary particles.

Inclusions do not sort perfectly based on volume and sphericity, but as a general rule: the larger the inclusions, the less spherical they are in this sample. Broad categories based on combining grain-size categories developed in section 6.2.3.1 were used to visualize trends in sphericity (see Table 6.7), though I excluded Specimen 011 (Table 6.8) from comparison given that percentages were skewed by the lack of the smallest volume inclusions recorded in that scan. Individual specimen tables underscore that, as inclusions increase in volume, a higher percentage are less spherical (see Tables 6.8-6.14). Notably, in all samples, between 83% and 98% of the smallest inclusions (medium, fine and very fine sand) had a sphericity value of 0.5 or higher. Those percentages steadily decrease through larger inclusion volume categories, so that 60%-94% of very coarse sand volume category inclusions score below a 0.5 sphericity value, while 96%-99% of gravel-sized inclusions score below a 0.5 sphericity value. The greatest variation between sherds occurs within the coarse sand volume category, with Specimens 024 (51%/49%) and 042 (54%/46%) exhibiting close to an equal split of inclusions with less than and greater than a 0.5 sphericity value. Specimen 070 (73%/27%) had a significant percent of coarse sand sized inclusions scoring less than 0.5, while Specimens 038 (36%/64%), 050 (20%/80%), and 061 (30%/70%) had significant percentages of coarse sand sized inclusions scoring over 0.5.

Table 6.7: Categories used to sort inclusions by sphericity.

Category	Volume range in mm^3
Medium, fine and very fine sand	0.00-0.06
Coarse sand	0.07-0.52
Very coarse sand	0.53-4.19
Gravel	4.20 and above

Table 6.8: Specimen 011 sphericity values for inclusion by volume categories.

sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	0
0.1-0.19	0	0	0	0
0.2-0.29	0	0	0.1	2.2
0.3-0.39	0	0.4	4.3	24.3
0.4-0.49	0.7	7.6	28.1	46.5
0.5-0.59	19.6	49.6	58.6	26.7
0.6-0.69	67.6	42.2	8.8	0.2
0.7-0.79	11.1	0.2	0	0
0.8-0.89	1	0	0	0

Table 6.9: Specimen 024 sphericity values for inclusion by volume categories.

sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0.1	0
0.1-0.19	0	0.4	2.6	9.9
0.2-0.29	0.1	4.4	10.9	30.8
0.3-0.39	1.7	13.2	29	40.7
0.4-0.49	9.9	33.5	41.9	17.6
0.5-0.59	39.7	42.9	14.9	1.1
0.6-0.69	44	5.7	0.6	0
0.7-0.79	4.3	0	0	0
0.8-0.89	0.3	0	0	0

Table 6.10: Specimen 038 sphericity values for inclusion by volume categories.

sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	1
0.1-0.19	0	0.3	4.8	16.3
0.2-0.29	0.1	5.2	14	30.9
0.3-0.39	1.3	9	21.3	31.5
0.4-0.49	6.5	22	37.9	20.2
0.5-0.59	30.2	53.8	22	0.6
0.6-0.69	54.9	9.6	0	0
0.7-0.79	6.6	0	0	0
0.8-0.89	0.4	0	0	0

Table 6.11: Specimen 042 sphericity values for inclusion by volume categories.

sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	0
0.1-0.19	0	0.5	0.7	6.5
0.2-0.29	0.1	2.4	10.8	37.4
0.3-0.39	0.9	14.3	34.6	38.3
0.4-0.49	6.3	36.9	42.4	16.8
0.5-0.59	32.9	42.8	11.5	0.9
0.6-0.69	53.6	3.2	0	0
0.7-0.79	5.8	0	0	0
0.8-0.89	0.3	0	0	0

Table 6.12: Specimen 050 sphericity values for inclusion by volume categories.

Sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	0
0.1-0.19	0	0	0.1	0.9
0.2-0.29	0	0.1	0.9	10.9
0.3-0.39	0.1	1.5	14.3	48.3
0.4-0.49	2.2	18.5	44.5	36.3
0.5-0.59	20.3	52.1	39.3	3.6
0.6-0.69	66.7	27.8	0.9	0
0.7-0.79	9.8	0	0	0
0.8-0.89	0.8	0	0	0

Table 6.13: Specimen 061 sphericity values for inclusion by volume categories.

Sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	0.3
0.1-0.19	0	0	0.7	8.8
0.2-0.29	0	1	6	29.3
0.3-0.39	0.6	6	20.3	42.3
0.4-0.49	5.5	23.3	42.4	17.7
0.5-0.59	30.2	51.9	30.5	1.6
0.6-0.69	56.8	17.8	0.2	0
0.7-0.79	6.5	0	0	0
0.8-0.89	0.5	0	0	0

Table 6.14: Specimen 070 sphericity values for inclusion by volume categories.

Sphericity value	% of medium, fine and very fine sand	% of coarse sand	% of very coarse sand	% of gravel
0-0.09	0	0	0	0
0.1-0.19	0	0.1	10.5	64.3
0.2-0.29	0	12	41.7	28.6
0.3-0.39	2.6	34.1	26.4	0
0.4-0.49	14.5	26.9	15.4	4.8
0.5-0.59	41.8	21.9	5.9	2.4
0.6-0.69	36.9	4.9	0.2	0
0.7-0.79	3.9	0	0	0
0.8-0.89	0.3	0	0	0

While an imperfect measurement of the spherical and smooth shape of inclusions, these results suggest that larger inclusions, which are likely predominantly temper additions, are at least less spherical. Moreover, the significant sphericity variation between six of the specimens within the coarse sand category of inclusion volume, likely points to where the spectrum of natural inclusions transition with temper additions in clay fabrics. Likewise, though tentative, the stark variation seen in this volume category (ranging from 20% to 73% of coarse sand inclusion volumes scoring below 0.5 sphericity), may also hint at variable fabric recipes or temper preparation practices.

The porosity and inclusion module from VGStudio MAX 3.0 also included graphical reports on sphericity, further illustrating that, as the diameter of the inclusion increases (on the y axis), sphericity decreases, meaning that inclusions with larger diameters are less shaped like a sphere (Figure 6.17).

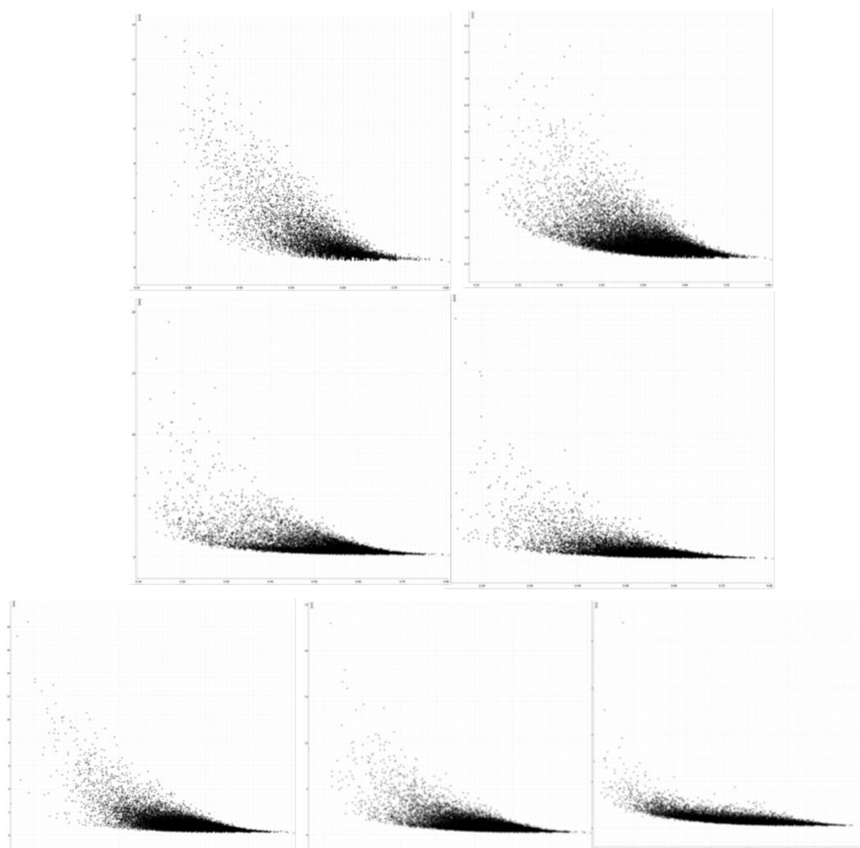


Figure 6.17: Diameter and sphericity graph output from the porosity and inclusion module of Specimens 011, 024, 038, 042, 050, 061 and 070. The diameter of inclusions appears on the Y axis, while the sphericity value appears on the X axis.

Without the ability to also calculate roundness, the VGStudio MAX calculation of sphericity only hints at possible further interpretive insights CT scan data could provide for inclusions, since presumably temper material that has been crushed will have more angular and irregular surface shape than natural inclusions in the clay matrix. Minimally, and in the absence of a petrographic bimodal curve to fall back on, it does seem reasonable to assume from this sample of vessels that the transition in clay fabrics from natural to intentional inclusions occurs in the transition through medium and coarse sand volume categories. This trend would also suggest that the intentional temper introduced into clay was a much smaller additive volume than is represented by the totality of inclusions actually present in the clay, allowing us to think about clay fabric recipes beyond their geological and functional characteristics and as the potter's understanding of working to achieve a "right" mix.

The fact that temper additives in these ceramics are mostly stone grit that had to be intentionally crushed to generate particles small enough to work into the clay grit also suggests a reason why larger inclusions generally lack sphere-like shape. Specifically, Howie's initial petrographic study of Arkona vessels noted a high presence of crystal minerals like quartz and feldspar in the clay pastes she examined (Linda Howie, personal communication 2018). She also felt that these materials were coming primarily from crushed fire-cracked rock. This heat altered material would have generated a great deal of coarse tempering material that was highly angular, and likely not spherical in shape. Further considerations of inclusions are discussed in Chapter 7.

6.2.4 Calibrated Scans

While not a standard step in the scanning protocols I followed, calibrating scans offers the ability to distinguish inclusions qualitatively. As such, I wanted to explore the potential of calibrated scans in analyzing fabric inclusions. Radiodensity values or attenuation coefficients are also known as Hounsfield Units (HU) (Hsieh 2009; Stock 2009). The HU scale is a linear transformation of the original linear attenuation coefficient measurement into one in which the radiodensity of distilled water at standard pressure and temperature (STP) is defined as zero HU, while the radiodensity of air at STP is defined as -1000 HU (Stock 2009). Attenuation scales are arbitrarily defined, and although HU is standard for medical applications and most published studies still use HU, industrial CT systems are sometimes calibrated so that air has a value of 0, water of 1000, and aluminum of 2700 (Johns 1993; UTCT 2013). However, geological materials, and ceramics which include these geological materials, have a large chemical variability and are scanned under a wide range of conditions, thus precluding any close correspondence to density in most cases (UTCT 2013).

A micro-CT scanner has been used to scan geological samples at the University of Texas High Resolution X-ray CT Facility (UTCT 2013). This research has the potential to contribute to the understanding of 3D ceramic petrology because they are scanning materials that are often included in ceramics as temper or as mineral inclusions. The UTCT (2013) suggests that the best way to gain insight into scanning a geological sample is "…to plot the linear attenuation coefficients of the component materials over the range of the available X-ray spectrum." Mass attenuation coefficients can be obtained from the XCOM photon cross section database managed by the NIST (National Institute of Standards and Technology; Berger et al. 2011). For example, I can enter the chemical formula for quartz as SiO2 and the energy level of the scan to obtain a total attenuation value. The attenuation value represents the number of atoms encountered by the X-ray beam. Mass attenuation coefficients are a material's property. They are a strong function of the atomic number of the absorber Z, as well as the X-ray wavelength λ (the inverse of energy; Stock 2009:13). Knowing these attenuation values for different minerals may aid in identifying the mineralogy of temper and inclusions in micro-CT scans of ceramics.

Different minerals exhibit a wide range of specific gravities and vary in lightness compared to clay. For example, through radiographs Carr (1993) was able to achieve a better sorting of sherds than through visual sorting. Research on mineral imaging at UTCT supports the possibility that different minerals can be differentiated through CT imagery (UTCT 2013). For example, quartz and orthoclase are similar in mass density and have similar attenuation coefficients at high (around and above 125kV) energy, while at low energy the high Z-potassium in the orthoclase causes them to attenuate differently (UTCT 2013). In this way, dual-energy techniques may be able to identify minerals (McKenzie Clark and Magnussen 2014).

The XCOM program provides attenuation coefficients that may be used as a starting point for determining mineral-specific values (Berger et al. 2011). In addition, other studies have proposed the potential for radiographic techniques in petrography. Carr and Komorowski (1995) conducted blind tests using x-radiographic techniques to identify minerals in a collection of 726 sherds of Ohio Woodland pottery and found that experts familiar with petrography can identify minerals from x-radiographs at a 75-85% success rate. Middleton (2005) also pointed out the possibility of interpreting radiographic densities of different particles to gain insight into their mineralogical identity.

To explore the potential of mineral identification based on density using micro-CT, I conducted calibrated scans on two separate specimens from the Arkona assemblage. These were scanned with a known phantom (i.e., water) to generate density values for each sherd to be calibrated against a known density. I then calibrated the scans using the calibration tab in the CT Pro 3D reconstruction software, assigning an industrial HU value of 1000 to the interior of the water in the scan. Once the calibrated scans were opened in VG, I was able to isolate inclusions as well as give a range, minimum, maximum, and mean density value for inclusions in the fabric (Table 6.15). I could also isolate any particular inclusion, and use the minimum and maximum density values within that specific inclusion to isolate all other inclusions of the same density range.

Table 6.15: Some basic density measurements in industrial HU (where water should =1000 and air should equal=0) for calibrated scans.

Specimen	Mean density of water	Mean density of air	Mean density of inclusions	Minimum density of inclusions	Maximum density of inclusions
057 (same as 048)	991.74	150.13	5772.51	4799.95	9490.26
059 (same as 042)	1044.83	2.79	6333.14	5099.86	9442.44

The results of this limited exercise indicate there is the possibility to group and examine inclusions in a way that is distinct from simple volume and shape frequencies. A classification of inclusions by shared density ranges thus has the potential to further distinguish intentional additives from existing clay inclusions or even accidental additives by clustered density range frequencies. More significantly, the correlation of documented densities to known mineral densities could begin to isolate and identify particular minerals in the clay fabric.

6.3 Analyzing Ceramic Manufacture using Micro-CT

Manufacturing attributes that can be explored in the micro-CT scans relate to how the potter formed the mixed and prepared clay into a pot. These attributes relate to primary and secondary formation practices, and provide insight into how the potter manipulated the clay with their hands and other tools, and before undertaking finishing work on the vessel**.** Also visible in the micro-CT scans are voids, created through the manipulation of the clay and subsequent drying and firing of the vessel. I explored void percentages, shape, distribution and orientation.

6.3.1 Voids

Voids are formed in the clay through manipulation and joining of pieces of clay, clay shrinking during the drying process, and organic material burning out in the firing process and leaving behind pockets of air (Rye 1977; Sanger 2017). In the micro-CT scans voids appear in a variety of shapes including irregular vughs, elongated forms that appear planar when sliced in 2D, as well as more spherical vesicles (Figure 6.18). This range of voids can all be visualized and followed throughout the structure of the ceramic in 3D (Figure 6.19). When displayed in greyscale, they appear black because of the low density of air. Notably, these by-products of clay manipulation, through the vessel production processes, are accessible in both 2D and 3D in the micro-CT scan data (Figure 6.20), while they only appear as 2D blank space within thin section faces. As such, voids at least have the potential to offer unique insight into manufacture through micro-CT scan analysis, since the ability to follow void structures in 3D throughout scanned vessel section can only be completed through CT analysis Throughout the following discussion of voids, 2D slices of rim sections in all figures will be oriented with the exterior surface of the vessel on the left and the interior surface of the vessel on the right.

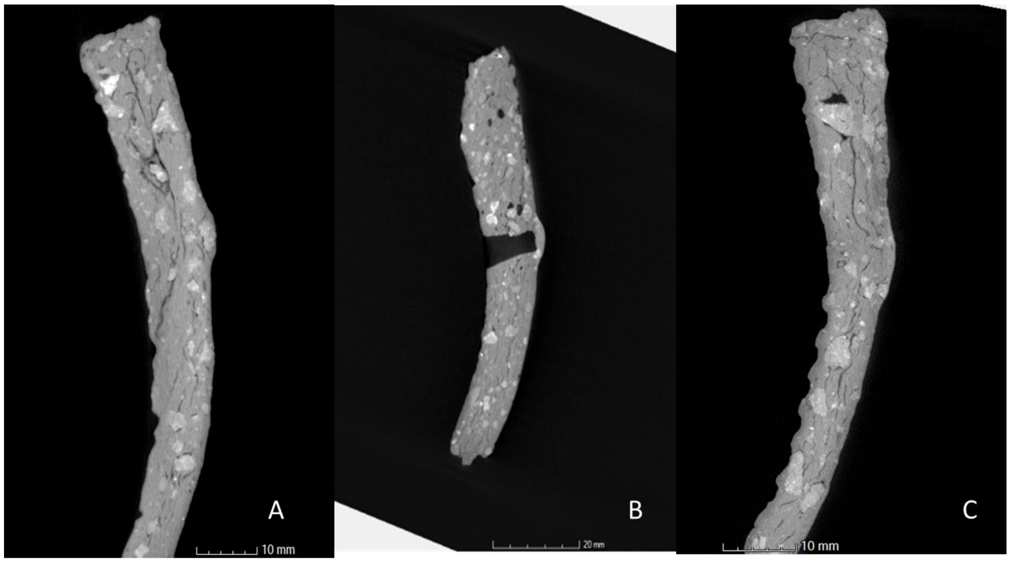


Figure 6.18: Different types of voids visible in 2D slices. A: Elongated voids formed as a result of folding and pressing layers of clay together in Specimen 105. B: Some rounded vesicles in the upper portion of Specimen 026, above a deep punctate. C: Irregular vughs formed as a result of pressure applied and clay drying around the large inclusion near the rim of Specimen 106.

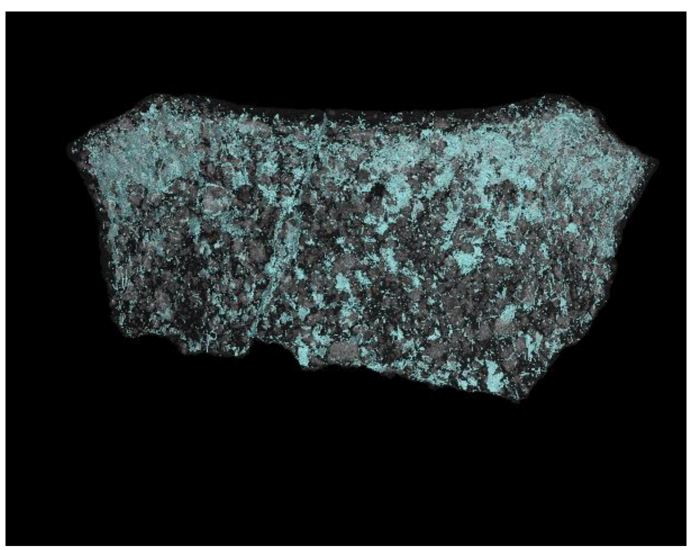


Figure 6.19: Voids in Specimen 105 visualized in 3D to highlight the large flat void structures that appear along the rim, caused by pressing/folding two pieces of clay together.

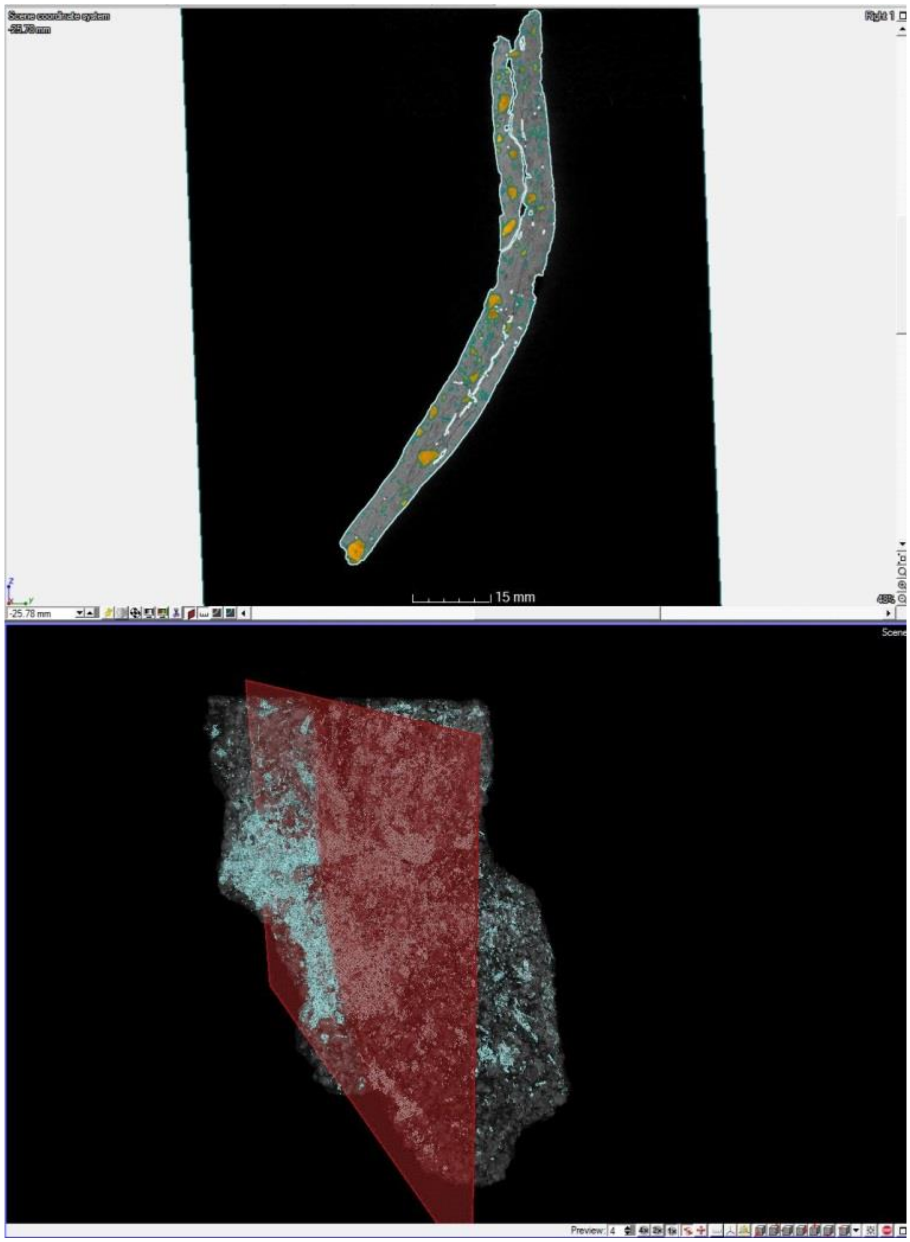


Figure 6.20: Specimen 006 with voids highlighted in both a 2D slice and 3D volume that show where clay was applied to the vessel. The red plane in the 3D image represents the location of the 2D slice along the X plane. The orange areas in the 2D view are inclusions.

Although they appear as blank space, and are characterized as air or the absence of material, voids contain information about ceramic technology and affect the physical properties of vessels such as its weight, thermal conductivity and permeability (Quinn

2013:61). Voids can be formed during firing as organic matter burns out of the clay fabric, and these sometimes maintain the shape of or some of the charred material itself (Quinn 2013:97; Sanger et al. 2013). Bloating pores can be found in highly fired ceramics (above 1200ºC) or those used in high temperature industries (Quinn 2013:67), but the Arkona ceramics were not likely exposed to such high temperatures. Void spaces in the clay can also represent trapped air created during the folding and kneading of clay by potters (Quinn 2013:61). The paddle and anvil forming technique also forms elongated voids in the clay fabric by compacting and thinning clay vessel walls (Braun 2015:144), and this tight packing of clay can also result in cracks around larger mineral grains (Rye 1977). Voids can also be formed during the drying stage of potting, as the clay shrinks and loses absorbed water (Quinn 2013:61), and the orientation of these voids is influenced by the type and direction of force applied by the potter during the forming stage (Weglorz 2018). Voids can also be the result of coil joins in forming, and often relic coils can be seen in thin section (Quinn 2013:176) and in micro-CT scans. Forces applied during various forming methods can orient both inclusions and voids in the fabric of vessels and indicate what forming methods might have been used (e.g. Carr 1990; Berg 2008; Sanger et al. 2103; Quinn 2013:176; see Figure 6.21).

It is important to note that void spaces in ceramics are not always related to manufacturing processes, but can also form subsequent to the firing process. Physical shock, heating and cooling, and freeze-thaw weathering can result in the formation of cracks in vessels (Quinn 2013:67). While it may be difficult to differentiate between elongated voids related to forming and cracks or micro-cracks in some 2D petrographic sections, or in a single image from a micro-CT scan, the ability to follow these voids through the ceramic's structure in 3D from micro-CT data can clearly confirm the non-random patterns of voids that are related to forming. So, while some of the small voids included in volume percentages in this analysis may be related to cracks, the qualitative analysis of voids related to forming is readily apparent in micro-CT analysis. The large voids related to forming allow us to access the pressure applied to clay by potters and the gestures they used to form pots.

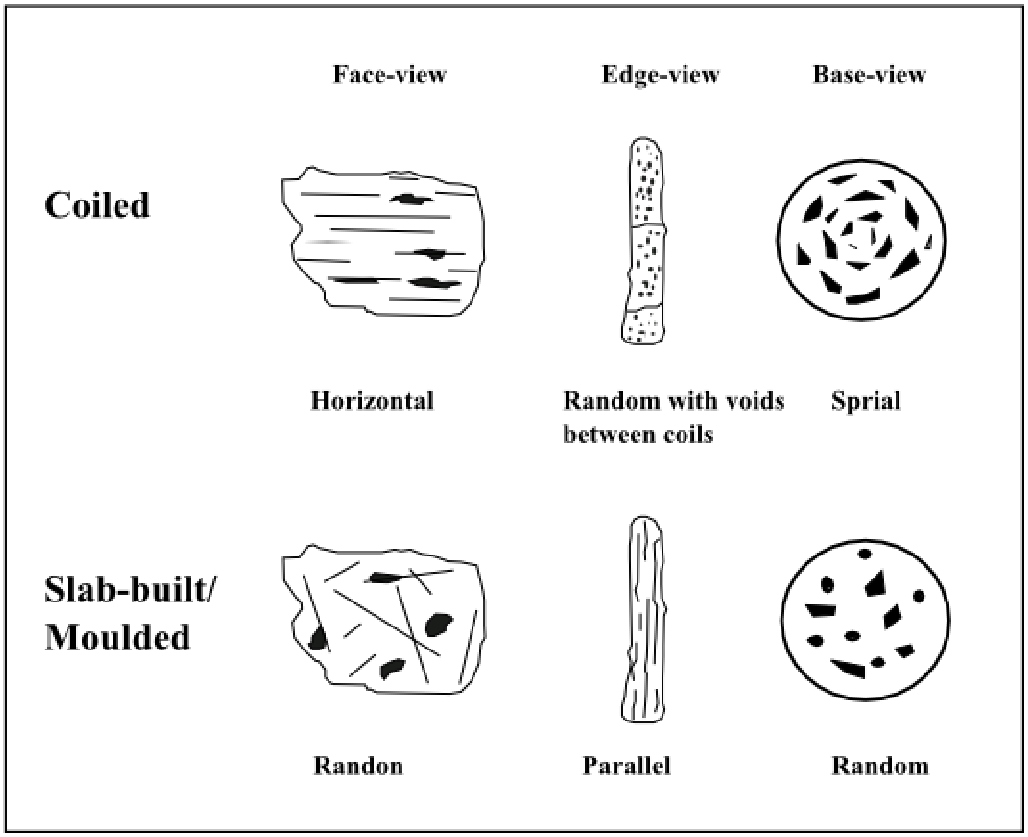


Figure 6.21: Examples of how void and inclusion orientations are affected by forming techniques (Adapted from Carr 1990:17 and Sanger et al. 2013:836).

6.3.1.1 Clay Lumps and Void Creation

As an exercise in exploring what local clay sources might have been composed of, I scanned eight lumps of clay present in the Arkona collections, with the intention of sending them for thin section analysis. While that study was not completed, the scans of the clay lumps confirmed they were clearly manipulated by humans (I was able to identify a fingerprint in at least one of the samples; see Figure 6.22), and proved valuable for illustrating void spaces created through human manipulation of clay. The lumps ranged in size from approximately 2-4 cm in length, were oval to flat and angular in shape (see Figure 6.23), and came from a range of feature contexts from AgHk-42 (five specimens), AgHk-52 (two specimens), and AgHk-54 (one specimen). Lumps of fired or sunbaked clay on Late Woodland sites from this part of the world are typically

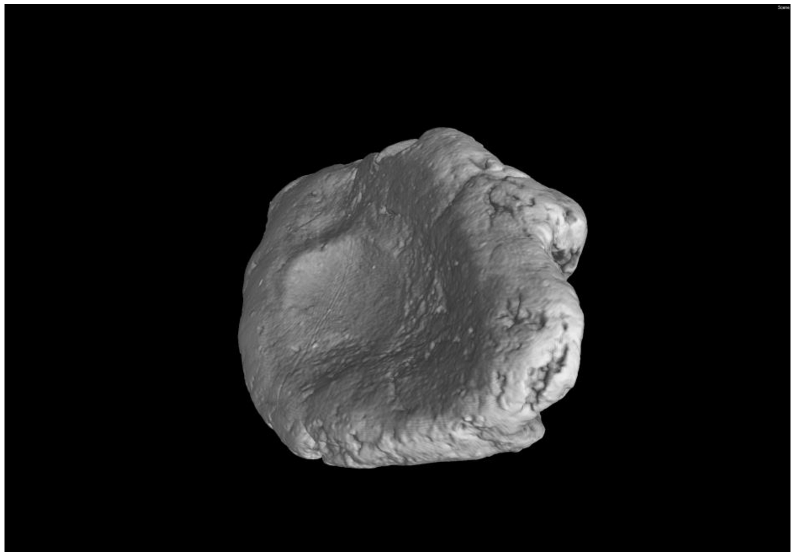


Figure 6.22: A fingerprint can be seen on the exterior of Specimen 139b in this 3D rendering.

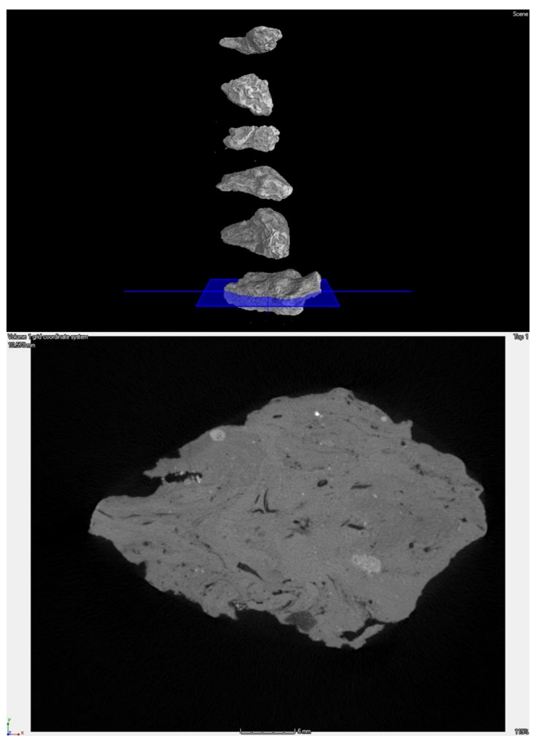


Figure 6.23: Lumps of clay. Inclusions and poorly mixed clay in the cross section of Specimen 140. The blue plane on the 3D image (top) shows the location of the 2D slice in the lower image.

interpreted as either clay wastings from the manufacture of clay objects, or fragments of unfired daub used as part of the material covering residences or other structures (e.g., Murphy and Ferris 1990). Daub fragments exhibit exterior impressions of thatch, bark, or other plant matter used to make up the structural cover. However, in the samples I scanned, none showed exterior impressions, which suggests to me these objects were wastings from clay object manufacture (see Figure 6.23).

Some of the objects clearly exhibit folding or rolling, evident by long, curvilinear void spaces and fold gaps in the formation of the lumps, and compression of clay in the direction of folding and rolling (Figure 6.24). These patterns are a clear reflection of the interaction between clay and craft producers, and affirm the future potential of exploring this feature within the Arkona vessels more generally.

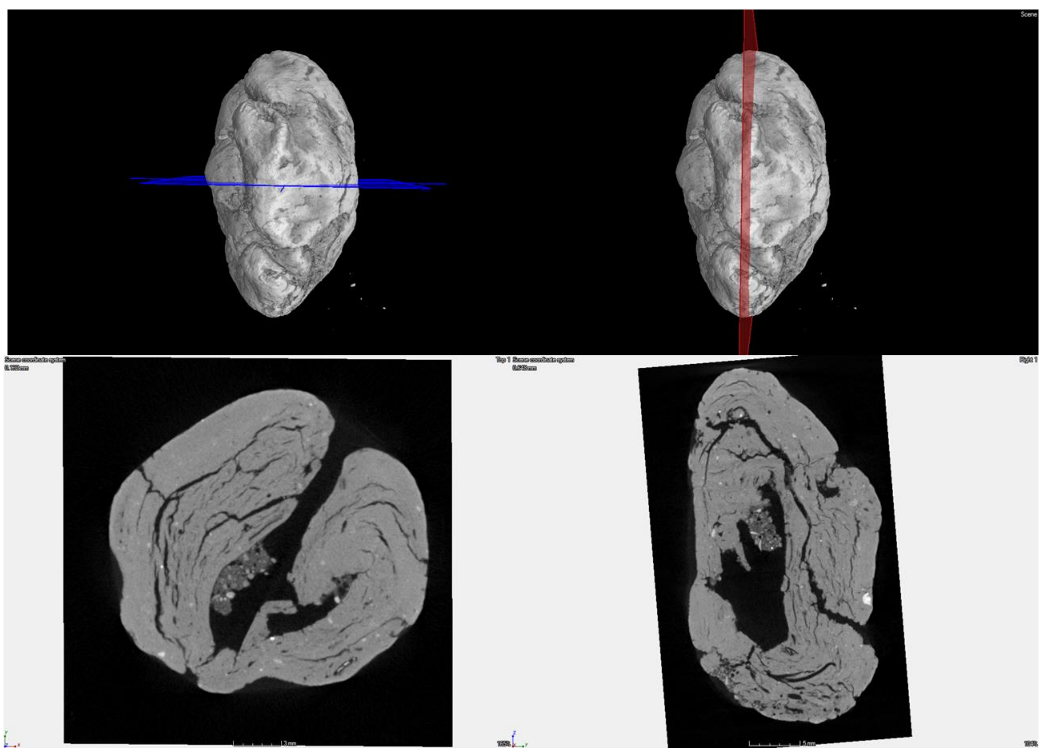


Figure 6.24: Cross-sections of Specimen 139a. Rolling or folding of the clay is visible by the central large void structure that was created when the piece was rolled or folded together, and in the curving patterns of smaller surrounding void structures.

There is very little direct evidence for the manufacture worksites of clay objects in the archaeological record of the Late Woodland in Ontario. Multipurpose and non-permanent manufacturing locales make pottery production in the archaeological record rather elusive (Allen 1992:144; Chilton 1998:143; Martelle 2002:49). Most of the tools used for pottery making were probably expedient, used for other activities and were also organic making them difficult to recognize within, or absent from artifact collections (Cunningham 2001; Martelle 2002; Michelaki 2007). Firing locations may have been located outside of village palisades or at peripheries of sites; areas rarely excavated in Southern Ontario (Martelle 2002:368). Some evidence of production has been uncovered in various contexts in the form of these small masses of clay or clay lumps and tempered clay (Martelle 2002; Pearce 1982; Timmins 1997a, 1997b; Wright 1974; Wright 1979), suspected “wasters” (Martelle 2002:380), and suspected production and firing sites (Kapches 1994; Lennox 2000). Given this ephemeral dimension to potters’ worksites, these clay lumps from the Arkona Cluster, and their clear evidence of manipulation in the micro-CT data, are one of the only traces of the potter clay interaction left in the archaeological record aside from pots themselves.

6.3.1.2 Void Volumes

Individual void spaces in specimens appear on all scans in abundance, with imaging software identifying between 25646 (Specimen 053) and 836852 (Specimen 009) void spaces across individual sherd scans. These void counts have more to do with the size of the specimen (i.e., larger specimens contain more voids) than with the techniques used by potters, so these counts simply give a sense of how plentiful voids are in individual sherds. The abundance of voids in ceramic fabrics indicate the extent a vessel wall was worked and compressed, and how small pockets of air were worked out of the clay (Striker 2018:158).

Voids are entirely inaccessible in ceramic analyses without micro-scale methods. In petrographic analyses, the percentage of pores or voids within a ceramic sample is referred to as the specimen’s porosity. Quinn notes that porosity can vary widely but is “normally <30% in earthenware” (Quinn 2013:65). This norm suggests there is a large range of expected void volume percentages in ceramics that serve similar functions. A vessel with lower void volume within the expected range may have been worked more intensively before drying and firing. Additionally, larger temper inclusions in ceramic fabric can create a fabric with more voids, which may allow for a more efficient heat transfer to the vessel's contents through convection (Braun 2015:155). So while the general assumption in ceramic analyses is that large voids are not desirable because they can create cracks or faults in drying and firing, higher porosity might be beneficial for vessels used in cooking (Braun 2010; 2015).

Though there are not many studies of Indigenous Ontario ceramics that suggest what "typical" void volume percentages might be, there are a few studies that address this variable. Striker's (2018:159) microscopic investigation of ceramics from Ancestral Wendat communities describes channel voids as "few, moderate or abundant", with most of the vessels she analyzed falling into a "few" or "moderate" category. Braun's (2015) petrographic study of fourteenth-century Late Woodland ceramics indicated that pots had between 5-15% void percentages, with many falling into the 9-11% range. Weglorz's (2018) petrographic study of fifteenth-century Ancestral Wendat castellations estimated void percentages, finding they ranged between 3-13%.

For my analysis of micro-CT scans, the measure of void volume percentage represents the total volume in a given specimen made up of void space. It thus represents a measure of the vessel's (or more accurately the sherd's) porosity. Overall, void volume percentages per specimen, both in the entire sherd and within 2 cm^3 prisms, were comparatively low for the Arkona sherds scanned. Most sherds (89.4%) fell between 1-4% void space as a portion of the overall total volume of the sherd, and 92.3% of all sherds were below 4% void volume (Table 6.16). For rectangular prisms, void volume percentages were slightly more variable, with only 64.2% of prisms generating between 1-4% void volume and 82.1% below 4% void volume. Notably, 17.9% of prisms were made up of less than 1% void volume, while 25.4% were made up of 3-4% void volume and 18% were above 4% void volume (Table 6.17).

This higher variability in void percentages within the prism may be related to the relatively small area of prisms that either encompass more or less voids than elsewhere

Table 6.16: Void volume percentages for whole specimens.

% Void Volume Whole Specimen	Frequency	%
< 1 %	2	2.9
1-2 %	29	43.2
2-3 %	24	35.8
3-4 %	7	10.4
4-5 %	4	5.9
5-6 %	1	1.5
6-7 %	0	0
Total	67	99.7

Table 6.17: Void volume percentages for 2 cm^3 prisms.

% Void Volume 2cm^3 Prism	Frequency	%
< 1 %	12	17.9
1-2 %	13	19.4
2-3 %	13	19.4
3-4 %	17	25.4
4-5 %	5	7.5
5-6 %	4	6.0
6-7 %	3	4.5
Total	67	100.1

along a rim, resulting in low percentages if the prism happens to be placed outside of the largest void structures. But this variation may also be because prisms are located in the rim portion of the scan. Higher frequencies of void volumes within rim sections of vessels may reflect some of the greater manipulation of clay that occurs here, with the adding and folding of clay in this area leading to larger volumes of void space (Figure 6.25). In the 2 cm^3 prisms, 18% of specimens have void volume percentages above 4%, but within the whole specimens only 7.4% of specimens have void volume percentages above 4%.

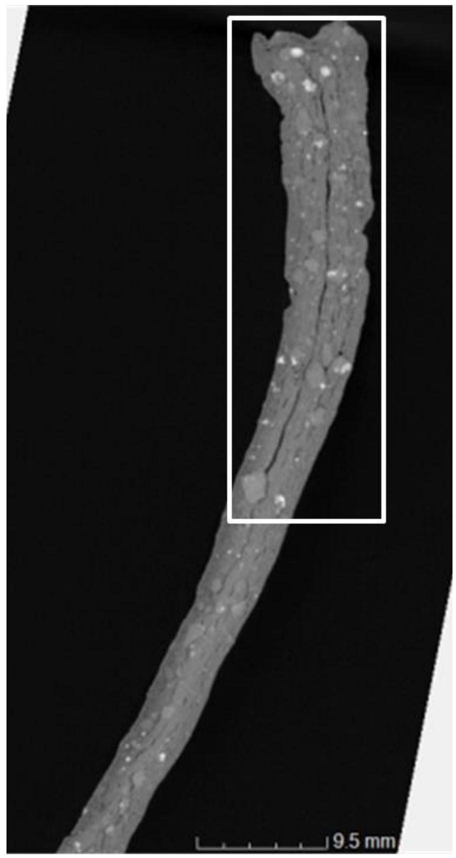


Figure 6.25: Large voids are typically found in the upper portion of the rim and become smaller and less frequent in the neck and body of vessels. Larger voids are visible within the center of the rim pictured within the box but are smaller as they move down the neck (Specimen Ferris Vessel 36). This pattern was observed on many Arkona vessels (see Appendix A).

Regardless of the variation, overall the range of void volume percentages across the scanned Arkona vessels was generally lower than the percentages seen in other petrographic studies on Ontario ceramics (Braun 2015; Weglorz 2018). While these differences may be an artifact of differing potting practices, it is more likely that they are an indication that 2D petrographic analysis and micro-CT are not measuring void volume in the same way, making these results difficult to directly compare. These differences also indicate the importance of the sampling position, and this is explored further in Section 6.6.

Across the different sites of the Arkona Cluster (Figure 6.26), the distribution of void volumes were evenly spread (e.g. not all the higher void volume percentages or lower volume percentages were found at one site). Further analysis of void volume percentages yielded no real patterned associations, across either sites context, or other potentially linked variables, such as vessel wall thickness or rim manufacturing methods. For example, 54% of vessels with a wall thickness of 10 mm and thicker had less than 2% void volume, while 48% of vessels with a wall thickness of less than 10 mm had less than 2% void volume.

% Voids AgHk-32	frequency
< 1 %	0
1-2 %	5
2-3 %	2
3-4 %	3
4-5 %	0
5-6 %	0
6-7 %	0
Total	10

% Voids AgHk-40	frequency
< 1 %	0
1-2 %	1
2-3 %	2
3-4 %	1
4-5 %	0
5-6 %	1
6-7 %	0
Total	5

% Voids AgHk-54	frequency
< 1 %	0
1-2 %	5
2-3 %	3
3-4 %	0
4-5 %	1
5-6 %	0
6-7 %	0
Total	9

% Voids AgHk-56	frequency
< 1 %	0
1-2 %	1
2-3 %	0
3-4 %	0
4-5 %	0
5-6 %	0
6-7 %	0
Total	1

% Voids AgHk-42	frequency
< 1 %	0
1-2 %	8
2-3 %	8
3-4 %	2
4-5 %	2
5-6 %	0
6-7 %	0
Total	20

% Voids AgHk-52	frequency
< 1 %	2
1-2 %	6
2-3 %	5
3-4 %	1
4-5 %	1
5-6 %	0
6-7 %	0
Total	15

% Voids AgHk-58	frequency
< 1 %	0
1-2 %	3
2-3 %	4
3-4 %	0
4-5 %	0
5-6 %	0
6-7 %	0
Total	7

Figure 6.26: Void volume percentages tables for all Arkona sites for the whole sherd specimens. These illustrate that void volume percentages did not vary by site.

6.3.1.3 Void Shape, Distribution and Orientation

In 3D scan data, voids exhibit different shapes, orientations, and distributions (i.e., where they are concentrated across the specimen). I recorded the primary (most common) and secondary (second most common) void shapes visible in each of the specimens. This exercise was simply done by visual estimation while scrolling through 2D slices of scanned specimens, as the imaging software had no functionality to sort voids by shape (although some newer software can do this). All but two sherds (Specimens 021 and 024) had planar voids, created through the manipulation of clay fabrics, as the primary void shape when viewed in 2D slices. Less common were voids that could be characterized as vughs, and these were found mostly around inclusions. Vughs represented the secondary void shape in 63 of the 67 Arkona Cluster vessels. Two Arkona vessels (Specimens 021 and 024) had vughs as the primary void shape recorded. However, these two specimens had planar voids as their secondary void shape, indicating that all Arkona vessels exhibited planar voids. Two other sherds (Specimens 051 and 060) had vesicles as their secondary void shape, though they also contained vughs around inclusions as a tertiary void shape. Vesicles can be formed from the release of gasses during a firing as the clay matrix vitrifies (Quinn 2013:97), but the specimens with vesicles I examined for this study do not appear to be fired differently from other Arkona specimens.

My observations on voids were more qualitative than quantitative, looking for patterns or deviations from general trends across the scans. This method was necessary because the image analysis software did not provide information on the orientation, distribution, individual volumes or shapes of voids. I recorded the distribution of voids (as either uniform or non-uniform), and their primary orientation (parallel or not, relative to vessel walls). I also noted any secondary orientations, such as where particularly large voids, indicative of joining (Rye 1981:62), were located, and their angles relative to vessel walls (see Figure 6.27). Full observations of voids for each specimen are presented in Appendix D. Most vessels exhibited void distributions that were non-uniform, with larger voids tending to cluster the rim of the vessel and in the center of the vessel walls. It is worth noting that six vessels were more uniform in void distribution, and all of these were vessels that had no obvious rim formation techniques visible (identified as a “plain” rim forming technique). These vessels lacked large central voids present in many other vessels where rims were formed by folding or the adding of a strip of clay.

In visual observation, almost all voids were oriented parallel to vessel walls, except in folded rims where there were sometimes horizontal voids near the lip of the vessel. Also, in folded rims and rims with added clay, angled voids could be noted where the folded or added pieces of clay met the vessel walls (Figure 6.27).

Figure 6.27: Example of a vessel (Specimen 100) with voids running parallel to vessel walls, but angled where the added section joins near the rim of the vessel. The void measured runs at a 49 degree angle then curves to run perpendicular to the vessel walls as it meets the interior wall.

These distinctive void alignments in rim sherds offer a way of accessing the gestures, movements and strategies potters used to form the rims of pots. These void structures, and evidence of compression between and within pieces of clay that were manipulated through the process of forming the rim, become visible in both the 3D images of voids and in the thousands of 2D slices micro-CT scans provide (see Figure 6.28). Video flythroughs of specimen scans readily convey this manipulation (see https://youtu.be/pkoKRN1Z9T0).

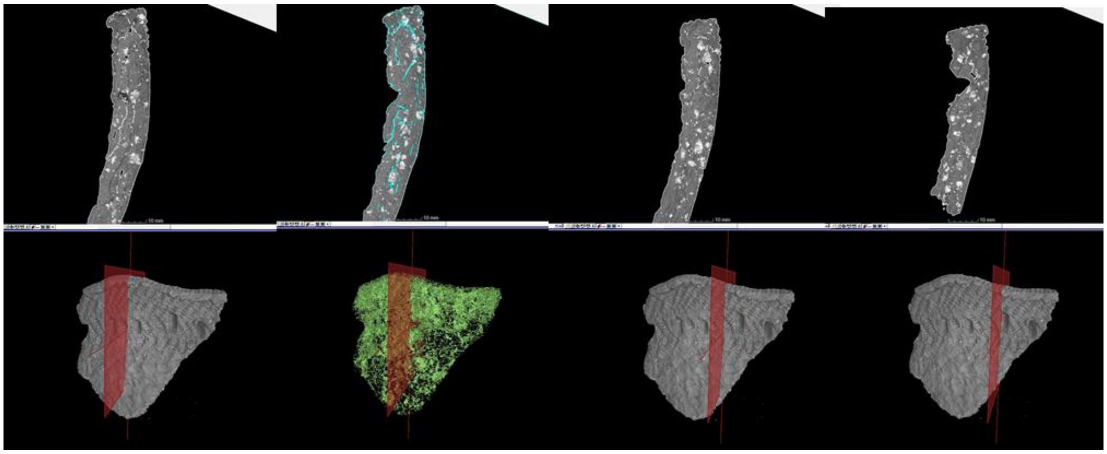


Figure 6.28: Void structures visible in successive slices through the Specimen 050 rim sherd, and in 3D void representation (illustrated in the second 3D image from the left).

6.3.2 Rim Forming Techniques

In the Arkona sample of 67 vessels from seven sites, the way that potters formed the upper rim and lip of a vessel was reflected clearly in the micro-CT scans. Given both the critical role the rim/lip plays in defining the form of the vessel, and the focus on the rim in the application of decoration during finishing, it is not surprising to see extensive evidence of clay manipulation focused by potters on this part of the vessel. I initially sorted these techniques into six rim forming categories, along with an unidentified designation (see Table 6.18). Note that while I scanned five neck sherds, one (Specimen 066 from AgHk-42) included most of the rim and part of the lip, with only an added clay portion of the upper rim exfoliated off. As such, several rim attributes could be identified for this specimen as such is included in the totals.

Table 6.18: Initial rim construction technique types used for Arkona vessel analysis.

Rim Construction Technique	Number of Vessels	%
Folded to exterior	27	40.3
Folded to exterior with added clay	13	19.4
Added clay at exterior/applique	9	13.4
Plain	8	11.9
Added clay to exterior and lip	5	7.5
Added clay at interior	1	1.5
Unidentified (no upper rim present)	4	6.0
Total	67	100

<u>Rims Formed by Folding Clay to the Exterior</u>: There are 27 examples (40.3%) of this rim formation method out of the 67 vessels examined. These are identified by large vertical voids where the potter had not fully compressed the clay at the fold, along with horizontal voids near the lip (Figure 6.29). In 3D renderings, these large vertical voids are visible as planar void structures near the lip of the vessel, but do not extend all the way up to the lip. The rim formation method is created by the potter choosing to fold the upper edge of the clay out and pressing the fold onto the exterior of the vessel. This action forms an upper rim that is thicker than below the fold. The finished rim thus sometimes exhibits a pseudo or “incipient” collar (see also Murphy and Ferris 1990).

<u>Rims Formed by Folding and Adding Clay:</u> There are 13 (19.4%) vessels of the 67 scanned that were formed using this technique. This method is distinguished from the exterior folded method by evidence of added clay placed on top of the fold. The same void pattern is evident for these specimens as is seen for folded rims, but the pattern appears lower down from the vessel lip. While not always located adjacent to castellations (this technique was observed in Specimens 043, 066 and 117 which are sherds that do not contain castellations: see Figure 6.30), when castellations are present in examples, there is typically more clay added around the castellation. The added clay is

then feathered out across the top of the rim away from the castellation (see Figure 6.31). Usually, the added clay appears to be the same composition as the base clay, but in one specimen (050), the clay appears to come from a different recipe (see Figure 6.31). This difference in clay fabric is speculative and based on my visual examination. But to my eye Specimen 050 exhibits a difference in density conveyed in the greyscale of the scan between the clay body that appears above and below the fold, suggesting the added clay is of a different, lower density than the main clay body of the vessel.

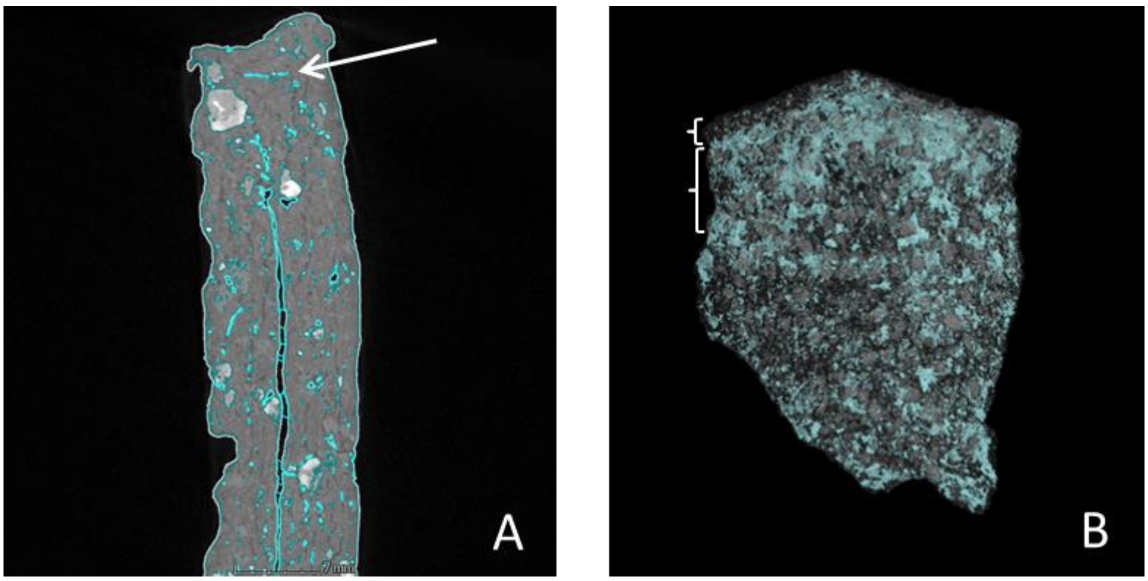


Figure 6.29: Void structures in folded rims. A: Folded rim in Specimen 023. Voids are outlined based on density. Note the large vertical void running parallel to vessel walls does not touch the lip of the vessel. Small horizontal voids near the lip, indicated by the arrow, are due to folding clay towards the exterior. B: Specimen 106 3D rendering of void structures. Note that large voids stop below the lip of the vessel (within upper bracket). Large, flat or planar voids run the length of the sherd where the folded layer of clay was not fully compressed onto the base layer (within lower bracket).

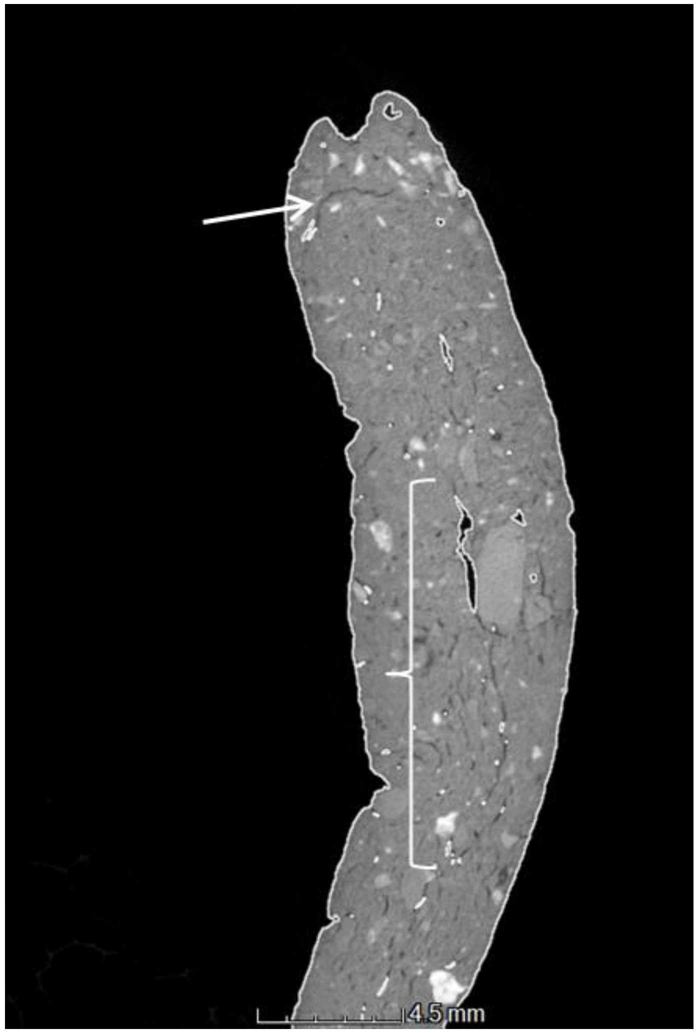


Figure 6.30: Specimen 043. No castellation is present, but there is clay added consistently along the lip of the vessel above a fold. The large vertical void indicated by the bracket is from clay layers not being fully compressed while folding, and the horizontal void indicated by the arrow is the joining where the extra clay was added to the lip of the vessel.

<u>Rims Formed by Adding Clay to the Exterior:</u> There are 9 (13.4%) vessels formed using this technique, which entails applying a strip of clay onto the exterior of the vessel. In scans this method is identified by a vertical void structure that meets the lip. In 3D renderings of voids, large planar or flat void structures can be seen extending up to the lip of the vessel (Figure 6.32).

Figure 6.31: A rim (Specimen 050) that has been folded and then clay added on top. The scanned cross section at the left is through the castellation on the vessel. There is more clay added to create the castellation in this case. The joining void where clay has been added is indicated by arrows. Note also the difference in density in the clay above and below the fold; the clay above the fold appears as darker, indicating it has a lower density than clay below the fold.

<u>Plain Rims or Rims Formed Without Folding or Adding Clay:</u> There are 8 (11.9%) vessels that fit this description. This category includes specimens with rims that end abruptly, possibly cut off to form the lip. They are identified by even void distribution throughout the rim section, and no additional forming techniques applied (Figure 6.33).

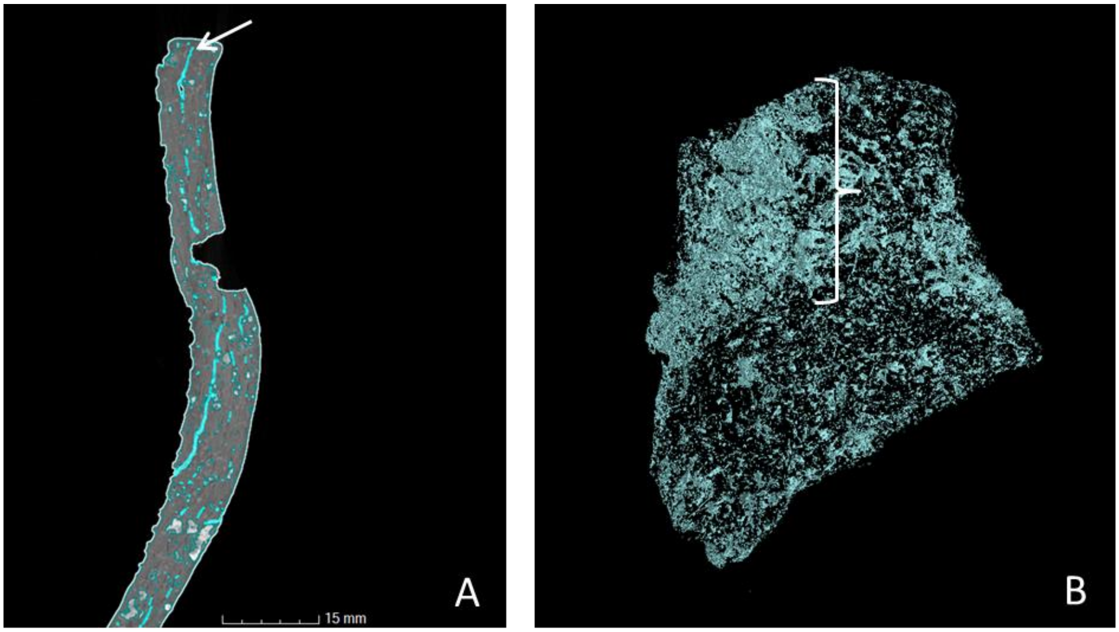


Figure 6.32: Rims formed by adding clay to the exterior. A: A 2D slice of Specimen 008 with voids highlighted. Note the large vertical void meeting the lip of the vessel at the arrow. This slice cuts through an interior punctate. B: A 3D rendering of voids in Specimen 052. Large voids within the area indicated by the bracket extend to the lip of the vessel.

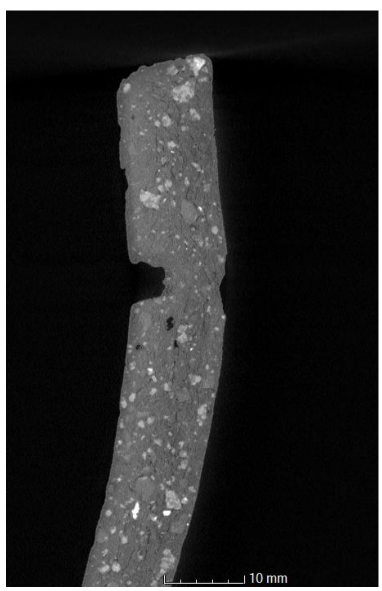


Figure 6.33: A vessel with no visible added or folded clay (Specimen 109). There are small planar voids parallel to vessel walls throughout and some vughs around inclusions, but lacking are the characteristic large vertical voids visible for rims that are folded or have added clay. This slice cuts through an exterior punctate.

Rims Formed by Adding Clay to the Exterior and Lip: Five (7.5%) of the 67 vessels scanned exhibited rims formed by a strip of clay, creating the entire top of the rim exterior as well as the vessel lip. These examples are similar to those that exhibit added clay, except instead of the interior void meeting the lip, the void created by the addition of clay extends to the interior of the rim below the lip (Figure 6.34).

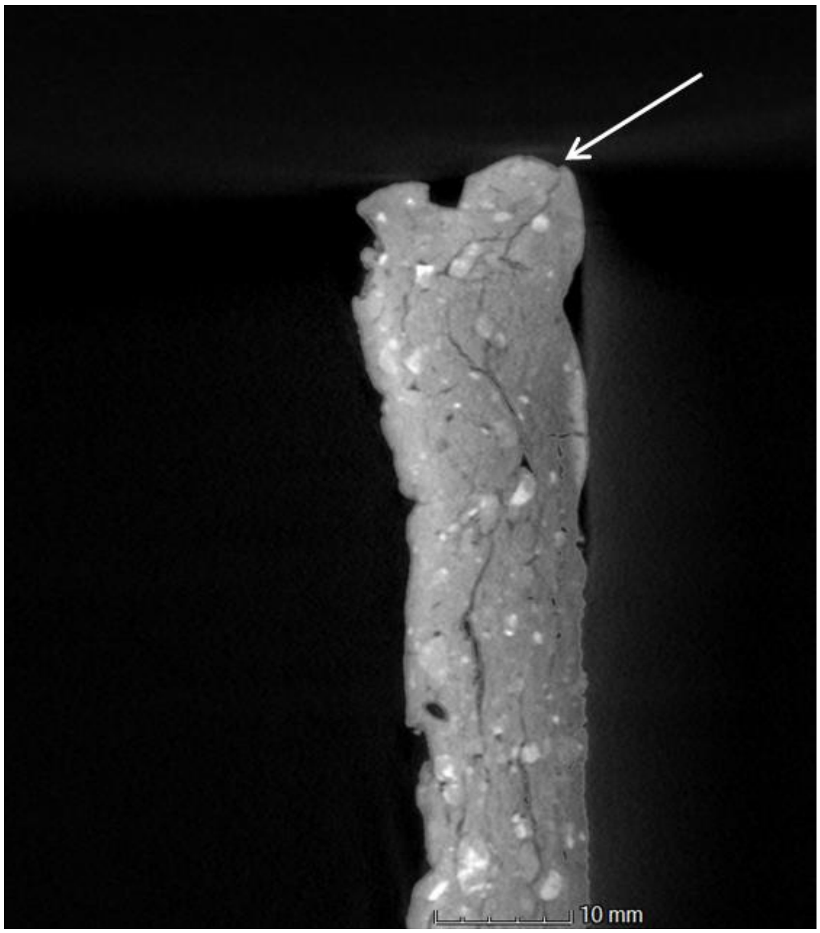


Figure 6.34: Added clay to the exterior and lip in Specimen 100. Note that the void meets the interior wall of the vessel lip at the arrow, rather than the center of the lip.

Rims Formed by Adding Clay to the Interior: One vessel (1.5%) exhibited added clay on the interior of the vessel wall, visible by a vertical void structure that meets the vessel wall at the interior (Figure 6.35).

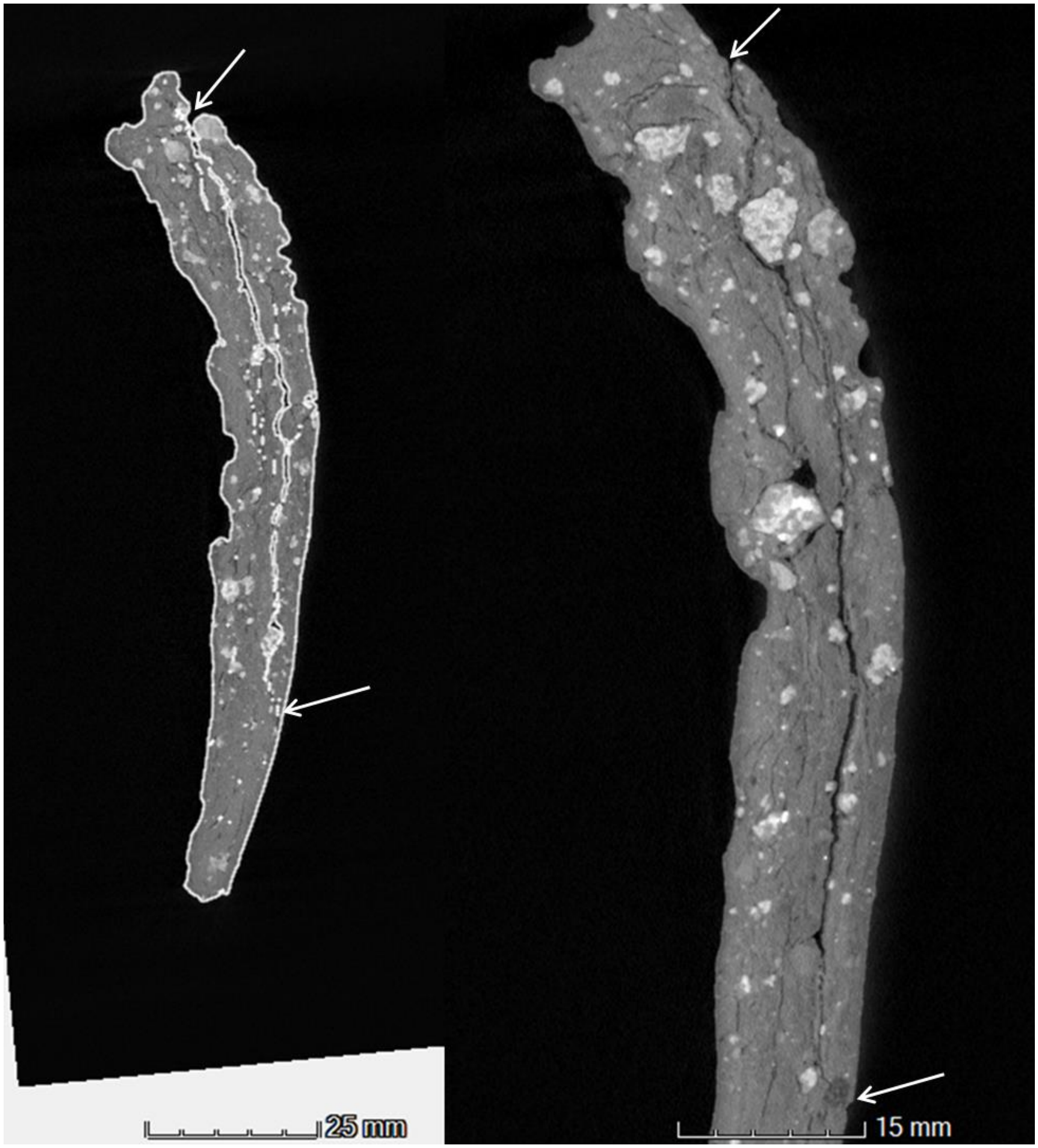


Figure 6.35: Two 2D slices of Specimen 091, illustrating added clay at the interior of the vessel. Note how the void meets the interior vessel wall at the arrows.

Unidentified Rim Forms: There were also four vessels (6.0%) in the scanned specimens where no manufacturing technique could be identified. All four of these specimens (005, 067, 053 and 071) were neck sherds where the uppermost portion of the vessel was not present, making identification of the rim forming technique impossible.

To try to gain further insight into rim formation practices, I also scanned ten additional sherds from the same vessels to explore how rim formation may have varied across the same pot. These extra scans are distinct and not included in the broader analysis conducted for this study. Table 6.19 identifies which vessels had additional sherds scanned. In six of the ten examples where I examined an additional rim sherd, the rim formation technique identified was the same for both sherds. In three instances, I had initially identified a folded rim in one sherd and a folded rim with added clay in the other of the matching sherds. The last example was identified as having clay added to the exterior, while the second sherd exhibited added clay to the exterior and lip. In all, 40% of these additional sherds suggest potters deploy variable forming methods, or slight adjustments when making the rim across a single vessel, notably adding clay to ensure the form is correct and consistent across the orifice.

The results of the additional sherd scans also suggest that rim forming categories can be distilled down to the presence or absence of basic techniques (Table 6.20). In this way, it becomes clear that folding was the most common technique used by potters across the Arkona Cluster sites. When considering just those scanned specimens where the method of rim forming could be identified, rims exhibiting the folding method, either exclusively (42.9%) or in combination with folded and added clay rims (20.6%), make up 64% of the sample. Vessels exhibiting the addition of clay, either exclusively (23.8%), or in combination with folding (20.6%), make up 42% of the formed rims. Only eight rims (12.7%) lacked the application of either of those techniques. In other words, 87% of all identified rim formation methods included the potter folding or adding clay, or doing both to finish the rim. Moreover, the additional sherd scans suggest it is not possible to rule out that adding clay, which can occur on only part of a rim, was not a method used on the folded rims beyond the sherds I scanned.

There are fairly even distributions of these techniques across the sampled vessels from the various Arkona sites. No one site has all folded rims or all applied rims (Table 6.21). While samples scanned from each site are too limited to draw any clear conclusions, in general I can note that folding as a stand-alone method or in combination with adding

Table 6.19: Each row represents two separate rim sherds from the same vessel. The pairs were scanned separately, underwent analysis separately and were then compared.

Pairing	**Specimen number**	**Rim Manufacturing Method**	**Specimen number**	**Rim Manufacturing Method**	**Do the rims match?**
1	008	Added clay at exterior	055	Added clay at exterior	Yes
2	050	Folded to exterior with added clay	097	Folded to exterior with added clay	Yes
3	044	Folded to exterior	101	Folded to exterior	Yes
4	020	Folded to exterior	070	Folded to exterior	Yes
5	118	Folded to exterior	119	Folded to exterior	Yes
6	105	Folded to exterior	106	Folded to exterior	Yes
7	064	Folded to exterior	098	Folded to exterior with added clay	No
8	049	Folded to exterior	102	Folded to exterior with added clay	No
9	096	Folded to exterior	090	Folded to exterior with added clay	No
10	051	Added clay at exterior	100	Added clay at exterior and lip	No

Table 6.20: Rim construction for Arkona vessels with wider categories. Note: Unidentified sherds are not tabulated here

Rim Construction Method	**Number of Vessels**	**%**
Folded Rims	27	42.9
Rims with added clay	15	23.8
Rims with fold and added clay	13	20.6
Plain	8	12.7
Total	63	100

clay ranges from 50% to 80% for each scanned site assemblage. Adding clay, alone or in combination with folding, ranges from 22% to 80%, and is never more frequent than folding. Plain rims are absent, or no more than 22% of a site assemblage. The absence of rims with added clay at AgHk-54 might suggest the potters at this site preferred folding techniques, but the sample size is too small for this to be anything but allusive. The two highest frequencies of plain rims come from AgHk-54 and AgHk-52 (Inland West Location 3 and Figura), which are immediately adjacent to each other, though again, numbers are too limited to draw any further conclusions.

Table 6.21: Rim technique by site for Arkona vessels. Note: Unidentified sherds are not tabulated here, including the one rim scanned from AgHk-56.

Rim Construction Technique	**AgHk-40**	**AgHk-54**	**AgHk-32**	**AgHk-52**	**AgHk-42**	**AgHk-58**
Folded Rims	1 (20%)	5 (56%)	4 (40%)	6 (43%)	8 (44%)	3 (43%)
Rims with added clay	1 (20%)	0	4 (40%)	4 (29%)	5 (28%)	1 (14%)
Rims with fold and added clay	3 (60%)	2 (22%)	2 (20%)	1 (7%)	3 (17%)	2 (29%)
Plain	0	2 (22%)	0	3 (21%)	2 (11%)	1 (14%)
Total	5	9	10	14	18	7

6.3.3 Adaptive Irregularities and Improvisation

Micro-CT scans allow us to visually document the hidden steps in clay manipulation and vessel formation and how materials and producers interacted. One distinct advantage of this method, then, is that we can see instances of when potters needed to adapt to the situation at hand, and improvise while making ceramics. While artisans and craftspeople work in regular rhythms established through practice there is also space in craft for incidents of improvisation and adaptive irregularities in the craft as the materials and person (or persons) interact (Ingold 2010:99; Sennett 2008:134). As skilled craftspeople work they undertake a process of ongoing movement that is at once “itinerant, improvisatory and rhythmic” (Ingold 2010:91), and “making” becomes not imposing a form on materials, but an engagement with force and material wherein forms are generated (Ingold 2010, 2013). In some cases the resistance of materials - moments of breakage, or limitations of malleability - drive the potter to improvise within their established gestures and rhythms.

I want to emphasize that my impression of the finished product of the vessels I scanned is that they are very accomplished and made by skilled artisans. However, interacting with these materials and bending these to a generated result that is either ideal or “good enough” is something that is only learned over time and with experience, and can always suffer from distractions or working in a less than ideal setting (Crown 2014; Dobres 2000; Gosselain 1998; Hagstrum 1985; Ingold 2010; Roddick and Hastorf 2010). Well-crafted vessels can and do occasionally exhibit evidence of improvisation and adaptation.

In addition, being able to identify instances of improvisation is a difficult, judgemental conclusion to reach; in effect distinguishing between what intentional conscious construction practices “should” look like, and what irregularities and adaptations in these practices look like. In my analysis of vessel scans, I relied on a deductive reasoning that assumed if a pot with fewer joins or added clay (that can create cracks in the fabric) is functionally less likely to fail in firing or during use, there is at least some incentive to avoid adaptive steps that create more joins. Therefore, a vessel exhibiting more spot joins or locations of added clay would be suggestive of adaptive irregularities in rim formation being taken despite the risk of failure, representing the dialogue between the potter and material in creating a vessel form.

Since the focus of my research was on rim sherds, rim and castellation incidents of improvisation were the main examples that I was able to note from vessel scans. Castellations are raised projections that extend upwards from the rim of a ceramic vessel (Curtis 2004:45), which are formed along with the rim of the vessel. Of the 31 rim sherds exhibiting castellations in this study, eight specimens were formed through the adding of clay, and three with more pronounced clay folding at the castellation than elsewhere on the rim. As I was mostly working with single shreds from a vessel, it was difficult to say whether a void pattern represented an adaptive irregularity, the material asserting its agency, or part of the potter's original rhythms and gestures across the vessel. There is, after all, a lot of leeway for individual production methods to be reflected in these ceramic materials to arrive at a similar end product. As discussed previously, one way I tried to get to a sense of regular versus irregular gestures was by scanning additional rim sherds from vessels already scanned. Inconsistencies across those sherds may indicate adaptive irregularities. The differences noted in four of the ten duplicate scans pointed towards what might be inconsistencies. Using these duplicate scans as a starting point, I then looked for these idiosyncratic joins and additions in all specimen scans.

Examples of what I perceived to be improvisation in rim forming included clay joined or added to rims in several ways. The following figures illustrate the variations in rim manufacture observed. The most common improvisation noted was the addition of clay on top of a folded rim. As noted earlier, there are vessel rims with added clay on top of folds, but the norm across the scanned collection is just a single addition of clay, or a fold, not clay added on top of that fold. In all, there are 13 rim sherds that exhibited an addition of clay on top of a fold. The extra clay on top of the fold was added around or was thickest at the castellated part of the rim in eight of the 13 examples (see Figures 6.36, 6.37 and 6.38) and there was added clay in locations that were not underneath castellations in five examples (See Figure 6.39). In addition, there were six examples (Specimens 022, 039, 042, 065, 068 and 069) in which I noted the addition of clay. These differed from the folded and added clay rims because these specimens exhibited smaller,

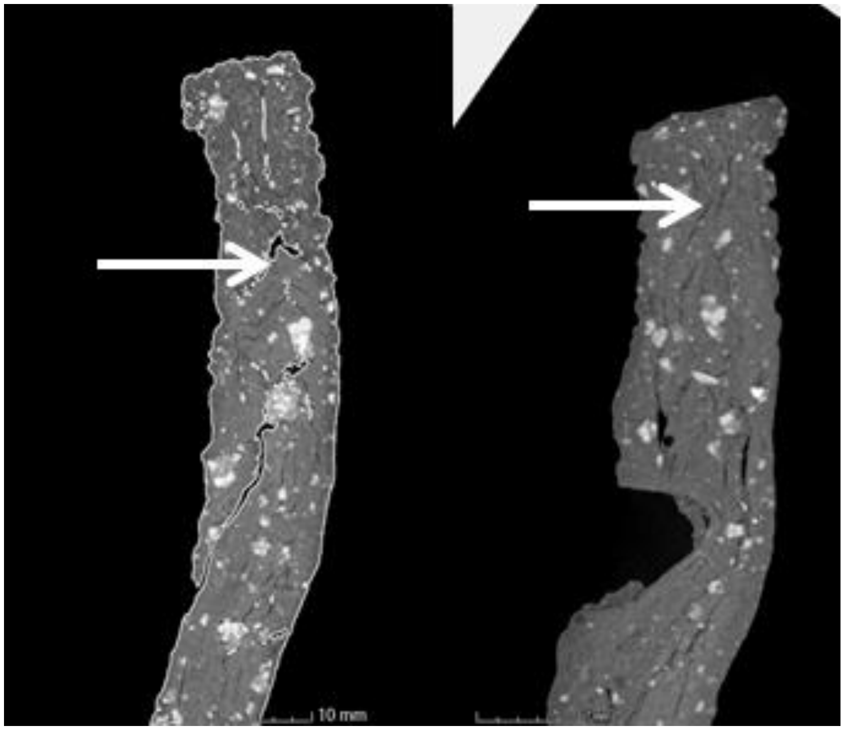


Figure 6.36: Specimen 050 (left) and Specimen 097 (right), from the same vessel. While there is clay added on top of the fold in both pieces, extra clay is added to form the castellation in Sample 050 on the left. Arrows indicate where the top of the fold is located.

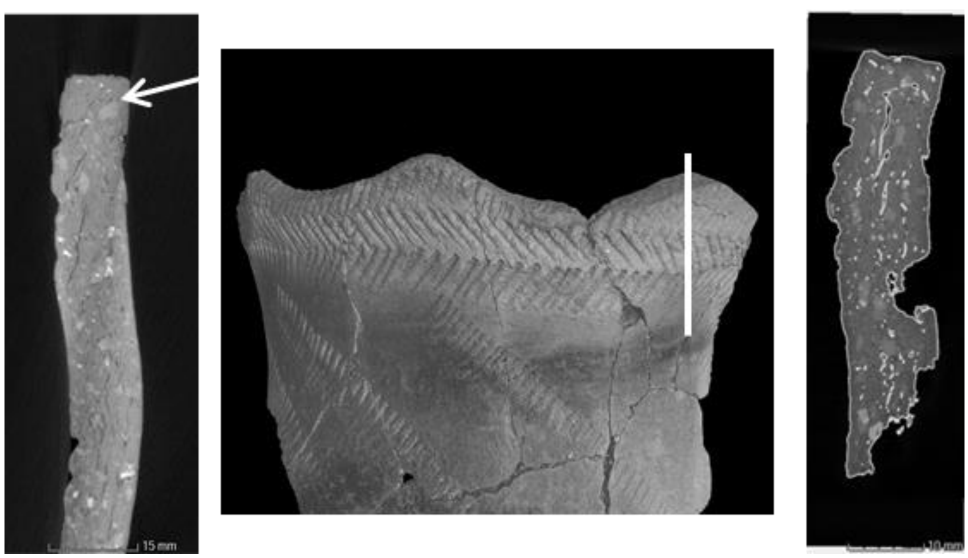


Figure 6.37: Specimen 098 (left and center) and Specimen 064 (right), both from the same vessel. Specimen 098 has clay on top of the fold. A void join can be seen at the white arrow. The location of this slice is illustrated by the white line. Specimen 064 had no clay noted on top of the fold.

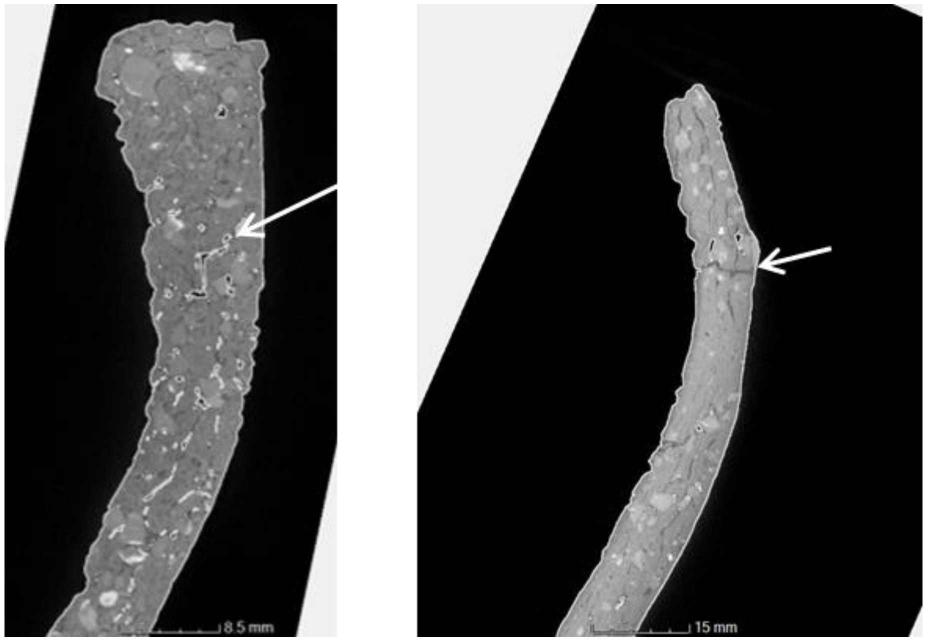


Figure 6.38: Specimen 113 (left) has a folded rim with clay on top, which is thicker at the castellation. The arrow points to the void at the top of the fold. It appears to be a small coil used to create the castellation in this case. For Specimen 069 (right), the entire rim at this location on the vessel is added. The arrow points to the void where this rim piece was joined. These two specimens are not from the same vessel.

more ephemeral additions. The clay additions were only noted in some but not all 2D slices for the specimen. In some cases, there were pieces of clay or coils used to form the entire upper rim in a small portion of the vessel orifice (Figure 6.38). It may have been that there was not enough clay to form the rim of the pot in this section. There are also examples where very small pieces of clay have been tacked on to the rim, in what appears to be an effort to raise that part of the rim to form the castellation (Figure 6.40), or may have just been used to level out an uneven or slightly cracked rim or lip surface where necessary (Figure 6.41). In speaking with a modern potter while hand building coiled pots, when a small crack appeared in the lip of the pot as the clay dried, he suggested the use of a small patch of clay along the lip to fix this flaw (Chris Snedden, personal communication 2020). Specimen 039, (Figure 6.41) indeed exhibits a small piece of clay added to the front and lip of a vessel with a thickened rim or incipient collar. This vessel had a larger piece of clay added to form the bulk of its rim, but in this one place had an additional patch of clay on top of that.

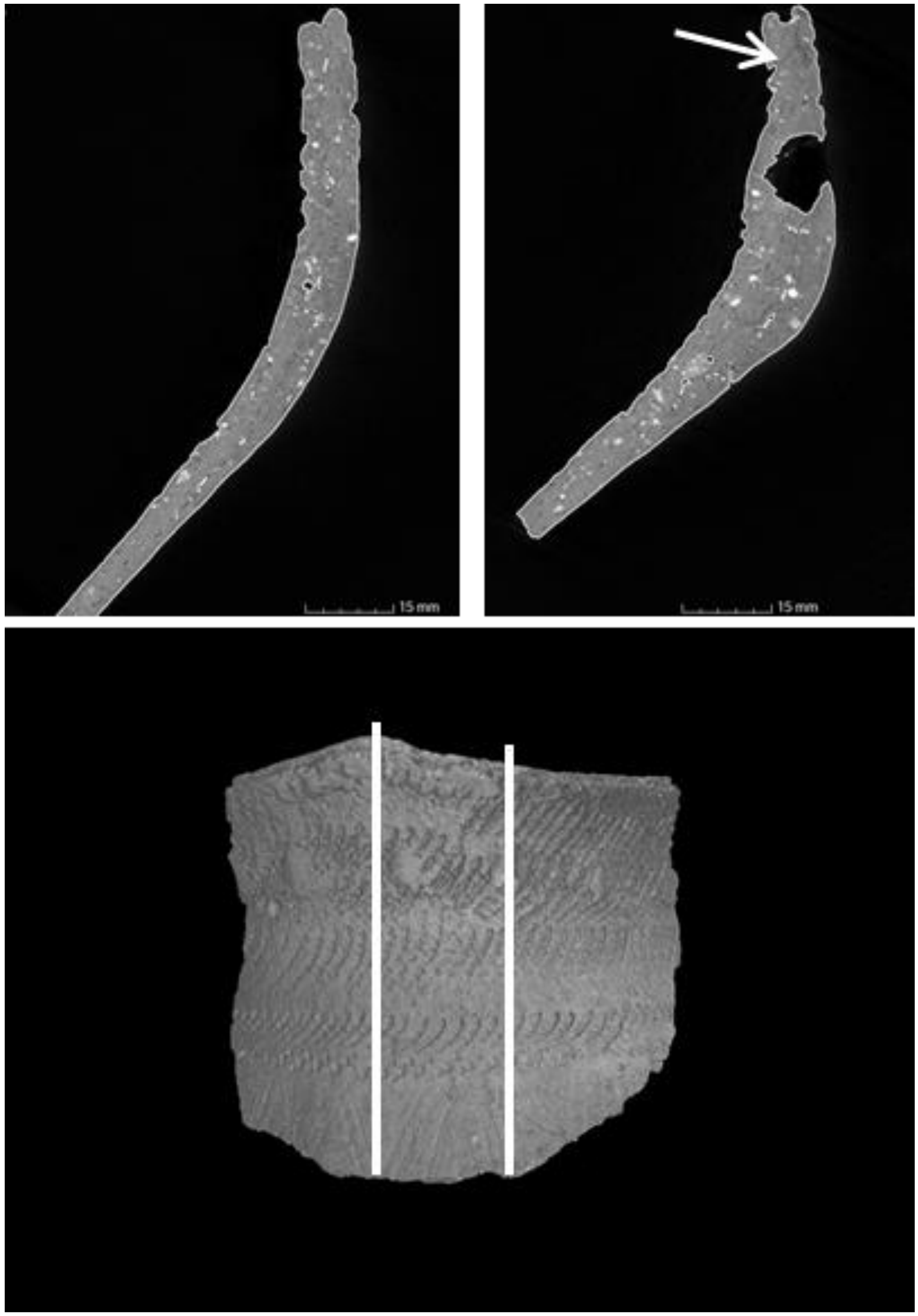


Figure 6.39: For Specimen 049, added clay is noted to the right of the castellation. The left line on the 3D rendering illustrates the location of the 2D slice to the left and the right line illustrates the location of the 2D slice on the right. The joining void for the added clay is indicated by the arrow. The slice at the right intersects a large boss/internal punctate, which can be seen in the profile.

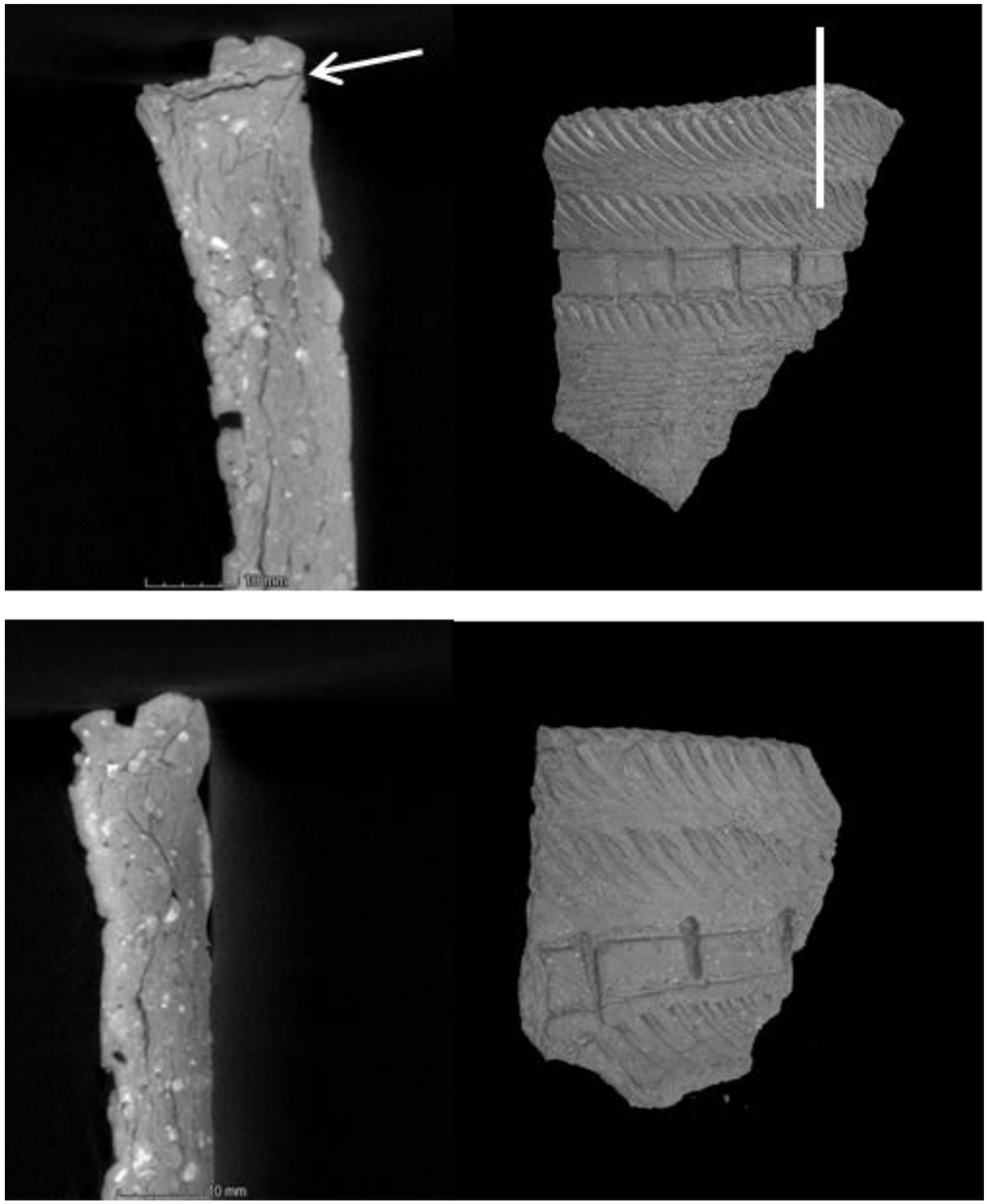


Figure 6.40: Specimen 100 (upper 2 images) and Specimen 051 (lower 2 images) are part of the same vessel. In Specimen 100, one small portion of the vessel has a bit of clay added, probably to make a castellation (location of the 2D slice is illustrated by the line). The void joining this added bit of clay is indicated by the arrow. In Specimen 051 there is no extra addition of clay.

Figure 6.41: Specimen 068 (left) illustrating a small piece of clay added on the rim. The arrow points to the void where this clay was joined. Specimen 039 (right) illustrates a small piece of clay added on to the front of the thickened rim at the exterior of the vessel. The arrow points to the void where this added clay was joined. These two specimens are not from the same vessel.

All together these specimens make up 19 examples in which clay was added as an adaptive irregularity onto the rim shape (for full information about each specimen, please refer to Appendix E), and it is possible that more of these small additions might be found upon further examination of specimen scans, as many of these features were discovered in my fourth or fifth time examining the specimens. But at 19 examples of 63 vessel rim sections scanned, that represents 30% of all vessels scanned. So just under a third of all vessels examined here exhibited adjustments or instances of improvisation in the forming of the rim, suggesting the need to tweak rim forms and adjust and adapt during the making of rims was a relatively common practice potters used when making their vessels.

These instances of improvisation or adaptive irregularities are found on scanned rims from all Arkona sites where rim sherds were scanned (Table 6.22). While these sampled specimens do not represent complete assemblages from each site, some general observations can be offered here. Sherds scanned from these six sites each included at least 20% of vessels with corrective incidents. Both the Bingo Village site (AgHk-42), and Bingo Pit Location 3 (AgHk-40), located close to each other and northwest of the other cluster sites examined, yielded higher percentages of sherds with adaptive irregularities than for the rest of the cluster (10 of 23 sherds total, or 43%; versus 9 of 40 sherds total, or 22%). This difference might be hinting at distinct practices, or range of potter skills within communities across the cluster. However, the limited sample sizes used for this study preclude this observation from being more than a suggestion at present.

Table 6.22: Adaptive irregularities by site.

Site	Total specimen scans at site (minus neck sherd scans)	Frequency of adaptive irregularities	% of vessels at each site with adaptive irregularities	% of all adaptive irregularities
AgHk-32	10	2	20.0%	10.5%
AgHk-40	5	3	60.0%	15.8%
AgHk-42	18	7	38.9%	36.8%
AgHk-52	14	3	21.4%	15.8%
AgHk-54	9	2	22.2%	10.5%
AgHk-58	7	2	28.6%	10.5%
Total	63	19	30.2%	100

As noted, these alterations or improvisations appear entirely on the rim portion of vessels. Where my specimen scans included lower elements (e.g., neck, shoulder, body), I did not see any evidence of additions of clay or other irregularities. This focus on the rim portion of vessels is further discussed in Chapter 7.

6.3.4 Morphological Attributes Related to Forming

The morphological attributes typically examined in archaeology are those readily visible during the analysis of vessel sherds. Morphologically, and at a generalized level, ceramic vessels during the early Late Woodland associated with Wrights's (1966) Ontario Iroquoian Tradition tend to exhibit vertical to everted rims, can be collared or not, and have constricted necks, pronounced shoulders and globular bodies (Watts 2006:8). Western Basin Tradition vessels of this time period exhibit a lot of regional variation. There is a high degree of experimentation resulting in different vessel forms and finishings. Vessels often have castellations and incipient collars or "thickened" rims fashioned (Watts 2006:88; Murphy and Ferris 1990:202-203). Vessels have rounded, or "bag shaped," bodies (Murphy and Ferris 1990:207).

Generally, the morphology of pots can help define the extent that potters at the Arkona Cluster of sites were working to achieve an ideal pot form, by exploring how rigid or variable those attributes were across the vessels examined. While this can be done using traditional archaeological measurements, micro-CT scans offer a unique way to record and visualize morphological shape, because of the ease of non-invasively slicing vessel profiles that otherwise could only achieved through archaeological illustration.

The vessel morphological attributes noted tend to reflect the broader temporal and regional contexts potters worked within. For example, basic attributes from the Arkona sample included a predominance of lips that are flat, rim profiles that are concave, and necks that are short and curve out at the shoulder (see Figures 6.42 and 6.43 and Table 6.23). Note that total counts for each attribute varied, since not all sherds exhibited all three attributes. Likewise, I removed indeterminate specimens when calculating percentages. The frequencies of these attributes are generally consistent with ceramic assemblages from the 13th century in southern Ontario, which typically also exhibit a smaller percent of secondary forms for each of these attributes (Murphy and Ferris 1990; Watts 2006).

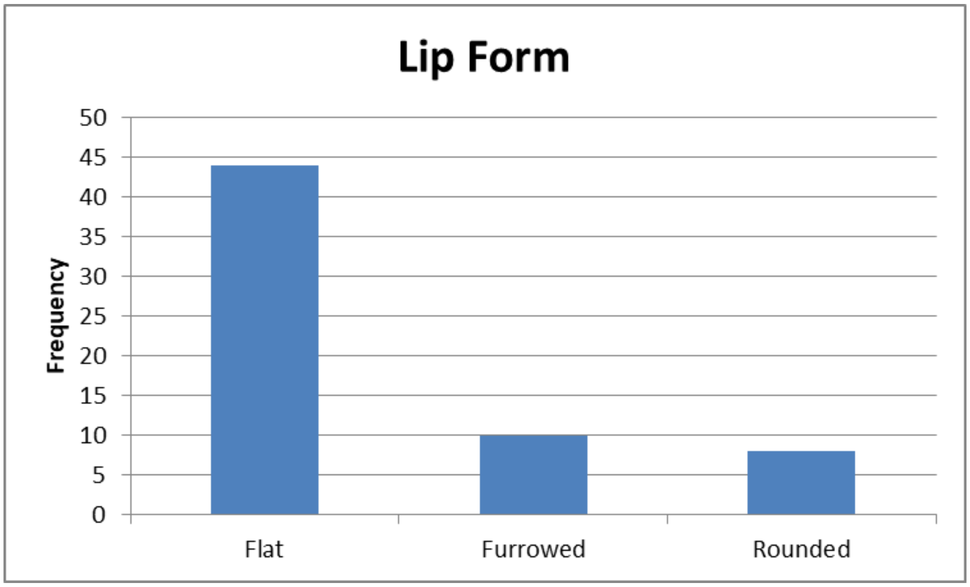


Figure 6.42: Frequencies of lip form for Arkona vessels.

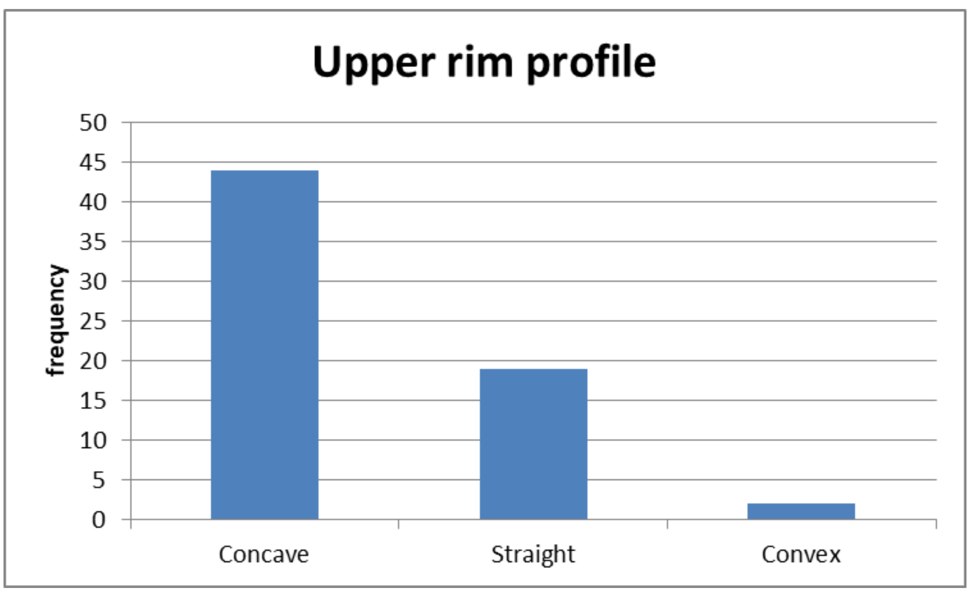


Figure 6.43: Frequencies of upper rim profiles for Arkona vessels.

Notably, the Arkona assemblages suggest that flat lips (unaltered by decorative furrowing) and concave or straight rim profiles and short necks represent relatively rigid vessel form morphological traits, though the use of elongated necks is a secondary attribute of choice for some artisans. Upper rim profile and lip form (Figure 6.44) were defined after categories used by Watts (2006:253-254), with the addition of furrowed or splayed lips as defined by Mather (2015:114). Lip form was fairly easily differentiated, since rounded lips stand out from flat lips in the collection. Upper rim profile varied more, especially within the concave rim category. While upper rim profiles classed as "straight" were fairly straight, those in the convex category were all close to straight as well, while the concave category ranged between those that were quite out-flaring or curved and those that were close to straight with only a slight curve. This variability suggests that there was some flexibility in the degree of concavity of the upper rim profile for potters, or variable forming intents across rim design. Neck shape was the most subjective of these variables to define. Neck shape curvature appeared to vary across a spectrum based on the curvature from the base of the rim into or through the length of the neck (Figure 6.45). Neck shape was also difficult to determine for sherds where only a small portion of the neck was present, and the angle of the rim had to be used to make an estimate. This attribute was defined from both 2D slices and from the curvature exhibited in the 3D rendering of sherds.

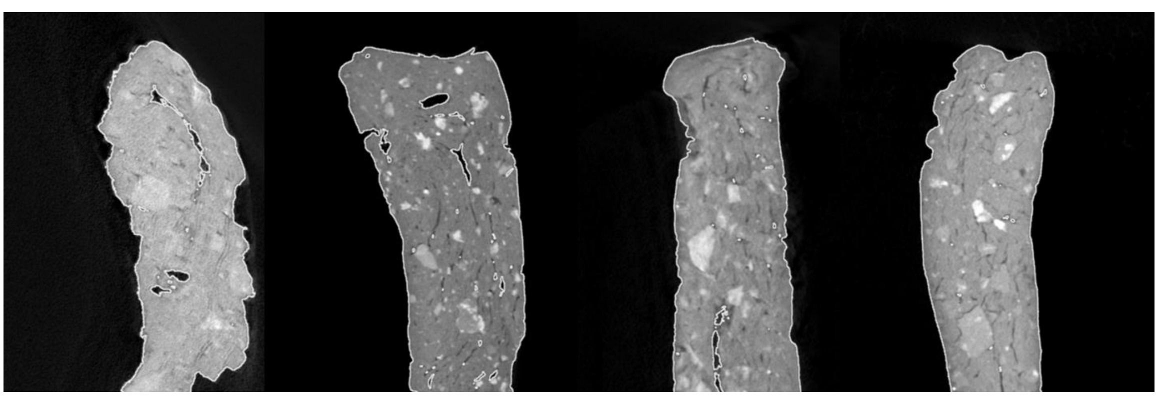


Figure 6.44: Examples of upper rim profiles and lip forms. Left to right: concave upper rim with rounded lip (Specimen 029), concave upper rim with flat lip (Specimen 048), straight upper rim with flat lip (Specimen 025), and convex upper rim with furrowed lip (Specimen 062).

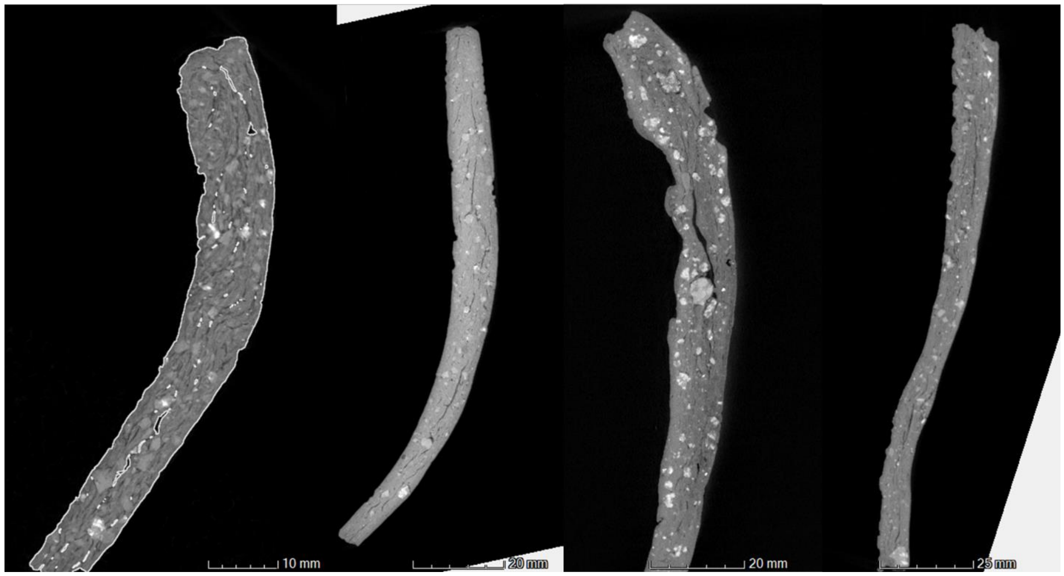


Figure 6.45: A range of neck profiles from Arkona. Images are not all at the same scale. Left to right: Specimen 041, 096, 091 and 066. The two at the left were classified as "short" neck profiles and the two at the right as "elongated" neck profiles.

While most sites in the Arkona Cluster followed the general trends of the total assemblage for lip, rim and neck profile or shapes, there were some exceptions to these patterns worth noting (Table 6.23). Rounded lip forms are more common in the AgHk-52 sample than elsewhere, making up 29% of the lip forms, suggesting there was more flexibility in lip form at this site than others. AgHk-54 varies notably from the other sites in terms of both a high percentage of short necks (89%) and 100% concave upper rim profiles. These two traits may relate to construction as the short neck curves into a concave upper rim profile, although there are also several elongated necks that exhibit a concave upper rim profile. Potters in the community at AgHk-54 might have preferred the shorter neck profile; an analysis of the whole assemblage beyond this scanned sample would reveal whether this is true. In contrast, potters at AgHk-32 used diverse upper rim profiles, and this was the only site that exhibited straight rather than concave rim profiles as the most common type. Neck profile at AgHk-32 was also evenly split between elongated and short necks, whereas at every other site short necks dominated the samples.

Table 6.23: Morphological variables frequencies and percentages for Arkona specimens: totals and sorted by site.

Site	Lip			Rim Profile			Neck shape	
	Flat	Furrowed	Rounded	Concave	Straight	Convex	Short	Elongated
AgHk-32 Van Bree	8 (80%)	2 (20%)	0	3 (30%)	6 (60%)	1 (10%)	4 (50%)	4 (50%)
AgHk-40 Bingo Pit Loc. 3	3 (60%)	2 (40%)	0	3 (60%)	2 (40%)	0	5 (100%)	0
AgHk-42 Bingo Pit Village Loc. 10	13 (76%)	2 (12%)	2 (12%)	14 (74%)	5 (26%)	0	12 (75%)	4 (25%)
AgHk-52 Figura	8 (57%)	2 (14%)	4 (29%)	10 (67%)	4 (27%)	1 (6%)	12 (80%)	3 (20%)
AgHk-54 Inland West Loc. 3	7 (78%)	1 (11%)	1 (11%)	9 (100%)	0	0	8 (89%)	1 (11%)
AgHk-56 Inland West Loc. 6	n/a	n/a	n/a	n/a	n/a	n/a	0	1 (100%)
AgHk-58 Inland West Loc. 9	5 (72%)	1 (14%)	1 (14%)	5 (71%)	2 (29%)	0	4 (80%)	1 (20%)
Total	44 (71%)	10 (16%)	8 (13%)	44 (68%)	19 (29%)	2 (3%)	45 (76%)	14 (24%)

Since AgHk-32 is the earliest site in the Arkona cluster, it is possible this difference is temporal and vessels with straight upper rim profiles and elongated necks became less common over time. Again, complete assemblage analyses would reveal if this pattern represents a real trend or is just a result of my sampling strategy.

I also explored these morphological attributes as they relate to rim manufacturing techniques (Table 6.24). While generally the morphological variables are found throughout all of the rim manufacturing techniques, there are more flat rims in the folded clay rims and more furrowed lips on rims with added clay than in other categories. Rims with added clay also have more of a mixed rim profile distribution, while the other rim formation categories lean more heavily towards concave rims. Perhaps the addition of clay to the exterior of a rim changed shape towards more of a straight or convex profile, as the potter supported the rim from the interior while applying the clay in a manner that the folding motion did not require. All rim manufacturing techniques also seem to have similar high percentages of short neck shapes, though both folded rim types have a slightly lower percentage of elongated necks than the added clay or plain rim types do. Potters may have been technically conceptualizing the rim and the neck as different zones when constructing the vessel.

Another measure of morphological variability is lip thickness. I measured lip thickness at the lip of the vessel using the digital caliper in the imaging software. I was only able to record this on vessels with an intact lip, meaning I did not take this measurement for the five neck sherds I scanned. Lip thickness was highly variable, with no single predominant, or ideal, thickness standing out (Figure 6.46). Overall, 76% of the assemblage ranges in lip thickness between 7 to 12.9 mm, a range that almost doubles in thickness. This variation is not surprising, given the predominance of folding or adding clay, or both, to upper rims, and suggests there was a great deal of leeway in dealing with the thickened lip as a result of those methods.

Table 6.24: Morphological variables for Arkona specimens sorted by rim manufacture. Indeterminate values are not included in counts. Unidentified rim forms are not included in counts.

Rim	Lip			Rim Profile			Neck shape	
	Flat	Furrowed	Rounded	Concave	Straight	Convex	Short	Elongated
Folded	22 (81%)	2 (7%)	3 (11%)	21 (78%)	6 (22%)	0	20 (83%)	4 (17%)
Added clay	8 (53%)	5 (33%)	2 (13%)	7 (47%)	6 (40%)	2 (13%)	10 (77%)	3 (23%)
Folded and added clay	9 (75%)	2 (17%)	1 (8%)	8 (62%)	5 (38%)	0	9 (82%)	2 (18%)
Plain	5 (63%)	1 (13%)	2 (25%)	6 (75%)	2 (25%)	0	6 (75%)	2 (25%)

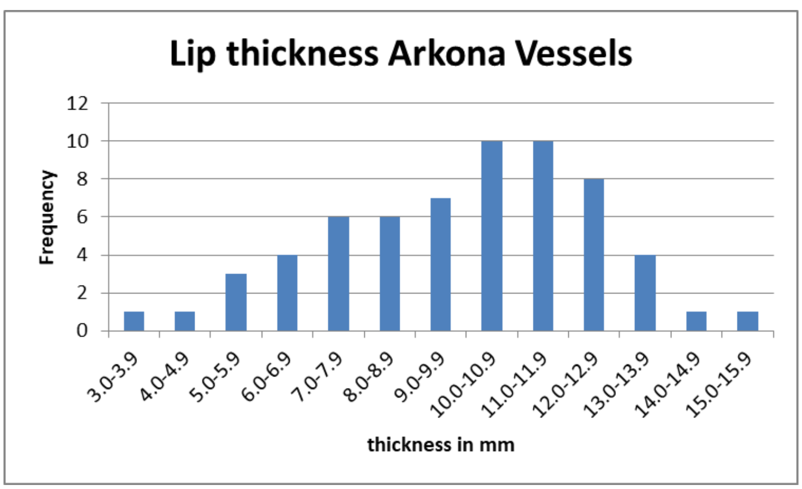


Figure 6.46: Bar graph illustrating the distribution of lip thickness of Arkona specimens. Indeterminate values were not included.

Since thickness measurements taken at various points along a vessel profile are a standard variable recorded in ceramic analysis, I also measured wall/rim thickness, taken at either 5 cm down from the lip, or at 4 cm, when sherds were too short to get to 5 cm. For neck sherds where the lip of the vessel was missing, I estimated and measured 4-5 cm from where it appeared as though the lip would have been. Overall thickness measurements cluster around 9-11mm, and drop off significantly in the 12-13mm thickness categories, indicating that vessel walls are generally a bit thinner than at the rim (see Figure 6.47). However, when the difference between lip thickness and wall thickness was calculated (lip value-wall value), 23 specimens (37%) were thicker below the lip than at the lip, 3 specimens (5%) were equal, and 36 specimens (58%) were thinner below the lip than at the lip. The difference between the lip thickness and wall thickness was less than 5.3 mm for all specimens, with the exception of one thin-walled vessel (Specimen 011) where there was a difference of 7.5 mm from lip to wall. Most vessels (88%) had a difference of less than 4 mm between the lip and wall/rim thickness. Whether the lip or the wall/rim of a specimen was thicker did not appear to relate to different sites (see Appendix D for this data). I suspect it is the case that this measurement was not taken far enough down the rim to capture thinning that may have been happening into the neck of the vessel, but because some rim sherds were only 4 or 5 cm in length it was taken at this location for consistency. It is also possible that more measurements per specimen might have revealed variation in thickness in more detail.

Whether variation in thickness related to forming techniques used was not immediately clear. I grouped lip thickness measurements into 2 mm categories (expanding the largest category to include one vessel that fell above 15 mm), and within all four rim manufacturing techniques, lip thickness values ranged between 7-12.9 mm (Table 6.25). In the plain rims, there is a slightly higher percentage (25%) that fell into lower lip thickness categories, and there were no plain rims 13 mm or thicker, suggesting the lack of added or folded clay might have resulted in thinner lips. Interestingly, the rims with a fold and added clay, are the most evenly spread across thickness categories. Potters may have been maintaining wall and lip thickness regularity using these secondary techniques of adding or folding clay when they felt it necessary after the initial forming of the upper portion of the vessel was complete.

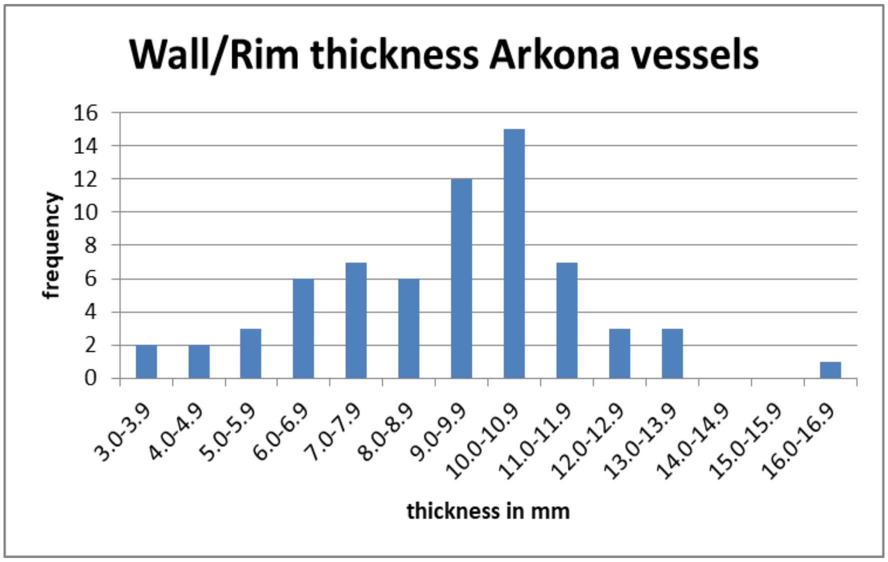


Figure 6.47: Wall/lower rim thickness in Arkona vessels.

Table 6.25: Lip thickness of Arkona specimens by rim manufacturing technique. Indeterminate values not included.

Lip thickness by rim manufacture	3-4.9mm	5-6.9mm	7-8.9mm	9-10.9mm	11-12.9mm	13-15.9mm	total
Folded	1 (4%)	1 (4%)	5 (19%)	6 (22%)	12(44%)	2 (7%)	27
Added clay	0	2 (13%)	5 (33%)	5 (33%)	2 (13%)	1 (8%)	15
Fold and added clay	1 (7%)	2 (17%)	2 (17%)	2 (17%)	2 (17%)	3 (25%)	12
Plain	0	2 (25%)	0	4 (50%)	2 (25%)	0	8

Finally, orifice diameter was a measurement that I was able to record for some vessels during the time I had access to a trial version of the coordinate measurement module for VGStudio MAX 2.2. The coordinate measurement module allowed me to obtain an orifice radius easily. I used a slice through the X plane close to the lip of the vessel to place points along the edge of the rim (Figure 6.48). The coordinate measurement module calculated a radius for the circle created from these points, from which I was able to calculate the diameter (2 x radius; Figure 6.49).

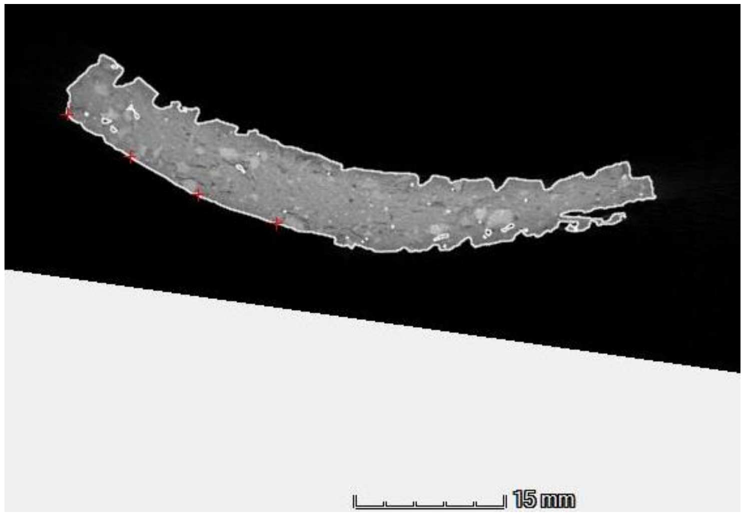


Figure 6.48: Placing points along the wall in a slice through the orifice of Specimen 132**.**

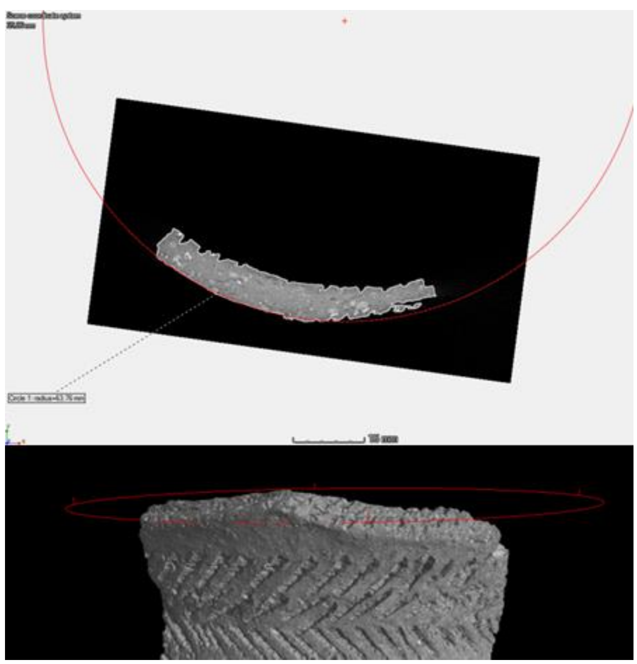


Figure 6.49: VGStudio MAX software calculated the radius measurement from the points placed along the orifice of Specimen 132 seen here in a slice through the Y axis and a 3D rendering. Radius here reads 63.76 mm.

Recording orifice measurements this way is a less subjective method for taking rim diameter than using traditional rim diameter charts (Rice 1987:238). Digitally placing points along the curvature of the slice through the Y plane seemed less of a judgement call than my previous experiences with sliding a ceramic rim along a rim diameter chart to estimate a best fit. I was only able to take this measurement for 24 Arkona specimens. In terms of results, orifice diameters for the 24 specimens ranged between 11 and 43 cm, with nine specimens under 20 cm in diameter, nine specimens falling between 20 and 30 cm in diameter and six specimens above 30 cm in diameter (see Appendix D). There was no apparent relation between different Arkona sites or rim manufacturing methods and orifice diameter, indicating that potters at all Arkona cluster sites were creating vessels with similar size variability, perhaps a result of participating in a shared community of practice. Variation in orifice diameter did, not surprisingly, roughly align with lip thickness, suggesting that vessels with larger openings had thicker lips (Figure 6.50). Potters were generally using thicker lips and walls to create larger vessels. There also appears to be a potential relationship between upper rim profile and orifice diameter. While only 29% of all upper rim profiles in the entire sample were straight, of the rims with orifice diameters of more than 30 cm, five out of six specimens (83%), fell into the straight upper rim profile category. While this is a small sample to make conclusions from, potters may have been working towards a more upright rim profile when they were constructing the larger vessels at the Arkona Cluster.

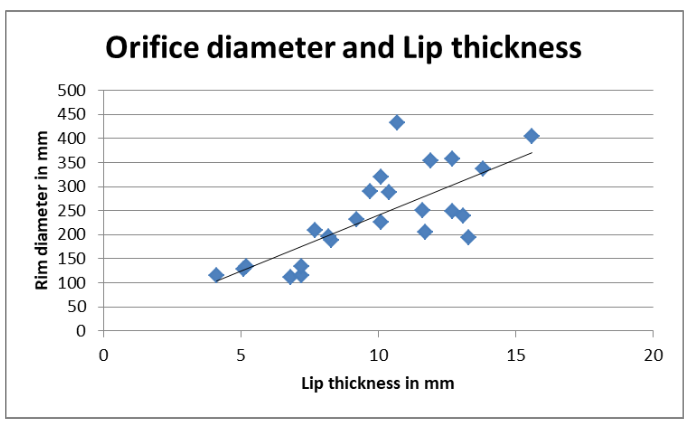


Figure 6.50: A plot of the 24 specimens sorted by orifice diameter and lip thickness. The plot roughly follows an upward trend, suggesting a relationship between the size of the orifice of a vessel and the thickness of that vessel's lip, n=24.

6.3.5 Castellations

Castellations are intentional upward projections along the top of the vessel rim and are common on Late Woodland pottery (Williamson 1990:298). They can appear as a single, distinct rise at one location of the rim, as two or four castellations at opposing halves or quadrants of a pot orifice, or appearing continuously, in a crenellated fashion across the entire rim (Murphy and Ferris 1990). This variability in the use of castellations means determining the presence or absence of castellations is partly affected by whether the rim section analyzed has a castellation. I noted whether or not one or more castellations were present on a rim section, to begin to get a sense of how many castellations might exist in the assemblages. Of the 62 sherds scanned where the presence or absence of castellations could be determined (those with intact lips), 31 (50%) had castellations. Of those, 24 had one castellation, and seven had more than one. Castellations can be shaped differently in the Late Woodland, including pointed, squared and rounded forms. Of the 31 specimens with castellations in this study, castellation forms included 71% pointed, and 29% rounded (Table 6.26).

There may be a correlation between the gesture of folding rims, and the production of castellations (Table 6.26). Folded rims, in isolation (45%), or combined with added clay (32%), represent 77% of all castellated vessels. Rims made with added clay only contributed 13% to castellated rims (or 45% when folded and added clay are added), while plain rims added 10%. Furthermore, 62% of all rims formed exclusively by folding or with a fold and added clay were castellated and 83% of rims with folding and added clay were castellated. This correlation of castellations with folding may suggest folding was the preferred method used to create castellations on these vessels, especially when combined with added clay. This correlation between folding, and adding clay on top of folds and the presence of castellations also suggests the design and implementation of castellated rims was a complex series of steps the artisan had to learn through the use of repeated gestural movements, when shaping vessel rims, differing from the smaller improvisations seen elsewhere on vessel rims.

Table 6.26: Castellations by rim manufacturing method.

Rim manufacture method	Pointed castellations	Rounded castellations	Frequency and % of total castellations	% castellated within manufacture method
Folded	10	4	14 (45%)	14/27 (52%)
Added clay	4	0	4 (13%)	4/15 (27%)
Fold and added clay	7	3	10 (32%)	10/12 (83%)
Plain	1	2	3 (10%)	3/8 (38%)
Total	22	9	31 (100%)	31/62 (50%)

6.4 Analyzing Ceramic Finishing Attributes Using Micro-CT

The final stage in Late Woodland vessel production is finishing the object; typically after the item has been allowed to partially dry. Finishing consists of any trimming, surface treatments, or application of decoration before firing. These attributes, especially decoration on rims and necks, are a principal preoccupation of conventional ceramic analyses, and tend to inform regional ceramic typologies. For this study, I was more interested in comparing rim manufacturing and rim finishing practices, in particular exterior decorative methods, to see if there are any correlations between what choices the potter was making while forming and then decorating the rim. I was not interested in using these decorative attributes to classify ceramics or define "ethnicity" or "cultures," since I am more interested in exploring manufacturing techniques as knowledge transmission, learning and communities of practice (Gosselain 1998; Hagstrum 1985; Michelaki 2008; Roddick and Hastorf 2010; Wendrich 2012).

Because of the long history in archaeology, especially in Ontario, of linking the decorative elements on rims and necks of vessels to archaeological "cultures" or traditions, I examined the decorative elements involved in finishing with the particular goal of determining whether there was a correlation with rim forming techniques. If these decorative elements such as the motif and techniques used to decorate rims really relate to "cultures" then one would expect there to be some correlation between the way pots were decorated and the way they were formed, which in this case is represented by rim forming techniques. The goal here was not to conduct a detailed decorative analysis but to examine if finishing methods used by potters had any relation to how they were forming the rims and necks of pots. Applying decorative techniques is one of the many steps in the manufacturing of pots and there are particular gestures and motions that go along with these finishing steps that might relate to earlier stages in manufacture. More detailed decorative analysis, for example, one that explores the relationships between different decorative techniques and motifs used on these Arkona vessels, was not the desired outcome, as it had been in other attribute-based studies of Arkona ceramics (Cunningham 2001; Suko 2017a; Watts 2006).

The visible decorative attributes that archaeologists typically focus on to access the craft of ceramic manufacture, such as the tools and consistency in the implementation of decorative elements, are not any more visible in micro-CT scans than they are through visual examination. Certainly, it is possible to see tool application and directionality of tool use in scans, but not any more than can be seen from visual examination of the exterior of the vessel. It is possible to highlight features on the surface of a micro-CT 3D model through the digital control of light, but for finishing features I found examining the physical ceramic sherd under magnification and light more effective. Additionally, as I was collecting decorative data from the scans, I noted that it was hard to tell which way the clay was pressed in those images. One exception, however, was in examining the punctates present on many of the Arkona vessels. Because of the depth of application of this decorative feature, micro-CT slices provided information on the depth, directionality and shape of punctates that was easier to access than from visual examination. So, while many of the attributes are just as easily measured and compared by visually examining them, there are some, like the depth of punctates, and the placement and orientation of some tool applications, that can be more accurately explored and are easier to compare in scans of sherds.

While I have collected detailed attribute data related to decorative elements (following Watts 2006), I simplified the attribute categories to facilitate a comparison of decoration application to rim manufacturing techniques. Simplified finishing attributes are presented in Appendix E. These simplified categories included the presence of interior decoration on the rim, the presence of lip decoration, the main technique used for exterior rim decoration, the main motif used for exterior rim decoration, the presence of neck decoration, neck decorative motif, the presence of punctates on the rim, and the distance of punctates from the rim. For some finishing attributes, such as the presence of interior and lip decoration, and the main technique used for exterior rim bands, no real sense of a distinct pattern in relation to vessel forming was observed, because these particular attributes were present on the vast majority of specimens or varied little between specimens. As such, they are not discussed below. For detailed information on these and other decorative attributes recorded, see Appendix E.

6.4.1 Exterior Decoration

The exteriors of vessels were decorated with bands or rows of applied decoration, usually stamped, creating a motif of one or more bands of decoration around the vessel. These bands of decoration were recorded following the technique used by Watts (2006:122), and then simplified to ease comparisons to rim manufacturing techniques. While not all vessels were complete enough for all decorative bands to be recorded, where much of the rim and upper neck could be recorded (N=43), one (2%) consisted of a single band, three (7%) consisted of two bands, 13 (30%) consisted of three bands, 12 (28%) consisted of four bands, and 14 consisted of five or more bands (33%). Figures 6.51-6.54 illustrate various band motifs and applications.

Decorative elements were typically applied on an angle, or obliquely, within most bands. I recorded orientation as to the right, left, or alternating as the three predominant orientations (88% in total) on Arkona ceramics (see Table 6.27). The remaining 12% of decorative orientations included horizontal, vertical and a combined oblique and horizontal application.

Figure 6.51: Specimen 008 exhibiting, in bands, from top to bottom: stamped linear right oblique, linear horizontal incisions with row of bosses, incised linear left obliques, linear horizontal, and linear right obliques, and incised linear horizontals. The main motif is horizontals, and the main technique is incising.

Figure 6.52: Specimen 114 exhibiting, in bands, from top to bottom: stamped linear left oblique, bossed horizontal over linear left oblique, stamped linear left oblique, and incised linear left oblique over linear right oblique. The main technique is stamping, and main motif is left obliques.

Figure 6.53: Specimen 039 exhibiting, in bands, from top to bottom: stamped linear right oblique, stamped linear left oblique, stamped punctates, stamped linear right obliques, stamped linear right obliques, although these are almost vertical. The main technique is stamping, and the main motif is right obliques.

Figure 6.54: Specimen 132 exhibiting, in bands, from top to bottom: stamped linear right oblique, stamped linear right oblique, stamped linear left oblique, stamped linear right oblique, stamped linear left, stamped linear right, stamped linear horizontals. The main technique is stamped, and the main motif is alternating obliques.

These applications do not sort neatly by rim manufacture categories (Table 6.27), though it is worth noting that alternating obliques are found on 69% of rims that are folded with added clay, while right obliques make of the largest percentages of both the added clay (40%) and folded rims (37%). This result could suggest artisans preferred thicker rims for alternating applications, or that artisans who preferred alternating obliques found themselves having to add clay to repair rim deformation more frequently, or it could be coincidental.

Table 6.27: Exterior band main decorative application totals sorted by rim construction method.

Rim construction method	**alternating obliques**	**right obliques**	**left obliques**	**other**	**total number of vessels**
Folded	9 (33%)	10 (37%)	6 (22%)	2 (8%)	27
Added clay	4 (27%)	6 (40%)	3 (20%)	2 (13%)	15
Fold and added clay	9 (69%)	3 (23%)	1 (8%)	0	13
Plain	1 (12.5%)	4 (50%)	1 (12.5%)	2 (25%)	8
Unidentified	1 (25%)	1 (25%)	0	2 (50%)	4
Total	24 (36%)	24 (36%)	11 (16%)	8 (12%)	67 (100%)

I also examined how these frequencies were distributed across sites (Table 6.28). There might be a slight preference for alternating obliques (56%) at AgHk-54, and a preference for right obliques (55%) at AgHk-42, though these tendencies are slight. This tendency suggests there might have been some preferences among artisans at these sites at play, but overall the distribution of the application of these motifs does not cluster by site, indicating the community of potters within the entire Arkona Cluster, over 270 years and within the 3 km radius of these sites, used broadly similar decorative applications on the exteriors of ceramics.

Table 6.28: Main exterior decorative motif by site.

Site	**alternating obliques**	**right obliques**	**left obliques**	**other**	**total number of vessels**
AgHk-32 Van Bree	3 (30%)	4 (40%)	0	3 (30%)	10
AgHk-40 Bingo Pit Loc. 3	1 (20%)	1 (20%)	2 (40%)	1 (20%)	5
AgHk-42 Bingo Pit Village Loc. 10	4 (20%)	11 (55%)	4 (20%)	1 (5%)	20
AgHk-52 Figura	5 (33%)	7 (47%)	2 (13%)	1 (7%)	15
AgHk-54 Inland West Loc. 3	5 (56%)	1 (11%)	2 (22%)	1 (11%)	9
AgHk-56 Inland West Loc. 6	1 (100%)	0	0	0	1
AgHk-58 Inland West Loc. 9	5 (71%)	0	1(14%)	1 (14%)	7
Total	24 (36%)	24 (36%)	11 (16%)	8 (12%)	67 (100%)

6.4.2 Neck Decoration

Neck portions of vessels were typically smoothed prior to decoration being applied, although the occasional vessel from the Arkona Cluster reflects a partially smoothed or cord-marked surface beneath the applied decoration (Neal Ferris, personal communication 2020), but none were noted in this study. Some of the vessels I examined (18 or 27% of this study's assemblage) lacked any meaningful section of neck and thus were omitted from the neck attribute analysis. Of the 49 vessels that had neck sections, 43 (88%) were decorated. The remaining six vessels were plain, which either represent an artisan decorative choice or were plain for that portion of the neck I had access to, since some decorative neck motifs include open space on the neck.

Though exterior bands were recorded for both the rim and neck as one in Section 6.4.1, the neck portion of these vessels was also examined separately. While in some cases the motif elements used to decorate the upper rim continued down on to the neck (Figure 6.55), more often the decorative elements were quite different, switching from the common oblique bands to horizontal lines, horizontal combinations of elements, or elaborate triangle or diamond patterns on the neck (Figures 6.56 and 6.57). This distinct design of neck decorative application and motif suggests that potters thought of the rim and neck sections of the vessel as connected but separate sections. The freedom of decoration and variability found in the neck sections at Arkona shows that perhaps the finishing of the neck of vessels was not as structured as the decoration on rim sections.

There was a range of neck motifs in the assemblage. When selecting the sample for this study, I was particularly interested in making sure I scanned vessels exhibiting a "triangle/diamond" motif on extended necks, since this is a hallmark of early Late Woodland Western Basin Tradition ceramic assemblages. Indeed, this is why I included the five vessels lacking complete rims in the study. However, despite this emphasis, the triangle/diamond motif only made up 43% of all necks in the scanned specimens I examined, or 49% of all decorated necks if the plain necks are taken out of the sample (see totals in Table 6.29). "Triangle" motifs included those that were filled and open diamond or triangle patterns (Figure 6.56), as well as three examples that included figures within the triangle or diamond shaped zones (see Specimens 065, 066 and 068 Appendix

A). Other motifs included obliques (consisting of bands of angled decoration), horizontals (consisting of bands of horizontal lines and/or stamped elements) and line plaits (consisting of sequential combinations of horizontal or vertical units of decoration) (Figures 6.55, 6.57 and 6.58).

There was no clear correlation between rim construction method and neck motif, which simply indicates these two attributes were not directly related. There was more of a correlation between neck form and motif, however, with triangle motifs appearing more frequently on elongated neck forms (Table 6.30). Not surprisingly, since there are more short than elongated neck forms in the sample, most motifs appear more frequently on short necks. However, the triangle motifs appear on elongated necks 55% of the time, indicating potters creating vessels with elongated necks may have seen that neck form as an element of the vessel that needed to be filled with complex decorative motifs, which large triangular and diamond motifs accomplished. Alternately, potters could have been creating longer necks with these large scale decorative elements in mind, creating a sort of canvas upon which these triangles would fit.

Figure 6.55: Specimen 115 exhibiting bands of oblique decoration on the neck.

Figure 6.56: Left to right: Specimens 028, 053 and 054, all exhibiting variations of open, partially filled and filled triangle and diamond neck motifs.

Figure 6.57: Specimen 046 exhibiting horizontal neck decoration.

Figure 6.58: Specimen 111 with plaits on the neck below three bands of oblique applications.

Table 6.29: Neck motif sorted by rim construction method

Rim Construction Method	triangle motifs	horizonta l motifs	oblique motifs	plait motifs	plain	Total
Folded	6 (33%)	3 (17%)	5 (28%)	1 (5%)	3 (17%)	18
Added clay	5 (38%)	5 (38%)	0	1 (8%)	2 (16%)	13
Fold and added clay	3 (38%)	2 (25%)	2 (25%)	1 (12%)	0	8
Plain	3 (50%)	2 (33%)	0	0	1 (17%)	6
Unidentified	4 (100%)	0	0	0	0	4
Total	21 (43%)	12 (24%)	7(14%)	3 (6%)	6 (12%)	49

I also examined neck motif by site (Table 6.31), but only slight differences emerged. Of the sites with larger samples, there were more triangle motifs present at AgHk-32 (Van Bree) than AgHk-42, 52 or 54, indicating perhaps the frequency of this neck motif was more common earlier in the Arkona Cluster. Both the samples from AgHk-42 (Bingo Village) and AgHk-54 have oblique motifs appearing on necks while they are notably absent at AgHk-52 (Figura), perhaps suggesting the former two sites are more closely linked to one another than to Figura, either temporally or with more closely overlapping communities of potters. Despite these slight differences, the various neck motifs used by potters at Arkona appear to have been shared throughout the cluster.

Table 6.30: Neck motif sorted by neck form. Indeterminate neck forms were not included in counts.

Neck form	Triangle motifs	Horizontal motifs	Oblique motifs	Plait motifs	Plain	Total
Short	9 (45%)	10 (91%)	5 (71%)	3 (100%)	6 (100%)	33
Elongated	11 (55%)	1 (9%)	2 (29%)	0	0	14
Total	20	11	7	3	6	47

Table 6.31: Neck motif sorted by site. Percentages indicate the portion each motif makes up within a site.

Site	Triangle motifs	Horizontal motifs	Oblique motifs	Plait motifs	Plain	total
AgHk-32 Van Bree	4 (57%)	1 (14%)	1 (14%)	0	1 (14%)	7
AgHk-40 Bingo Pit Loc. 3	2 (67%)	1 (33%)	0	0	0	3
AgHk-42 Bingo Pit Village Loc. 10	6 (40%)	4 (27%)	2 (13%)	1 (7%)	2 (13%)	15
AgHk-52 Figura	5 (42%)	4 (33%)	0	1 (8%)	2 (17%)	12
AgHk-54 Inland West Loc. 3	2 (25%)	2 (25%)	3 (38%)	0	1 (12%)	8
AgHk-56 Inland West Loc. 6	1 (100%)	0	0	0	0	1
AgHk-58 Inland West Loc. 9	1 (33%)	0	1 (33%)	1 (33%)	0	3
Total	21	12	7	3	6	49

In terms of decorative technique, incising was far more common, occurring on 63% of necks, either in combination with stamping or in isolation (Table 6.32). The techniques were fairly evenly spread across rim construction methods (Table 6.33) with slightly higher frequencies of stamped necks that have rims formed through folding, and a higher frequency of incised decoration on necks that have rims that do not have folds or added clay. I also examined neck decoration technique by site and found that both incising and stamping were used on necks from all sites, although at AgHk-54 there is a higher portion of stamped neck applications with five out of seven (71%) vessels exhibiting stamping as the main technique on the neck. There was some correlation between the technique used in neck decoration and the form of the neck. Incising was used more frequently on elongated necks while stamping was used more on short necks (Table 6.34). Furthermore, when neck technique and motif are compared (Table 6.35) it becomes clear that triangle motifs are predominately created using incising or a combination of incising and stamping, while horizontal motifs can be created using either technique, and oblique and plait motifs are created using stamps in all but one case. This pattern fits with the notion that elongated necks might have been thought of as a different zone on the vessel from the rim, and that potters were comfortable switching to a different technique between rims and necks.

Table 6.32: Decorative techniques used on the necks of vessels.

Neck Main Technique	Frequency	%
Incised	19	44
Stamped	16	37
Combination	8	19
Total	43	100

Table 6.33: Neck main technique sorted by rim construction method

Rim construction method	Incised	Stamped	Combination	Total
Folded	6 (40%)	7 (47%)	2 (13%)	15
Added clay	6 (55%)	4 (36%)	1 (9%)	11
Fold and added clay	1(13%)	4 (50%)	3 (37%)	8
No fold or added clay	3 (60%)	1(20%)	1 (20%)	5
Unidentified	3(75%)	0	1 (25%)	4
Total	19	16	8	43

Table 6.34: Neck main technique sorted by neck shape. Indeterminate neck shape values were omitted.

Neck shape	Incised	Stamped	combination	Total
Short	8 (30%)	14 (52%)	5 (18%)	27
Elongated	9 (64%)	2 (14%)	3 (21%)	14
Total	17	16	8	41

Table 6.35: Neck motif sorted by neck technique.

Neck technique	Triangle motifs	Horizontal motifs	Oblique motifs	Plait motifs	Total
Incised	13 (69%)	5 (26%)	1 (5%)	0	19
Stamped	1 (6%)	6 (38%)	6 (38%)	3 (18%)	16
Combined	7 (88%)	1 (12%)	0	0	8
Total	21	12	7	3	43

6.4.3 Punctates and Bosses

A variable that the micro-CT scans are particularly well suited to explore is the use of punctates, which are fairly deep stamps or punctures into the wall of the vessel, usually appearing as a single row across the exterior or the interior of the vessel within or immediately below the upper rim. Usually, the opposite side of the punctate also exhibits bossing, which is a rounded rise in the vessel wall (Mather 2015:111). Punctates are a common decorative element on ceramics broadly during this time period across southwestern Ontario, and are present on 52 (78%) of the 67 Arkona vessels examined for this study. Twenty-one (40%) of these vessels exhibited interior wall punctates, while 31 (60%) of these vessels exhibited exterior wall punctates.

The micro-CT scans were particularly useful in exploring the directionality of punctates based on an examination of slices along the Z axis. These slices were generally aligned through the middle of the punctate, and directionality was measured as straight, right, or left from the middle of the punctate (Figure 6.59). Of the 52 specimens examined, I found that 36.5% of punctates were straight, 38.5% were pointed to the left, and 25% were pointed to the right (Table 6.36). Though some punctates within a specimen were slightly more or less angled than others, and some of them were only slightly angled left or right, I did not observe differing punctate directionality within any given specimen or vessel; both right and left punctates were never observed together.

Angularity of punctates could be suggestive of which hand an artisan held the stylus making the punctate (i.e., left hand for right-angled punctates; right hand for left-angled punctates). This suggestion assumes the potter moved the vessel while applying the punctates rather than reached around from a fixed position, and assumes the vessel was upright while being decorated (which the presence of fingerprints on interior bosses supports). It is also worth noting that almost half (48%) of the interior-applied punctates are straight, while only 29% of exterior-applied punctates are straight. This difference may imply a more careful application of punctates in the interior, perhaps due to the relative awkwardness of reaching in to do so, compared to the relative ease of applying punctates to the exterior of the vessel.

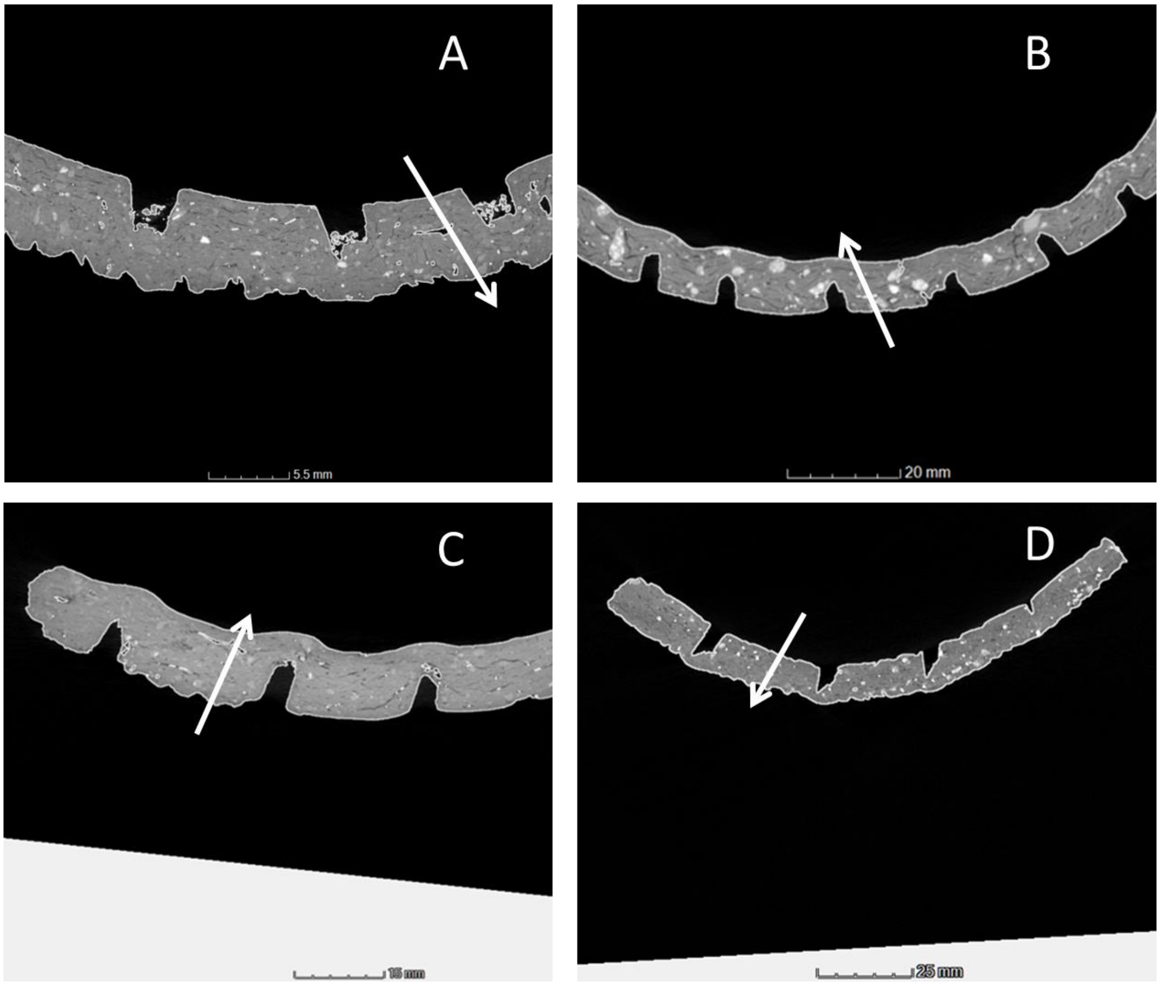


Figure 6.59: Punctate directionality. A: Left interior directionality. Debris or dirt seen at the interior of punctates in this example is left over from site context. B: Left exterior directionality. C: Right exterior directionality. D: Right interior directionality.

I measured the maximum depth of punctates and the shape of the tool used; both of which are easily visible in CT scan slices on the Z plane. Slicing through this decorative element gave a fuller picture of its shape and depth than simply looking at punctates straight on from the exterior of the punctate. I was able to use the caliper tool in VGStudio MAX to measure the depth from the exterior of the vessel to the deepest part of the punctate (Figure 6.60). Because this is not a commonly recorded decorative attribute, I originally chose to just eyeball an "average punctate" for each specimen and took the depth for that one punctate. The punctates measured vary in depth from 2 mm to 13 mm, although 82% of punctates fall between 3-9 mm in depth (Table 6.37). These depths clearly distinguish

Table 6.36: Punctate directionality for Arkona vessels

Punctate Directionality	**Frequency**
Straight interior	10 (19%)
Straight exterior	9 (17%)
Straight total	19 (36.5%)
Left interior	7 (13%)
Left exterior	13 (25%)
Left total (right handed)	20 (38.5%)
Right interior	4 (8%)
Right exterior	9 (17%)
Right total (left handed)	13 (25%)
Total	52

punctates from the application of incising or stamped decoration on vessel surfaces, which are far shallower on average – generally less than 2 mm deep. Upon further reflection, recording depth for a single punctate did not allow me to account for variability in depth across punctates within a specimen. So while not as useful a measurement as recorded currently, a more thorough documentation of depth could allow for an exploration of variation in the application of artisan decorative techniques across a single vessel. In turn, recording the regularity of punctate placement and depth could provide insight in to the ingrained hand motions used by craftspeople, and how skilled craftspeople do not count out steps in craft, like applying punctates, but establish a rhythm of application using their trained eye (Sennett 2008:176).

The tools used to make punctates vary. To record punctate tool form, I followed Watts' (2006:121 Figure 5) tool variables to divide the pointed instruments into round, elliptical, polygonal or annular by examining the 3D image of the exterior of the ceramic, and the front-on slice through the Y plane (Figure 6.61). I further examined slices through punctates in both the X and Z planes to determine the shape of the tip of the instrument.

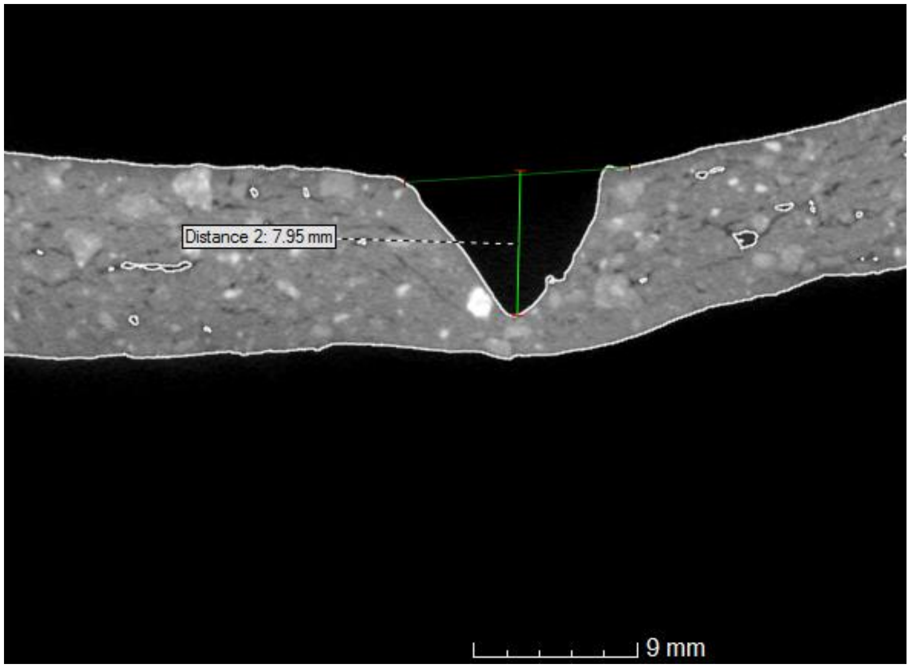


Figure 6.60: Using the digital caliper to measure punctate depth.

These observations were sorted into rounded, blunt, pointed and bifurcated categories (Table 6.38, Figure 6.62). When the tool appeared bifurcated in only the X or Y plane, and not both, I recorded both tooltip shapes (Figure 6.63). Elliptical tools are the most common tool shape making up 66% of the sample. The remainder of the sample consisted of round (24%), and polygonal (8%). Tooltip categories included bifurcated (32%), rounded (25%) pointed (25%), and blunt (16%). While a preference for elliptical and rounded tools is clear, the tip shape of the tool is more evenly split suggesting, not surprisingly, that the resulting shape of the punctate, as viewed from the exterior of the ceramic, was more important than the type of tool used to create it. Based on variation in the size and shape of the punctates left by tools, I did not note the repeated use of the same tool on more than one specimen. The lack of repeated tool use suggests tools used to create punctates may have been expedient, and that they were not shared between artisans.

Table 6.37: Punctate depth for Arkona vessels

Punctate Max Depth	Number of specimens	%
2-3mm	2	4
3-4mm	4	8
4-5mm	7	13
5-6mm	7	13
6-7mm	10	19
7-8mm	9	17
8-9mm	6	12
9-10mm	2	4
10-11mm	2	4
11-12mm	1	2
12-13mm	2	4
Total	52	100

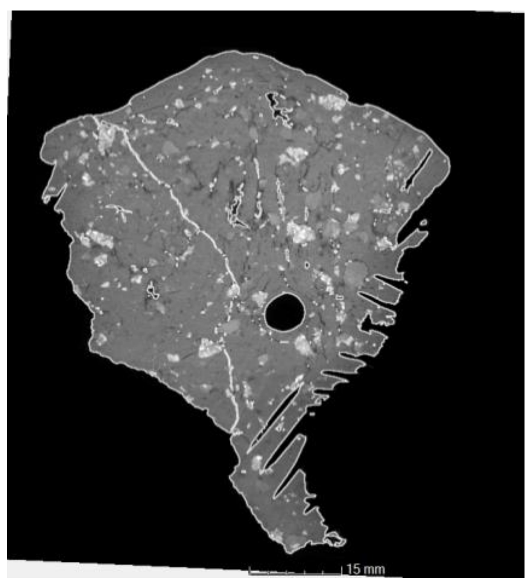


Figure 6.61: a round punctate in Specimen 038 viewed in a slice through the Y plane.

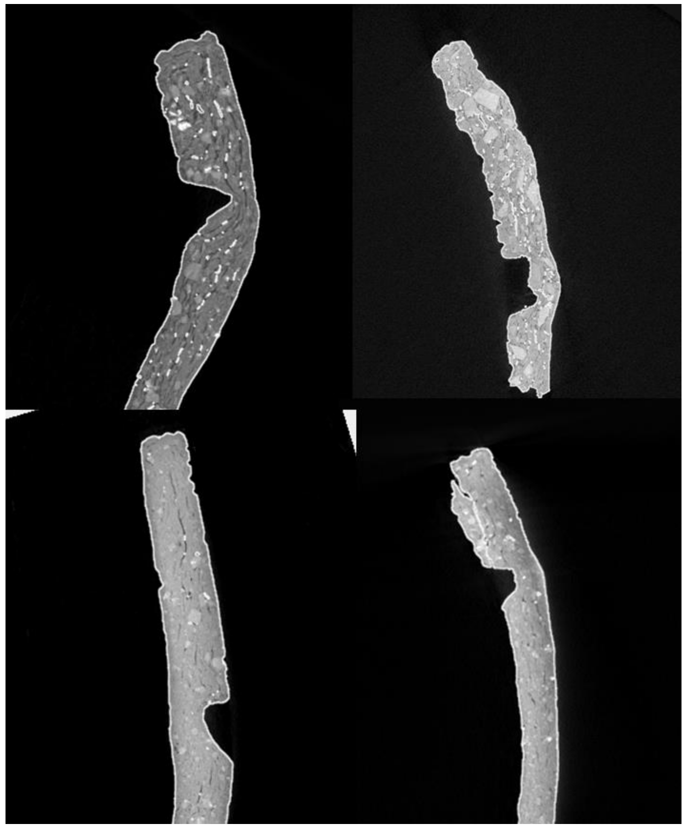


Figure 6.62: Tooltip shape in slices through the X plane. Top left: pointed (Specimen 041), top right: bifurcated (Specimen 016), lower left: rounded (Specimen 096) and lower right: blunt (Specimen 054). Not to scale.

Figure 6.63: Specimen 040 - a round tool with a tip that appears blunt in the slice through the Z plane and bifurcated in the slice through the X plane.

Table 6.38: Punctate shape/tool type for Arkona vessels.

Punctate shape	Number of vessels	%
Elliptical, rounded	12	23
Elliptical, blunt	3	6
Elliptical, blunt bifurcated	4	8
Elliptical, pointed	10	19
Elliptical, bifurcated	5	10
Polygonal, blunt	2	4
Polygonal, pointed	2	24
Round, blunt	3	6
Round, blunt and bifurcated	6	12
Round, rounded	1	2
Round, rounded and bifurcated	1	2
Round, pointed tip	1	2
Other	2	4
Total	52	100

I measured the distance from the lip of the vessel to the punctate as one decorative variable to explore if these deep decorative elements line up with rim manufacturing techniques (Figure 6.65). The majority (63%) of punctate rows tended to cluster tightly together in terms of distance from lip, situated between 25-39 mm below the lip (Table 6.39, Figure 6.64). More generally, 85% of all punctate rows fell within 15 and 44 mm of lip, which underscores that punctates are an upper vessel technique, though needing to be below the lip enough to not alter the rim or lip form. This prevalence of application placement may be simply a stylistic design choice. However, I wonder if punctate placement may also assist in pushing or compressing layers of clay together, such as the layers created when folding or applying clay to form the rims. I did check to see if there might be a higher frequency of punctates on the folded rims and rims with added clay, but there was a consistent use of punctates across all rim forming techniques. Punctates are prevalent in the Arkona Cluster, appearing on 52 of the 67 specimens sampled, and appear on between 75-80% of all vessels regardless of rim forming technique (Table 6.40) Considering 93% of the sample had stamping used as the main exterior rim decorative technique, these punctates could be simply be a form of decorative stamping, because that was the decorative tradition present at Arkona. However, considering most of the sample was made up of specimens that had additions of clay, folded over clay, or both in their rim sections, the appearance of punctates on most of the collection does not preclude them from also, or as needed, serving a functional utility to compress these layers of clay together.

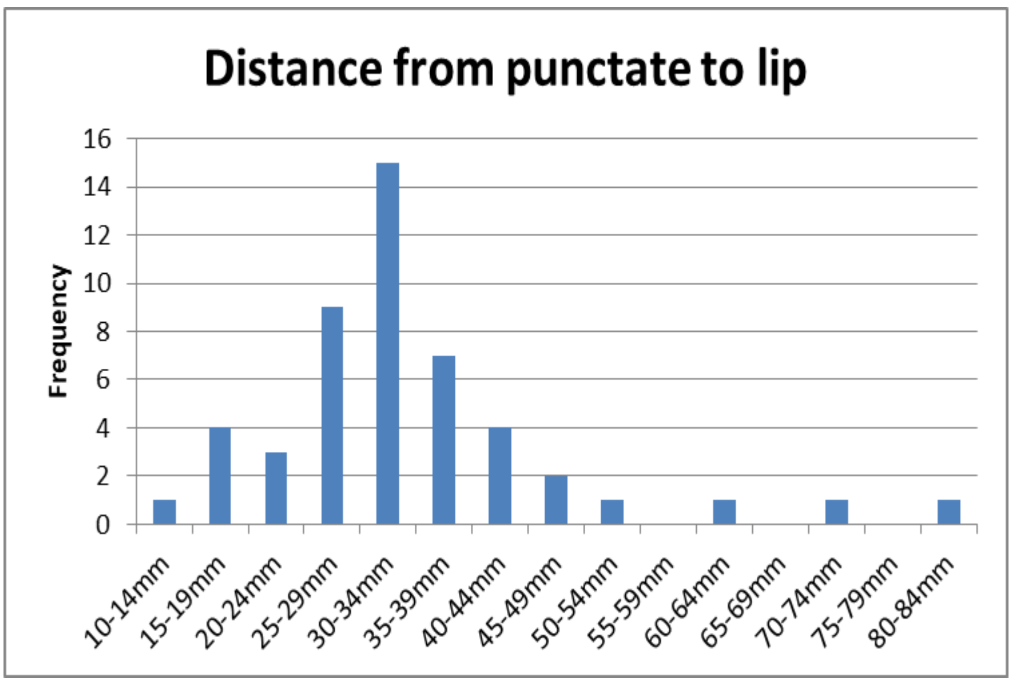


Figure 6.64: Distribution of punctate distances from lip.

Table 6.39: Punctate distances from lip. Note the total here is 49 and not 52, because I could not take this measurement on neck sherds that had punctates, where the lip was not intact.

Punctate distance from lip	Frequency	%
10-14mm	1	2
15-19mm	4	8
20-24mm	3	6
25-29mm	9	18
30-34mm	15	31
35-39mm	7	14
40-44mm	4	8
45-49mm	2	4
50-54mm	1	2
55-59mm	0	0
60-64mm	1	2
65-69mm	0	0
70-74mm	1	2
75-79mm	0	0
80-84mm	1	2
Total	49	100

Table 6.40: Punctate presence in correlation with rim construction method.

Rim construction method	Punctates present	Total number of vessels	%
Folded	21	27	78
Added clay	12	15	80
Fold and added clay	10	13	77
Plain	6	8	75

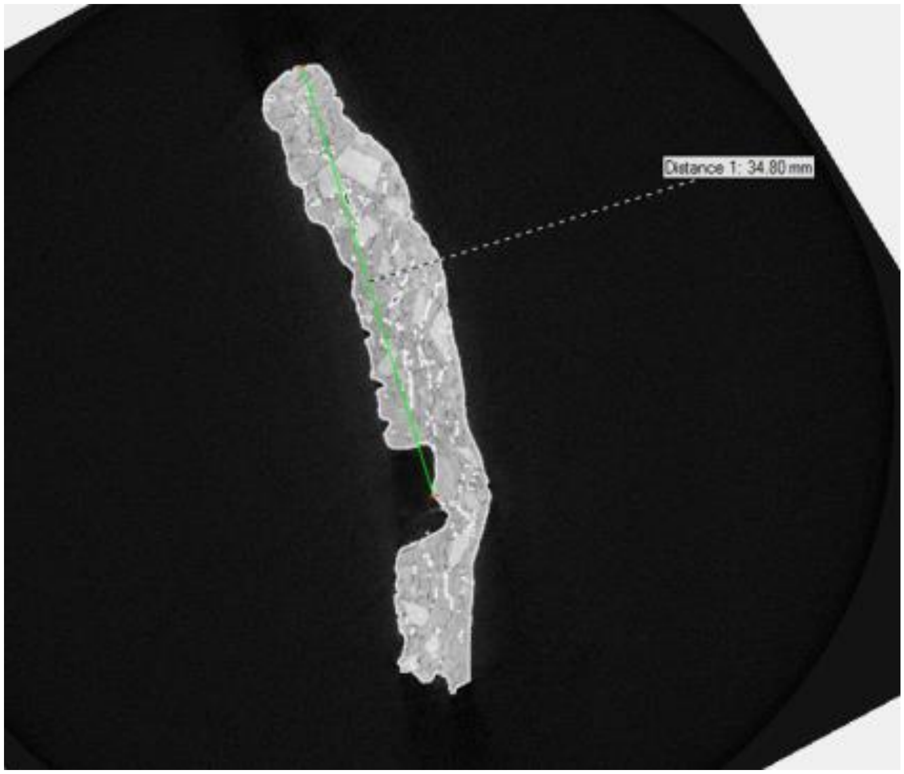


Figure 6.65: Specimen 016. Measuring the distance from the lip of a vessel to the punctate (Specimen 016). Note also the displacement of clay opposite the exterior punctate, creating interior bossing.

Punctates appear on between 70-100% of the vessels scanned for each site, with the larger samples from AgHk-42 (Bingo Village) and AgHk-42 (Figura) exhibiting the lowest percentages of punctates present (Table 6.41). While exterior and interior punctates are present at all sites with more than one specimen, generally, exterior punctates are more common, except in the sample specimens from AgHk-32 (Van Bree) and AgHk-54 (Inland West Loc. 3).

Forty-one (79%) of the 52 Arkona vessels with punctates also exhibited bosses on the vessel wall opposite from the punctate. In micro-CT scans (see Figure 6.65, 6.66 and 6.67), bosses appear as a displacement of the vessel's fabric caused by the creation of the punctate. Of the 21 interior punctated vessels, 18 (86%) exhibit bosses on the exterior wall, while 23 (74%) of the 31 exterior punctated vessels exhibit bosses on the interior

(Table 6.41). All sites with more than one punctated vessel exhibited both interior and exterior bosses. While the presence of bosses, especially exterior bosses, have been used as an indicator of temporal or material cultural difference (see Dodd et al 1990; Murphy and Ferris 1990; Williamson 1990; Wright 1966), in the Arkona Cluster, bosses on vessels seem to be the result of the widespread use of deeply impressed punctates as decorative features on both the exterior and interior walls of these vessels. Whether because this was a traditional technique passed down from potter to potter, or as an effective method of pushing layers of clay together, punctates and bosses are a visible example of potters' interactions with clay when forming and finishing a vessel. The application of pressure deep enough to create punctates with bosses on the opposite wall breaks up large void structures in the interior of vessels, interrupting these potential breaking points caused by adding clay or folding over clay in the rim forming process (Figures 6.66 and 6.67). This application, in turn, thus potentially strengthened the rims of these pots.

Table 6.41: Punctates and bosses present by site.

Site	Exterior punctates	Interior punctates	Interior bosses	Exterior bosses	% of sample with punctates
AgHk-32 Van Bree	3	5	3	3	8/10 (80%)
AgHk-40 Bingo Pit Loc. 3	3	2	3	2	5/5 (100%)
AgHk-42 Bingo Pit Village Loc. 10	10	4	7	4	14/20 (70%)
AgHk-52 Figura	7	4	6	3	11/15 (73%)
AgHk-54 Inland West Loc. 3	3	4	1	4	7/9 (78%)
AgHk-56 Inland West Loc. 6	1	0	1	0	1/1 (100%)
AgHk-58 Inland West Loc. 9	4	2	2	1	6/7 (86%)
Total	31	21	23	18	52/67 (78%)

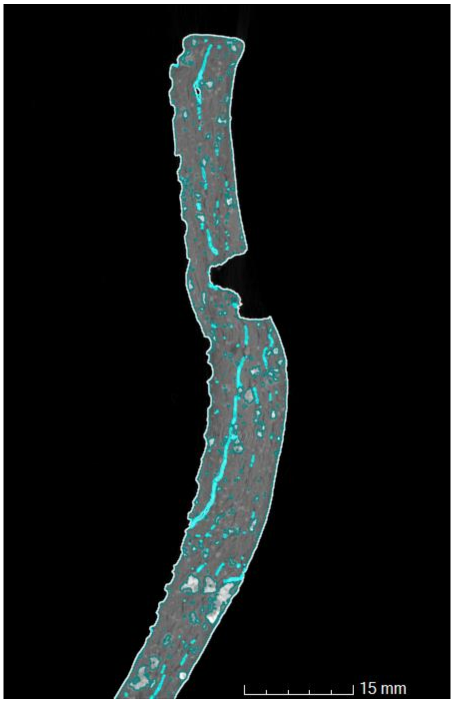


Figure 6.66: The large vertical void structure in Specimen 008 caused by adding clay to the rim is broken up by an interior punctate. The potter applied pressure or compression to create this feature. The small bump opposite the punctate is an exterior boss.

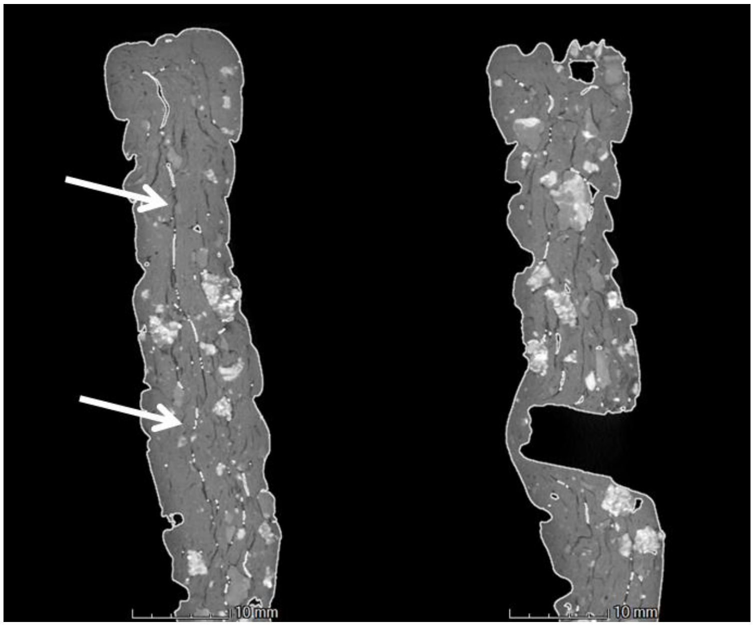


Figure 6.67: The large vertical void structure in Specimen 038, highlighted by arrows at the left, is pushed outwards and broken up by the pressure of an interior punctate at the right. The small bump opposite the punctate is an exterior boss.

Fingerprints found on bosses in the Arkona collection speak to the care that went into the application of punctates. Potters had to support the vessel wall opposite of the punctuate as they applied pressure to create these deep punctures, and this pressure left visible traces of this interaction between the potter and the clay (Figure 6.68). I noted fingerprints on 12 (16%) of the Arkona specimens included in the study, (Specimens 008, 063, 070, 101, 105, 119, 016, 011, 020, 038, 044 and 048). There might be more fingerprints present on the specimens scanned, as this was not a feature I was recording methodically. Also, I was only examining sherds and not vessels, so this feature is almost certainly underrepresented. Of the fingerprints identified, all were noted on bosses opposite punctates; six on exterior bosses and five on interior bosses. This suggests that potters were manipulating the vessel in such a way that they were supporting their punctates regardless of whether they were working from the interior or exterior of the pot, and suggests that pots were decorated right side up as it would be easier to reach into a pot to leave fingerprints on the interior. These fingerprints speak to the movements involved in the placement of punctates, the manipulation of the rim section of the pot and clay by the potter and the care, or lack of care, that went into erasing such smudges or small blemishes caused by decorative finishing gestures. Future work with fingerprints at Arkona could potentially compare prints to identify repeated work of individual potters.

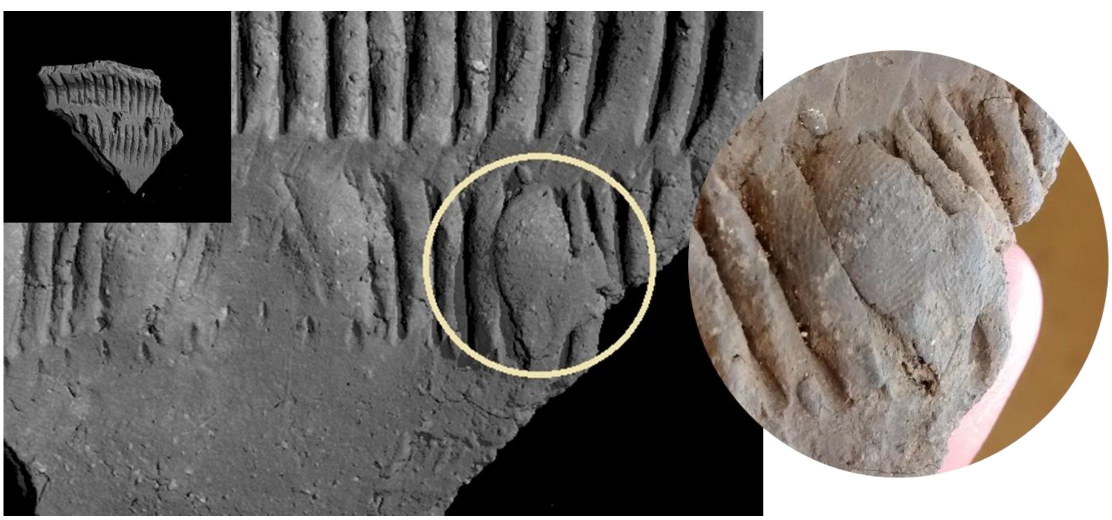


Figure 6.68: Fingerprint on Specimen 048 on an interior boss, seen both in a micro-CT scan (center image) and photograph (enlarged circle), found opposite deep exterior punctate (top left insert).

6.5 Other Clay Objects

A small sample of clay objects separate from the 67 vessels were scanned and underwent some limited analysis. These objects include clay pipes and small miniature or learner vessels from Arkona, as well as ceramic vessels from seven other Late Woodland sites in southern Ontario. The purpose of scanning these objects was to further explore the potential of micro-CT analyses on multiple types of ceramic materials and to explore how these materials might differ from the pots at Arkona. These samples were not large enough to offer substantial findings concerning the manufacture of clay pipes or learner pots at Arkona. However, micro-CT scans of these Arkona objects did illuminate individual artisan techniques and the process that went into making these clay objects. These preliminary results, then, offer much promise for future work. The results from the southern Ontario ceramic sample failed to offer further insights into micro-CT applications examining Ontario ceramics, and did not provide additional insight into Indigenous potting across Ontario, and thus will not be discussed further The Ontario sample was too small (one or two pots from each site) and the contexts were too varied to make meaningful inferences about ceramic manufacture. Refer to Appendices B and D for some basic information about those scans.

6.5.1 Arkona Cluster Clay Pipe Manufacture

I was able to scan five pipes from the Arkona Cluster sites to try and develop a preliminary understanding of clay pipe fabrics and craft, and the degree to which that differs from vessel manufacture. The five pipes scanned included four from AgHk-42, and one from AgHk-52. They were selected at random, with little knowledge about the pipe assemblage at Arkona, in a preliminary attempt at examining ceramic materials other than pots. The pipes from Arkona were more fully examined by McCartney (2018). I was able to compare descriptions of their exteriors in McCartney's work to what I was exploring in the interior of these specimens. Images of all pipe specimens scanned appear in Appendix A.

Pipes scanned included Specimen 086 (catalogue number 1103), "an obtuse angled pipe with a single row of punctates near the lip of the bowl, and a cluster of smaller punctates that face the smoker" (McCartney 2018:77). In the scans it appears there were two attempts at creating the borehole. There also may be a slab of clay at the base of the pipe that was connected to the bowl (Figure 6.69). Inclusions account for 7% of the volume of this specimen.

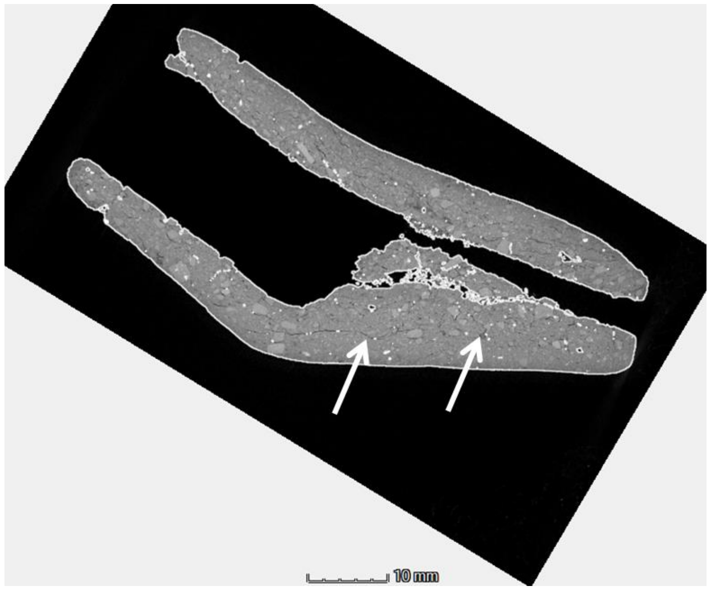


Figure 6.69: Specimen 086 illustrating two possible attempts at creating the borehole, the first of which (lower) was mostly sealed when pressure was applied while creating the second (upper). Arrows illustrate the void where there might be a join in the clay near the base of the pipe, reflecting the possible addition of clay.

The second pipe scanned (Specimen 087, catalogue number 9749) is described as a "plain, right-angled pipe with a wide, flat ventral surface and a rectangular stem cross section" (McCartney 2018:77). The scan revealed up to five attempts at creating the borehole, with what might be a slab of clay at the base of the stem portion of the pipe. It also looks like there might be a second layer of clay added at the interior of the pipe bowl used to patch or smooth the construction and a potential join between the upper stem and the bowl (Figures 6.70 and 6.71). I note that this pipe looks similar to learner vessels in terms of its void structures because they are irregular and vary in direction, possibly made by pinching, moulding motions similar to a pinch pot technique.

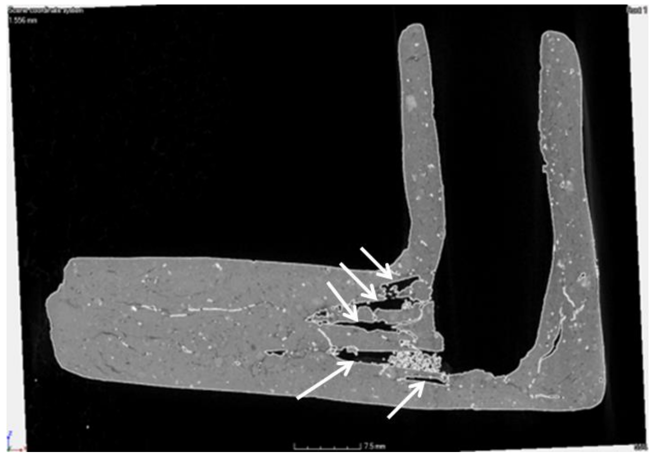


Figure 6.70: Five attempts at creating the borehole in Specimen 087 are each marked with an arrow. The fourth arrow down represents the borehole that the artisan decided to leave open for use. Some debris can be seen in this hole that was open. This debris is likely from either use or deposition.

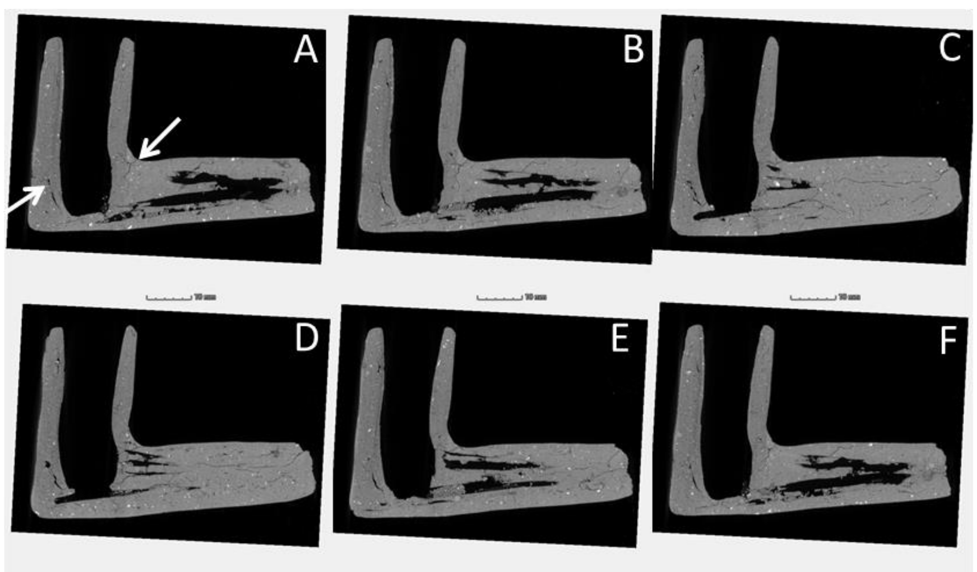


Figure 6.71: Sequential slices through the Y plane of Specimen 087. Arrows in image A highlight voids in areas where the clay in the bowl was joined together or patched. Scars from several attempts at creating the borehole are visible, although not all five are visible at once since they fall in different places along the plane. The top three boreholes never puncture the interior of the pipe bowl. The lowest borehole intersects with the fourth and final attempt, as seen in image F. In image C and D, it is visible where the implement overshot and went into the opposite side of the bowl. Debris can be seen in the lowest two holes, as the fourth down remained connected to the bowl as the functioning or "successful" borehole, and it intersected the lowest borehole in its creation.

Specimen 088 (Catalogue number 1682) is only the stem portion of a pipe, and while it has voids that may be joins between pieces of clay, I could not determine the method of manufacture (Figure 6.72). It did not exhibit any failed attempts at borehole construction.

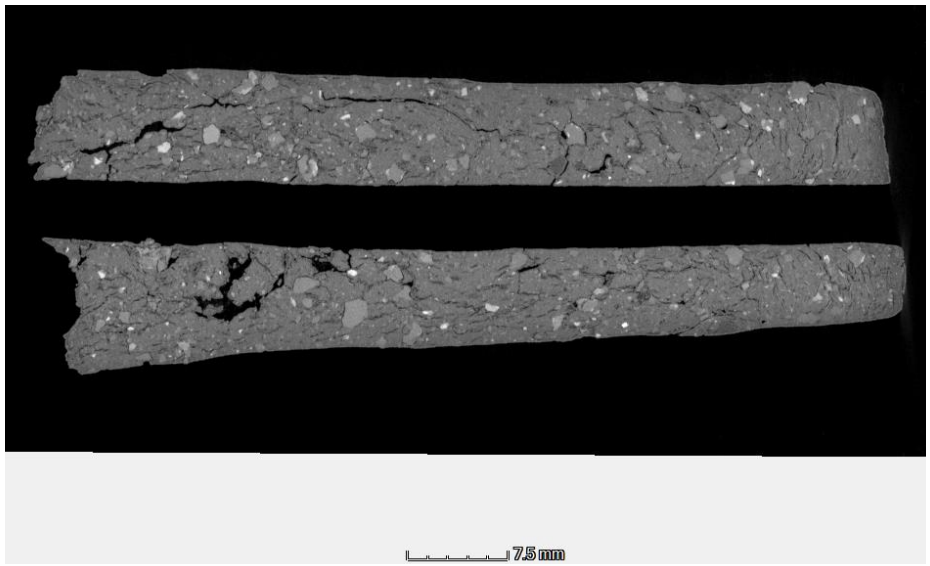


Figure 6.72: A slice along the pipe stem of Specimen 088. Fabric appears to be tempered based on the presence of angular inclusions.

Specimen 103 (catalogue 13129) consists of a pipe bowl. While McCartney (2018:76), described this specimen as a "separate stem bowl, which consists of the pipe bowl with a large borehole drilled at the base for inserting a reed stem," the micro-CT scan indicates this bowl was actually a more conventional elbow-shaped pipe, with the bowl broken off from the stem at the elbow. In scans, there is one large void where the exterior of the bowl and base of the bowl might have been joined to the elbow and base of the pipe (Figure 6.73). Inclusions account for 2% of fabric volume in this specimen.

The final pipe scanned is from AgHk-52 and is Specimen 089 (catalogue 1257). McCartney (2018:56) notes that it is different from other pipes in the Arkona assemblage: "It is an obtuse angled pipe that bends on a curved line, rather than the sharper elbow of other obtuse angled pipes. It features a dramatic outflare bowl that bears a strong resemblance to a trumpet flower, and its stem is decorated with an incised line that coils around." In the micro-CT scan there are visibly fewer voids in this specimen than the other pipes scanned, suggesting a differing method of manufacture or drying (Figure 6.74). There is one small void across the out flaring bowl, but this is from mending done by archaeologists and may or may not represent a join where the artisan merged pieces of clay.

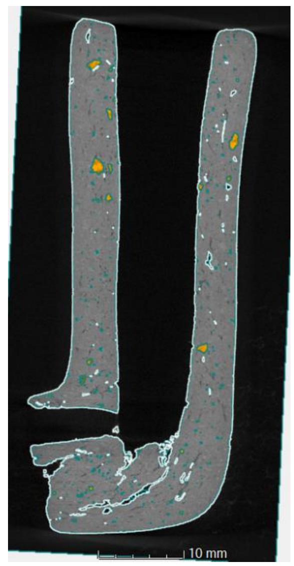


Figure 6.73: Specimen 103 exhibited one large void at the elbow of the pipe that may be where pieces of clay were joined in manufacture. Inclusions are highlighted in orange and account for only 2% of the total fabric volume.

The fabric for all the clay pipes looks different from the fabric I was familiar with for the "standard" Arkona vessels. The clay pipes all have inclusion percentages of less than 10%, and three of the five examples scanned have less than 5% inclusion volumes (Table 6.42). This range in volume percentages differs from the vessels in the Arkona sample, where 91% fell above 5% inclusion volumes. Specimens 088 (Figure 6.72) and 086 (Figure 6.69) appear to be tempered, and exhibit fabrics that seem more similar to the fabrics of ceramic vessels in the sample. Specimens 087 (Figure 6.70), 089 (Figure 6.74) and 103 (Figure 6.73) have noticeably fewer inclusions, and lack of angular inclusion fragments, which suggests these fabrics were either tempered differently from pots or were not tempered at all. The preparation of fabrics for making clay pipes thus appears to be a separate process from the preparation of fabrics for making clay pots in the Arkona Cluster, at least some of the time.

Figure 6.74: Specimen 089 exhibited fewer voids than other pipes. The void joining two pieces of clay on the bowl of the pipe at the top left of the image is the result of archaeologists mending this pipe bowl.

There was a lot of variation in void volume percentages for the five pipes I scanned (Table 6.43). In microcosm this variation encompasses the range of void percent volumes seen across Arkona vessels. But void volume percentages for these pipes in part appear to be caused by errors and efforts to construct a borehole along the stem, and in joining the bowl. Notably, it appears as though stem boreholes were created using a pointed tool forced through the stem, after the stem and bowl had been formed. This practice appears to have caused errors, since two of the five pipes exhibit repeated efforts to create that borehole. Creating boreholes may have also caused damage at the join of the bowl to the stem, which may account for instances of clay being added to repair this damage. The micro-CT scans readily reflect the agency of the clay and its material properties coming into play within the artisan’s craft, especially given the choice to create a borehole after forming the stem.

Table 6.42: Volume percentages of inclusions in clay pipes

% Inclusions	Number of Pipes
0-5%	3
5-10%	2
10-15%	0
15-20%	0
>20%	0
Total	5

.

Table 6.43: Void volume percentages in Arkona clay pipes.

% Voids	Number of Pipes
<1%	0
1-2%	2
2-3%	1
3-4%	1
4-5%	0
5-6%	0
6-7%	1
Total	5

In other studies, pipe fabrics are consistently distinct from pottery vessels during the Late Woodland by generally having smaller temper/inclusion volume frequencies (e.g., Braun 2012), so the Arkona examples are consistent with that more general pattern. Further research into the experiential qualities of the use of smoking pipes compared to cooking in vessels and degree of variability in the forming and finishing of this distinct ceramic object class, all require further consideration. However, the preliminary micro-CT results presented here offer a real promise of gaining new insights into this craft. Insights on pipes are further discussed in Section 7.2.5.

6.5.2 Arkona Cluster Learner Vessels

I scanned three learner vessels from Arkona sites, all three of which were from AgHk-54 (Specimens 012, 013 and 014). I conducted these scans to explore the potential for future micro-CT work on learner vessels in Ontario and elsewhere. The three learner vessels I scanned from Arkona have lower inclusion volume percentages than are typical of the full-size vessels (between 5-15%), with all of the learner vessels falling between 1-3% inclusion volumes. Voids volume percentages for the learner vessels ranged between 2-4%, which is typical of full-size vessels at Arkona.

In Specimen 012, I noted large voids throughout the vessel, suggesting it might be a pinch pot, but with some added clay at the rim (Figure 6.75). This vessel had only a 1.8% inclusion volume, suggesting it might not have been made from tempered clay. The exterior of the rim had one band of stamped linear right obliques, a common element found in the Arkona Cluster sample.

Specimen 013 scans appeared to show a rim that was folded to the interior or had clay added to the interior to form the rim. This vessel had 2.2% inclusion volume, and the inclusions present appear as relatively large and low density when compared with full-size vessels. I also noted that there was a large amount of void spaces that appeared to be created by an organic temper added to the fabric of the clay, either intentionally or unintentionally during manufacture (Figure 6.76). Alternately this fibrous material could have been in the clay when harvested and then not sieved or processed out, which would align with the presence of large inclusions. Exterior decoration includes a band of roughly incised triangles, a band of incised linear horizontals and a band of what appears to be stamped right oblique designs. This decorative motif may be an attempt to replicate the open diamond or triangle designs seen on the neck of many Arkona vessels.

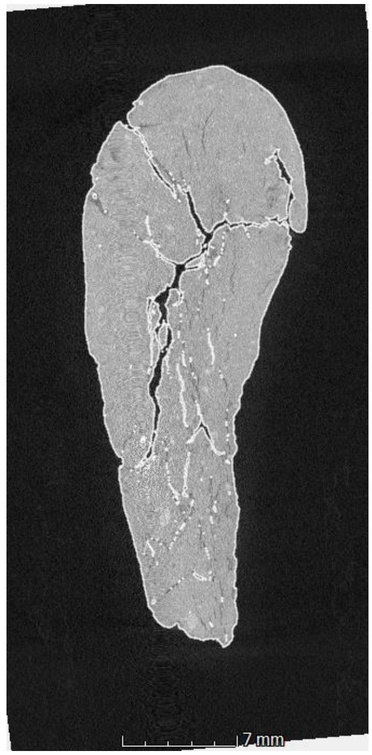


Figure 6.75: Specimen 012 exhibiting large voids throughout the rim, with pieces of clay potentially added to the front and top of the rim to form it. The fabric has few inclusions and lacks large angular inclusions.

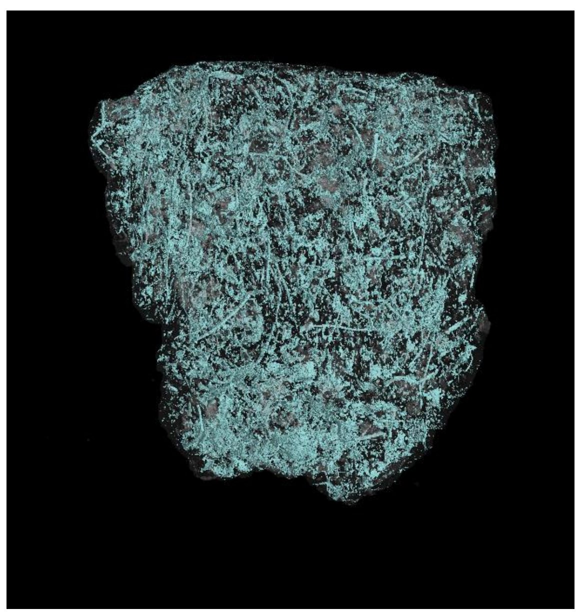


Figure 6.76: Specimen 013 with void structures highlighted in 3D, showing many fibre or hair-like structures.

In Specimen 014, I noted that voids suggested it might be a pinch pot, but I was unclear about construction techniques. This specimen had the highest inclusion volume percentage of the learner vessels at 3.1%, but the fabric still did not appear similar to that of any of the full-size vessels (Figure 6.77). Decoration on the exterior was made up of one band of linear, mostly like incised vertical lines. This pattern appears similar to the decoration I observed on Specimen 012, but without the oblique angle.

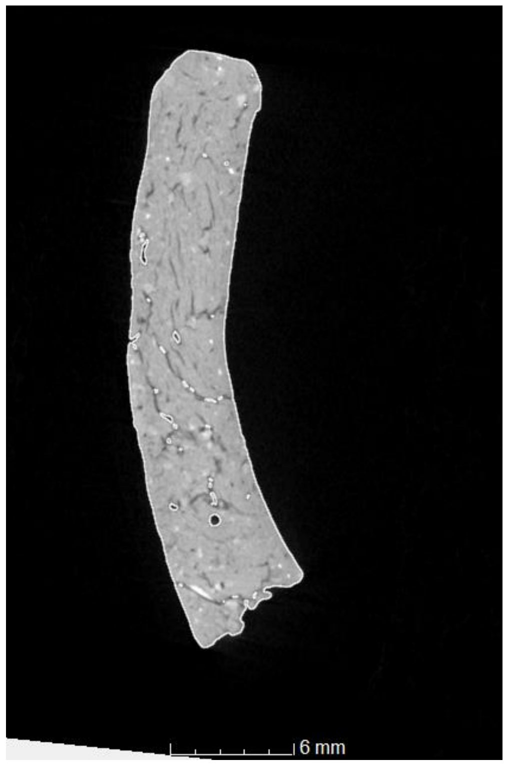


Figure 6.77: Specimen 014 with void structures suggesting pressure applied from both the interior and exterior of the vessel, perhaps indicating a pinch pot. The fabric has few inclusions and lacks large angular inclusions.

As suggested elsewhere (Howie 2012; Retter 2001; Smith 2005), manufacturing might be one of the first steps learned when making pots, while preparing clay fabric recipes and learning to decorate and finish pots was learned later. These three vessels from Arkona have evidence of some of the folding and adding clay techniques that are used on full size vessels, but the clay fabrics have fewer inclusions, and in the case of Specimen 013, unique organic material mixed through the clay. All three lacked the typical angular, granitic-looking inclusions of the larger vessels that suggest intentional tempering.

Learning potters had a sense that their pots should be decorated in some way at the exterior of the rim, and used decorative elements and applications seen on the more general vessels. This decorative practice suggests these learner pots were created by potters who were participating in the larger Arkona potting community, and learning to decorate and finish pots at the same time they were learning to form vessels.

Presumably, for the less finished, learner vessels, a lack of temper could also suggest a lack of concern for a successful firing or for any subsequent functional use of the object. Indeed, if the focus of making learner vessels was to practice forming and perhaps finishing, inclusion volume percentages may suggest a means of distinguishing between ceramic objects made just for the intent of making, and smaller vessels made with some post manufacture functional intent in mind, since both learner and miniature vessel forms are found on Late Woodland sites (e.g., Murphy and Ferris 1990; see also Braun 2010).

6.6 Petrography versus Micro-CT Comparison

As I worked through the data acquired from CT scans, especially the data related to clay fabric preparation, it became increasingly clear that simply using metrics from petrography to explore the 3D data was problematic, and that these are two complementary but very different techniques. To investigate my suspicion that these two methodologies offer compatible, not comparable datasets, I conducted a brief comparison of petrographic thin section representativeness with micro-CT volumes. This type of comparison was also conducted by Kahl and Ramminger (2012:2212). They effectively compared the results of 2D slices and 3D images in determining percentages of temper in a sherd, and demonstrated that the sampling position for thin section selection had a significant impact on these results. As my inquiry was exploratory, and the process of creating several regions of interest was time-consuming, I only conducted this analysis on one specimen.

For this comparison, I used data from one sherd that is typical of the collection (Specimen 048). I used thresholding to isolate inclusions and voids in the 3D volume to obtain void and inclusion volume percentages for the entire specimen. I then created five regions of interest as vertical slices of the entire sherd positioned at 10 mm intervals (Figure 6.78). I extracted these slices, which represent an entire 2D section through the X plane of the specimens (Figure 6.79), and then used the same density thresholds to determine inclusion and void volume percentages within the total vertical 2D slice (Figure 6.79). These are referred to throughout this discussion as *Slices* 1-5. These are useful for comparing 2D to 3D data, but did not accurately reflect the amount of data contained in a typical petrographic thin section since they are larger than a typical thin section.

To create "faux" thin sections, I then positioned a 15 x 50 mm 2D rectangle within each of these five vertical slices (Figure 6.79). This size was used as an approximation of typical thin section area based on images of thin sections (Quinn 2013), and my discussion with an expert in petrographic analysis of Iroquoian pottery (Gregory Braun, personal communication 2019). I positioned these in the vertical slices along the X axis as close to the lip of the vessel as possible, to mimic a thin section position that cut the rim of a vessel, since this is the typical section that petrographers use to examine vessel manufacture and fabric. These are referred to throughout discussion as *Sections* 1-5 (Figure 6.80).

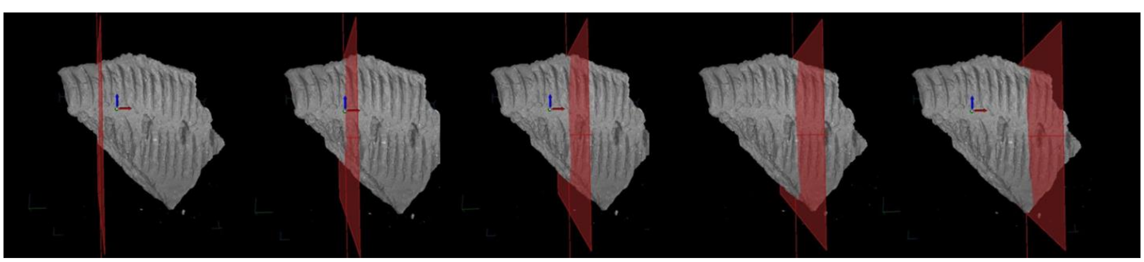


Figure 6.78: 2D slice positions at 10 mm intervals. Slices are at -30 mm, -20 mm, -10 mm, 0 mm and 10 mm along the X axis.

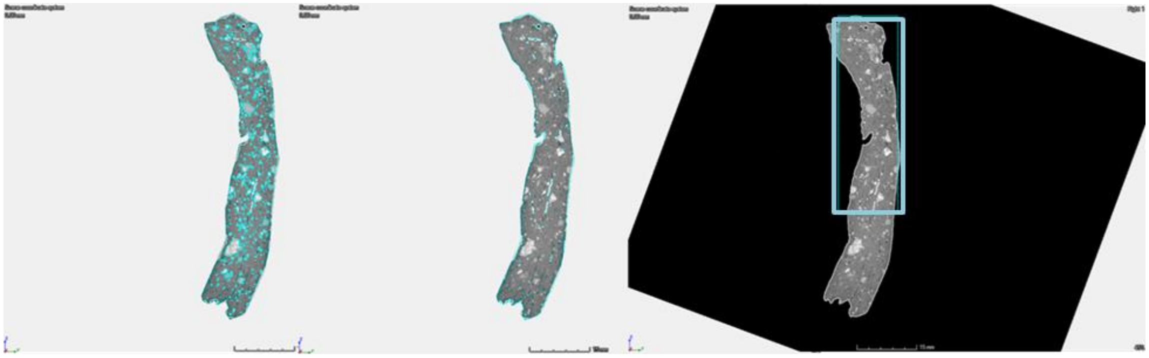


Figure 6.79: Left: Slice 4 at 0 mm on X axis. This image represents the 2D slice along the X plane. In this image, inclusions are thresholded. Center: Slice 4 with voids thresholded. Right: Section 4, highlighting the placement near the lip of the vessel of a 15 x 50 mm rectangle to mimic thin section size.

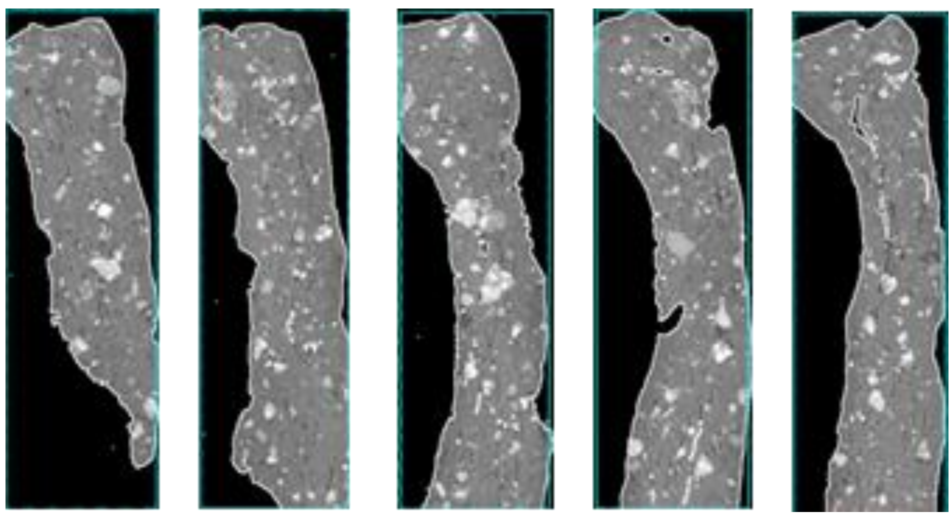


Figure 6.80: Sections 1-5 from left to right. All sections are 15 x 50 mm. Note the visible variability in inclusion and void volume percentages, and the abundance of inclusions that were sliced through in Section 3. Only Section 5 captures a large void created by folding the rim in manufacture.

The result of this exercise was that the 2D measurements tend to overestimate inclusion volume, and slightly underestimate void volume, compared to the 3D volume results (Table 6.44). While I am not entirely certain why this is the case, I suspect the 3D shape of both voids and inclusions comes into play. While the voids in these ceramics tend to be long, planar structures, the inclusions tend to be more spherical. If voids are sliced along their narrow side, as they usually are in a section oriented vertically along the X axis of the rim section, a 2D area measurement will underestimate the actual volume of that void. Conversely, 3D volumes of inclusions may be overestimated slightly from their 2D area, especially when their volumes are small and if they are sliced near to their center point. For example, a sphere with a radius of 1 mm has a volume of 4.19 mm^3, while a circle with a radius of 1 mm has an area of 3.14 mm^2. This difference in volume by shape means that one circular slice through that sphere has an area that only accounts for 75% of the inclusion's actual volume. As such, that slice of the inclusion visible within a 2D plane only makes up a portion of the actual volume measured in 3D. This distinction also suggests the location and direction in which voids and inclusions are sliced has an effect on the viability of area as a proxy for volume, as used in petrography, and actual 3D volume obtainable through micro-CT data.

Table 6.44: Inclusion and void volume percentages in the 3D volume, 2D slices and 15 x 50 mm sections.

Sample	% inclusion volume	%void volume
3D volume	11.98	1.57
Slice 1 at -30mm	13.13	0.78
Slice 2 at -20mm	12.45	0.87
Slice 3 at -10mm	15.20	0.96
Slice 4 at 0mm	13.75	2.18
Slice 5 at 10mm	11.86	1.08
Average for slices	13.28	1.18
Section 1 at -30mm	13.42	0.80
Section 2 at -20mm	13.57	0.42
Section 3 at -10mm	15.92	1.26
Section 4 at 0mm	14.92	1.09
Section 5 at 10mm	12.26	1.21
Average for sections	14.02	0.96

We can also see the influence slice placement has, for example, in the high percentage of inclusions in Slice and Section 3 (Table 6.44 and Figure 6.78), where the slice happened to cut through more inclusions than was typical for the sherd overall. In Late Woodland coarse earthenware, clay is not always perfectly mixed, resulting in pockets of clay with more or less inclusions (Braun 2015). Typically in thin section analysis, to limit damage to the specimen, only one section is taken per sample. While a limited exercise here, my findings suggest that working in tandem with petrography, micro-CT analysis might be able to “correct” for position variation caused by thin section placement. A 3D sample could help suggest the need for further thin sections if numbers are significantly different. However, more work on comparing the data obtained from actual thin sections to micro-CT scans would need to be done, as the data obtained from the two methods currently operates at differing resolutions. While the “faux” sections used here use the same method to pick up inclusions and voids through thresholding as is used in the 3D volume, inclusion and void volumes in thin sections are measured in different ways and any perceived differences may be because of the resolution or methodology used.

Sometimes void structures are visible in petrographic sections of rims, but CT scans give a fuller picture of manufacturing techniques across the entire vessel (or whichever portion of the vessel has been scanned). From any one of these sections, it would be difficult to determine the method of manufacture for this rim section. But the micro-CT data allows the researcher to scroll through thousands of sections and stitch together the voids into their larger, continuous structures illuminating manufacturing techniques in ways that thin sections simply cannot access. While Section 5 of the example examined here captured the large void present in Specimen 048 representing the folding of this rim, the other sections do not illustrate that structure as well (Figure 6.80). Overall, there is more work to be done in illuminating how petrographic and micro-CT data and analysis can be used in complementary ways to advance novel insights into the craft and practice of pottery making.

6.7 Cautionary Tales

There is no question in my mind that issues with the scanning system, the propriety software available to analyze the scans, and my own learning curve undertaking this study posed serious challenges and imposed limitations on what I could accomplish. The process of becoming both technician and researcher - setting up scans, reconstructing them and especially conducting image analysis - took the better part of two years to learn before I was comfortable and competent in both roles, a timeline which was further extended by delays while the micro-CT machine was broken, which were generally weeks or months in duration, not days (see timeline in Appendix F).Without prior X-ray imaging or 3D image analysis training, I found myself learning how to operate the micro-CT system, and use the image analysis software, as I undertook my research, while at the same time attempting to become enough of an expert in Late Woodland ceramics that I could interpret the resulting data. This learning curve was steep, and I was discovering what the micro-CT system and imaging software could and could not accomplish on the fly. As such, choices made early on in the life of this research project, such as obtaining complete scans of entire vessel sections to access large void structures associated with manufacturing methods, meant issues such as adequate resolution for examining inclusions could not be adjusted for later on during the analysis of the scans.

In terms of cautionary tales related to proprietary software, much of the variety and quality of data that can be collected from micro-CT scans is influenced by the type of software that is being used to conduct analysis on those scans. With unlimited access – and adequate training - this could have led to a very different study. I did not undertake an exhaustive exploration of the software available to use in the analysis of micro-CT scans. I completed most of my analysis with VGStudio MAX 2.2 (VG), which was the analytical software selected for the Western University system, so I can only speak to my experience with that program. I also initially tried Object Research Systems Visual (ORS), which was primarily designed for medical imaging, near the beginning of my analysis. However, I chose to focus most of my time on VG simply because learning two software programs, each with steep learning curves, proved too daunting to accomplish while also trying to complete scanning and that analysis. As well, I felt that VG, which is more focused on industrial/non-medical analysis, had the potential to meet more of the analytical needs I might require.

Both ORS and VG are proprietary and require licensing to access the basic software. As well, VG underwent a major upgrade during the time of this study. And, as we learned over the course of this project, VG also requires additional licencing for each of the many add-on modules available for the software, several of which are particularly suited to the analytical queries I wanted to pose of the scans. However, the cost of the modules is prohibitive (i.e., in the tens of thousands of dollars), so in the end I had to be content with working from a 30 day trial of VG 3.0 with access to all of the modules for a limited part of my analysis. During that 30 day window I was able to explore the potential of the fibre orientation analysis (useful for ceramics that had fibre temper, but not for the Arkona collections); a coordinate measurement add-on (useful for “best fit” digital mending procedures and rim diameter measurements); and a porosity and inclusion module (which I would argue is an ideal tool for all ceramic analysis because it easily isolates, counts, and gives both total and individual volumes for voids and inclusions). Access to the porosity and inclusion module provided data on volume, sphericity, quantity and other variables that were not obtainable through VG 2.2. Given the 30 day trial period, much of that time was used in simply familiarizing myself with the new modules and grabbing what data I could. In the end, my analysis based on the full potential of this complete software suite was limited and could only hint at directions for future research.

In the porosity and inclusion module, I used thresholding from templates that I created for both voids and inclusions, but there was also an option of running the VGDefX algorithm for both voids and inclusions, which automatically picked these features out of the fabric. The algorithm created nicer images than the threshold-only option, but took considerably longer in terms of computing time, and tended to miss many of the larger voids in the clay. Notably, the manual for this module stated that the porosity and inclusion algorithm was not designed for complex, multicomponent materials (Volume Graphics 2016), which presumably characterizes low fired ceramics exactly. Given more time with the module, I may have been able to work out how to make that algorithm work for these ceramics; in other words, I could have taught the software to provide what I needed. Time and budget limitations meant this was not possible.

I also experimented with ImageJ, which is a widely used, open-source freeware option often used by researchers undertaking analysis of ceramic fabrics (Braun 2015; Greene et al. 2017; Sanger 2016). When I experimented with ImageJ I found it quite useful for exploring individual 2D slices, but it was quite limited for examining entire 3D volumes. These limitations to the software could be in part because of the limited time I could invest in learning the program.

Dragonfly is an image analysis program by Object Research Systems designed for scientific and industrial data that was released after I had completed the bulk of my data analysis. Licensing is required for commercial use, but “non-commercial licenses are granted free-of-charge to qualified researchers and academics for a period of one year” (Object Research Systems 2020). As such, I was able to complete analysis on a couple of scans using this software, to explore the potential of this program in ceramic analysis. It certainly offers some of the capabilities of the VG 3.0 porosity and inclusion module, such as the ability to sort inclusions and voids by volume, shape and other variables. It has a different workflow to isolate voids and inclusions than laid out in VG 2.2. But the workflow is still based on the basic principles of creating regions of interest (ROIs) based on density or thresholding (called segmentation based on a range in Dragonfly), and then filling these ROIs to include voids, and subtracting them from one another to isolate portions of the clay fabric. These individual ROIs for inclusions and voids can then be split into their components using the analysis tools in Dragonfly. While I found the imaging in the version of Dragonfly I used less impressive than VG, the ability to run volume analysis on voids and inclusions would be enough reason to use it for future research even before considering the potential additional benefits new versions of this software might provide in colour imaging and segmenting. However, like VG, Dragonfly does have a learning curve that should start to be scaled before scanning and undertaking scan analysis.

Chapter 7

7 Interpretations and Conclusions

I set out to leverage the unique insights provided by the micro-CT scanner at the Museum of Ontario Archaeology offered to explore the craft and practice of ceramic making from the Arkona Cluster of thirteenth-century CE archaeological sites. In effect, I adopted two research questions: first, what is the value of micro-CT as a method of ceramic analysis in archaeology, and second, what insights can be advanced about the craft of pottery manufacture from the ceramic assemblages of the Arkona Cluster? Implicit in this research framing is that the second question on ceramic craft is only possible because of what I believe is the relative success achieved in addressing the first question. I thus explore both questions below before summarizing the value of the study in its entirety and suggesting directions for future research.

7.1 Micro-CT Scanning in Ontario Archaeological Ceramic Analysis

This section will discuss the benefits and limitations of using micro-CT analysis on archaeological ceramics, with a focus on the value it can add to studies of Ontario ceramics. The advantages of using micro-CT and the challenges posed by steep learning curves that go along with scanning and image analysis are addressed. The ability to answer research questions related to ceramic manufacture provides a shift in focus from ceramic typological analyses to a more complete understanding of potting practice.

7.1.1 Accessing Internal Features in Three Dimensions

As previously stated, most studies focused on Ontario ceramics (with a few exceptions: e.g., Cheng 2012; Howie 2012; Braun 2012, 2015) emphasize macro examination of exterior surface attributes of vessel sherds. This approach emphasizes the final stage of vessel production – or finishing – in analysis, beyond generally noting the presence and type (i.e., grit vs shell, etc.) of temper visible in fragmented edges. Using micro-CT technology, I was able to explore the interior structures of ceramics from Ontario; something that cannot be done otherwise without destructive analysis. This study represents the first time a researcher working on Ontario ceramics was able to visualize the internal features across a ceramic sherd.

Moreover, CT scanning is the only way to obtain 3D data related to the complete qualitative and quantitative attributes of ceramic fabrics for an entire sherd or vessel section. The volume and 3D architecture of these internal features are inaccessible otherwise, since traditional radiography confounds wall thickness and density in ceramic sherds by collapsing 3D structures into a 2D image (Pierret et. al. 1996). Also, a CT scan offers greater access to otherwise obscured data; in CT scans, crystal faces of inclusions and the shapes of voids are visible (Sanger et al. 2013:837). Other unique features within ceramic fabrics, such as the addition of hair or other types of elongated temper (e.g., Moody 2018), are also visible, as seen in learner vessel Specimen 013. While two dimensional data can be useful for identifying temper density, specific minerology, void distributions, firing practices and manufacturing techniques, the potters making these pots were not thinking in two dimensions when they were mixing their clay fabrics. Potters were more likely thinking about the components of these ceramics in terms of their 3D form and volume in their attempts to create a clay fabric that "felt" right to ensure success (Braun 2015).

The benefits of 3D analysis become immediately apparent when we begin to think about how the potter was interacting with these materials. The ability to isolate and quantify inclusions and voids in ceramic fabrics from micro-CT scan data was illustrated in this study by the ability to compare total inclusion and void volume percentages across all of the specimens used in this study. Further, preliminary results gained from working with micro-CT data on individual inclusion volumes generated by imaging software suggests a promising potential for micro-CT to conduct textural analysis, including grain-size distributions and inclusion shape analysis. This information on the volume percentage of inclusions in clay, and the ability to study the 3D shape and size of inclusions could not be accessed without micro-CT scanning. Throughout my analysis, as I tried to make sense of the data, it became clear that the larger sample size of inclusions in clay fabric accessible through micro-CT, and the use of 3D volumes, rather than 2D areas, differentiates insights into clay fabric obtained through micro-CT from those obtained through petrographic analysis. This difference is no better or worse, just underscores how micro-CT data complements established petrographic findings, and opens new opportunities for inquiry in the material science of ceramic making.

Micro-CT gives us a “big picture” and comprehensive view of ceramic manufacture, both in terms of datasets, and in terms of encompassing the entirety of possible insights accessible from vessel sherds and sections. Micro-CT scans access a much larger area of the ceramic than other techniques used for examining interior structures, yet still provides resolution enough to see micro folds and joins in clay. In this manner, micro-CT scanning has proven extremely useful for identifying primary manufacturing techniques and even variation within these techniques. Primary formation techniques are typically masked by secondary formation and finishing techniques when vessels are examined from the exterior. However, within the internal architecture of a vessel these techniques are not completely erased by later surface treatments, and so are visible in the alignment or orientation of inclusions and temper, and especially void spaces present in the ceramic fabric (Berg 2007:1178, 2008; Carr 1990, 1993:17; Kahl and Ramminger 2012; Middleton 2005; Rye 1977; Sanger et al. 2013; Sanger 2017). Likewise, the locations where bodies of clay have been joined together are also visible as joining voids and compression sites in ceramic fabric (Applebaum and Applebaum: 2005). This insight makes micro-CT scans useful for determining the method of attachment for appendages and how coil or slab made ceramics were formed. In Ontario, possible formation techniques include coiling, paddle and anvil manufacture and press moulding, among others (Ellis and Ferris 1990; Ferris and Spence 1995; Garland and Beld 1999; Jackson 1986; Spence et al. 1990). Coiled vessels in other studies show a horizontal, parallel pattern of voids and inclusions with a circular pattern at the base. Moulded and paddled vessels show inclusions aligned parallel to the walls of the vessel and voids which are flattened and show up as circles. The vughs I noted in all scans around large inclusions were likely evidence of the pressure applied during manufacture, such as from paddle and anvil application (see also Rye 1977). In this study, large joins between clay were immediately apparent in the micro-CT scans as voids in the ceramic fabric. Recognizing these planar and channel voids allowed for the identification of four major types of rim formation techniques that were used at these sites, including folded rims and rims with applied clay. While these large voids are occasionally visible in macro-analysis on broken edges of sherds, they cannot be followed throughout the vessels and studied in any detail by looking at the exterior of a specimen. Furthermore, the positioning of petrographic slices leave it up to chance whether these large voids will be revealed or recognized as related to fabric manipulation in the formation of rims. In my own limited comparison of 2D slices to 3D sections, I was only able to spot the large void caused by folding the rim in one of five faux thin sections created.

Smaller joins in clay, visible as voids in the micro-CT scans, also allowed exploration of corrective measures used by potters. These bits of clay added to the rims of pots, sometimes above folds in the rim, sometimes to enhance castellations and sometimes on the lip to level or fix it in some way, would not be visible without micro-CT scanning. These smaller, more ephemeral joins cannot be seen from the exterior of vessels. And the chance that a petrographic thin section would cut through one, and have the context to interpret it as a smaller idiosyncratic void, is low. Only by examining the void structures in 3D and by scrolling through thousands of 2D slices across that compiled 3D model can these interior features be recognized for what they are. Micro-CT allows us to access a larger scale view of the interior and exterior features of ceramics than existing methods, which contributes to a greater understanding of the choices potters made when engaging with materials and the push back of the materials on the potters. The engaged craftsperson (Sennett 2008) can be seen in traces left behind from the gestured they used. Voids structures, viewed through micro-CT analysis, show the hand and bodily movements that potters were using as they were making pots. In this way, these scans provided a new way to think about human-material interactions at Arkona.

Furthermore, while finishing techniques are visible on vessel exteriors, the ability of micro-CT scans to cut through decorative elements non-invasively revealed directionality of deeper elements such as punctates, and the interplay between finishing techniques and manufacturing or forming techniques in ways that could not be seen otherwise. Micro-CT 3D sections of punctates and bosses allowed for them to be examined as an element of the manufacturing process and not only as a decorative element. Punctates and bosses also provide insight into the movements and gestures of potters, as they represent the result of a repeated hand motions, and the pressures applied by potters are they established regular rhythms in the craft of potting (Forte 2019). The fingerprints left on bosses are quite literally the traces left from gestures used by potters as they interacted, moved with, and responded to the material while practicing their craft.

Micro-CT scans of other clay objects, including clay lumps, learner vessels and clay pipes, also show great promise for the application of this technique to larger and more varied collections of ceramic objects. The differences in manufacturing techniques that could be seen in void structures, and the differences in inclusion volumes found in these varied classes of objects using micro-CT scans allowed me to think about differing craft communities and learning this craft. The potential for recognizing idiosyncratic building methods, unique clay fabrics and error-correcting in both clay pipes and learner vessels was demonstrated even by the limited scanning of a few objects from each of these categories in this study.

Sanger et al. (2013) suggested that CT scanning has the potential to recognize not only differing manufacturing techniques but diversity within these techniques. By examining the patterning in voids they were able to recognize coiling techniques versus slab techniques but could not definitively recognize differences between slab and molded techniques. An examination of larger portions of vessels or even complete vessels may be necessary to differentiate these two techniques. In the present study, a variety of rim formation techniques and slight differences within them were identified. Berg (2011) used X-radiography with a 60-80% success rate for identifying primary formation techniques. I think this study had shown that micro-CT scan analysis can improve on this analysis, because vessel wall thickness is not the issue it was for Berg, and we have a much more detailed view of inclusions and voids to examine. Primary formation processes are important in investigating material culture practices and learning pools; a concept that will allow further CT research to examine the transmission of ideas and learning and apprenticeship through the archaeological record (Carr 1990). Through micro-CT scans we can attempt to reconstruct the communities of practice in which potters were learning and participating. Members within a communities of practice will use similar techniques and gestures and pass down these skills or sets of practices to subsequent generations (Roddick 2016). In micro-CT scans we can access traces left by these techniques and gestures used to form pots, allowing us to being to make connections between the materials left behind, craftspeople and their communities of practice.

Previous studies (e.g., Berg 2008; Greene et al. 2017) were able to identify primary forming techniques using X-radiography, and Sanger and colleagues (2013, 2017), and Sanger (2016), were able to identify variation within these techniques from CT data. But this current study (see also Kozastas et al. 2018), suggests that micro-CT analyses can take these interpretations further, exploring in more detail the precise gestures potters used to create ceramic vessels. I was able to use the presence not only of large void structures to examine primary manufacturing techniques, but also the smaller idiosyncratic manipulation of clay, to explore the technological gestures of potting, and the engagement between materials and artisans in Arkona. These void structures represent the repeated hand motions of potters: the gripping, touching, grasping and releasing (Sennett 2008) of potters hands on the clay. These motions allow us to explore the skill and craft of potting and how the engaged potter interacted and responded to materials and their environment, continually responding and improvising as they practiced their craft (Ingold 2010). Because of CT technology, we can move away from assumptions about how ceramics were made, based on archaeological supposition and ethnographic analogy, and examine the preserved gestures and motions that potters actually left in the fabrics and internal architecture of the ceramic vessels they made. My study was limited to one set of archaeological sites from a discrete region of southern Ontario extending over a relatively short period time. Additional micro-CT studies thus can build and expand these practices broadly across regions and across deep time. This ability to recognize potters' gestures and techniques in archaeological material thus adds great interpretive insight to ceramic materials regarding potting communities across the past (and potentially into the present), and how tradition and innovation were worked into the manufacturing of pots.

7.1.2 Petrography and Micro-CT

Several authors note that the use of 2D images, including petrographs, to classify the size, shape, distribution and frequency of inclusions in ceramics is limited, because of the sampling bias inherent by only looking at one slice of a sherd (Adan-Bayewitz and Wieder 1992; Applebaum and Applebaum 2005; Jacboson et al. 2011). Images in 3D give a complete picture and are thus have the potential to be of much greater value characterizing inclusions in ceramic fabrics. Kahl and Ramminger (2012:2212) illustrated the advantages of 3D imaging in determining the percentages of temper in a sherd. Using imaging software, I was able to isolate and determine the volume percentage of inclusions for all vessels non-invasively, meaning I was able to generate a more robust representation of inclusions in a sherd than can be accessed by thin section. But also the resolution I was able to work at meant I could not discretely separate inclusions below a 0.01 mm^3 volume size, something that is possible to distinguish from thin section analyses (e.g., Braun 2015). This research suggests the potential of micro-CT scanning to access complementary and different dimensions of inclusion patterns in ceramic fabrics from what petrographers can access. Future research, including use of higher resolution scans and calibrated scans, could further push micro-CT analysis towards generating complementary and comparable datasets to petrographic findings, possibly even offer a means of determining the mineralogy of inclusions (e.g., Carr and Komorowski 1995; McKenzie-Clark and Magnussen 2014; Middleton 2005). If so, understanding the limitations and potential of both petrographic and micro-CT methodologies will be vital to advance the material science of ceramics further.

The influence of sample location in petrographic thin sections matters a lot. When only sampling a small area of ceramics - artisan made objects and often unevenly mixed - the area sampled could be an outlier within that ceramic. I illustrated that this is the case in the limited comparison of 2D vs 3D imaging of a sherd conducted, where inclusion volume was overestimated, and void volume was underestimated, and variably so, depending on slice placement. Micro-CT examines the entire specimen, and accesses volume rather than diameter or surface area, both of which are very dependent upon which direction the void or inclusions were sliced. I also found that comparing 3D volume data to categories created for 2D samples from petrography and geology was a complicated exercise, illustrating that 3D data recorded from CT scans is truly a different thing altogether than established petrographic interpretive data.

Further advantages of micro-CT include the use of software to provide filtering (although this can also be done with digitized images of thin sections), and the ability to select images on any plane (e.g., Applebaum and Applebaum 2005). Magnification of x25, x40, x100 or up to x400 for small inclusions can be used in thin section petrography (Quinn 2013), and we can achieve comparable geometric magnification up to 150x with the micro-CT scanner used in this study, depending on the sample size.

The potentials and limitations of micro-CT analyses on ceramic fabric identification are not yet fully understood. It has not been used in archaeological ceramic petrographic analysis. We may be able to answer some of the same questions as those posed in destructive 2D petrography, but research may need to include ground truthing the information gained from 3D scans with 2D petrography, since petrography is a well-established technique in the field of ceramic analysis and micro-CT is a relatively new method in the field. I am not sure micro-CT analysis can examine clay mixing in the same way as ceramic petrography. For example, identification of different clays is based on colour and reflective properties (Quinn 2013), and most clay materials have a similar density to one another. Though it is worth noting that, in one case (Specimen 050), two clay fabrics in the sherd did appear to be of different densities. This might suggest that refining scanning techniques may be able to tease out clay differences in the future. But generally, micro-CT is more suited to examining voids and inclusions, rather than the clay itself, since micro-CT separates out density and presents it in greyscale. Isolating these elements in sherds of differing densities is easy using micro-CT, so studying the ratios of the components that make up a ceramic fabric is something that can be quickly achieved from micro-CT data. Isolating different inclusions from one another or isolating different types of clay from one another becomes more difficult if these materials are all of a similar density, which tended to be the case in the Arkona sample.

Temper choices have been a major focus of ceramic petrography. Temper types and varieties can be seen as a technological trend in pottery production and can be linked to functional differences in pottery (Carr 1990). However, there is not always a link between temper type and vessel type (Dickson et al. 2013). Braun (2012:1) noted that temper size and mineralogy is determined “through the negotiation of various constraints,” including tradition, social organization, intended function, and the availability and workability of raw materials. Raw materials including temper can be linked to engagement with the landscape (Michelaki et al. 2015). Day et al. (1999) emphasized that petrography is important not just for sourcing ceramics but for examining the choices potters made. And Howie (2012) used petrographic techniques to examine the choices that potters were making and then linked these to local and non-local traditions.

The minerology of inclusions could not be examined in this study, but inclusion volumes could. Inclusion volumes included both the total volume of inclusions for each specimen, and the individual volumes of each inclusion in the specimen (for the seven sherds where I focused on this additional level of analysis). Conducting grain-size distributions and textural analysis of these samples led to some insights about the size of temper that may have been used by potters. Using volume categories in grain-size distributions, I was able to estimate that the largest of these categories (coarse sand and larger) were likely intentional and that the medium sand category was likely at least in part made up of intentionally added temper. However, these designations are tenuous at best, and even in petrography where the resolution is higher and mineral identification is completed, the intentionality of inclusions is based on some degree of guesswork. I was also able to note slight differences between distributions in specimens. The differences noted were subtle, especially when we cannot say with certainty which of the inclusions were natural, accidental, or intentional. But these vast datasets of inclusions begin to allow us to tease out potters’ choices across the spectrum of inclusion volumes and size categories, such as the use of more temper, larger temper, and other differences across the specimens examined. By using this detailed information on inclusion volumes, obtainable through micro-CT, I can access clay fabric recipes used by potters in a way that is different than that achieved by existing techniques.

While grain-size distributions from micro-CT data were somewhat obscured by the massive amounts of very small inclusions included, they did suggest that inclusions dropped off in frequency in the very coarse sand category. This pattern suggests, however tenuously, that potters, for the most part, avoided keeping anything larger in their fabric, while adding some or all of the medium and coarse sand sized particles into that fabric as temper. However, this could also be the result of the depositional environment of the clay sources (Quinn 2013). While my findings did not provide neat bimodal distributions of inclusions, with natural inclusions on one peak and temper on the other (as are sometimes noted in petrographic studies), it did reveal what might have been intentional tempering materials through the steep drop off in volume that I was able to document. Sphericity, a 3D measure that cannot be fully obtained from existing software used for this study, also holds promise for exploring clay fabric recipes, if it can be combined with other measures such as roundness.

While much of the early work examining clay fabrics in micro-CT studies will be based on exploring metrics that have already been established in petrography (e.g., grain-size distributions, textural analysis, inclusion, void volumes), micro-CT analysis is becoming a distinct field and field of analysis in the suite of archeological sciences techniques used to examine ceramic objects.

7.1.3 Advantages and Disadvantages of Micro-CT

Analysis revealed that micro-CT is an extremely robust technique for examining ceramic manufacture, but the technique is not without limitations. The three dimensional nature of data is a benefit but also requires the development of new methods of data analysis.

7.1.3.1 Advantages of 3D Data

There are problems with traditional X-radiographs when examining ceramics (or other 3D structures). Thickness and density are confounded in X-rays when 3D objects are made into 2D images (Pierret et al. 1996). Kahl and Ramminger (2012) resolved some 2D issues by digitizing their images and using equations to derive porosity and thickness across the sherd. However, these issues are not a problem with CT scanning (Pierret et al. 1996). Representations of 3D objects provides quantitative information such as volume, size, shape, distribution, and connectivity of the void and inclusions can be obtained for the entire 3D volume of the samples (Machado et al. 2013; Sobott et al. 2014). Obtaining total inclusion volume percentages for the clay fabrics of the specimens could be easily achieved through thresholding based on density. These inclusion volume percentages typically ranged from 5-15% of the total fabric volume. Void volumes, on the other hand, were typically less than 4% in the specimens examined, and the upper rim portion of vessels had slightly higher void volume percentages than were found in the sherds overall. Micro-CT allowed for the visualization of voids quickly in the X, Y and Z planes, and it quickly became apparent that planar voids, followed by vughs around inclusions, were the most common types of voids. The ability to follow these large voids through a specimen is unique to CT analysis and proved useful in determining the shape and orientation of voids. This ability led to important conclusions about how potters were forming vessels and vessel rims.

7.1.3.2 Software and Data Representation

Another advantage of micro-CT (and other 3D imaging) is that the researcher can manipulate the volumetric data obtained through various software programs including, but not limited to, ImageJ (Ferreira and Rasband 2012), VGStudio MAX (Hoffman & deBeer 2012; Volume Graphics GmbH 2013), ORS visual (Object Research Systems), Dragonfly (ORS 2020), and 3D slicer (Fedorov et al. 2012). Data representation can be simple slices or complex three-, four- or five-dimensional representations of volumetric data either in grayscale or colour (Stock 2009:137-138).

Data representation is an important part of research on ceramics, and micro-CT produces fantastic representations of data. Videos or animations, and images, both in colour and greyscale, can be used to highlight different features obtained through 3D scans. Movies or animations are useful to represent 3D data, because more than one feature at a time can be represented, or different features can be represented successively (Volume Graphics GmbH 2013). Animations are also a wonderful tool for displaying results to academics, the general public, stakeholders and descendant groups (see for example: https://youtu.be/f0F0UQ-csTI , and https://youtu.be/-COjbsnP76U).

The ability to highlight relevant ceramic features in an animation makes the results of CT scans engaging. I found it was much easier and less time consuming to explore scan data within the VG interface than it was to animate the scans. However, the ability to present my analysis in an animation or video was a powerful tool to convey the concepts and data I was examining. A video that highlights the features contained in the ceramic (such as void structures and inclusion distributions; see https://youtu.be/qp5Z7qLqMAo and https://youtu.be/QOg4h35-vm8) is infinitely more accessible than a 3D reconstruction file that needs imaging software and a lot of computing power to open. I also found that sequential still images of various slices through a single specimen and 3D renderings of void structures proved to be effective tools in presenting the results of my analysis in this study.

7.1.3.3 A Non-invasive Technique

Using micro-CT, researchers can non-invasively gain information on internal structure: the proportions, spatial distribution and relative orientation of components (Griffin et al. 2012). These factors are important in the study of archaeological ceramics, and the non-invasive nature of micro-CT scanning allows for the examination of specimens that have previously been too fragile or too vital as heritage to be investigated in material science fields. However, while non-invasive, it is not fully understood what effect X-ray dosage has on ceramics, and it must be kept in mind that this process may interfere with thermoluminescence dating techniques (Tuniz and Zanini 2014; Huntley et al. 2016), which although destructive, are still widely used on archaeological ceramic materials around the world (e.g. Abboud et al. 2015; Anderson and Feathers 2019; Baria et al. 2015; Cano et al. 2015; Farias et al. 2009; Herbert et al. 2002; Khasswneh et al. 2011; Mejia-Bernal et al. 2019) Thus I have referred to micro-CT as non-invasive but not necessarily nondestructive.

The non-invasive nature of micro-CT scanning makes it a technique with great potential for community-based and collaborative research in North America, where Indigenous communities may prefer or consent to have only non- or minimally- invasive techniques conducted when it comes to archaeological research (e.g., Glencross et al 2017). Furthermore, in my experience, museum researcher access policies are more likely to allow for non-invasive techniques (e.g., Tite 2002), permitting researchers potential access to a greater variety of archaeological collections than when using a destructive technique such as thin section petrography.

7.1.3.4 Addressing Research Questions

Micro-CT allows archaeologists to ask questions about pottery manufacture that could only previously be answered using destructive techniques, or that could not be answered at all. Of the steps involved in ceramic manufacture, primary forming techniques are very difficult to access using conventional methods, but become apparent in micro-CT analysis. In this research I asked what micro-CT scanning could tell us about several steps in the *chaîne opératoire* of ceramic manufacture (including fabric preparation, vessel forming and vessel finishing), the gestures and practices related to those steps, and in turn how these were learned, used and passed down within a community of practice. Other CT and micro-CT studies have asked similar research questions with varying degrees of success.

Sanger's (2017) success in identifying formation techniques was in part because of the use of fibre temper in the pottery, which appeared clearly on scans as burnt out void spaces and aligned according to manufacturing techniques because they were linear. Void spaces did not suggest use of fibre temper in the Arkona collection. The vugh voids around solid temper particles suggest a paddle and anvil manufacture, and the smaller planar voids seen in all vessels probably relate to this technique as well. Little else could be determined from the alignment of particles in the vessels in the Arkona sample, and most of my conclusions regarding ceramic manufacturing techniques were based on voids left from joining pieces of clay, rather than alignments of temper or inclusions (or by proxy the void spaces left from temper). Sanger (2017) also argued for correlations between manufacturing techniques and decorative elements on pottery, which he inferred to be the products of several communities of practice, while the pottery at Arkona did not show strong correlations between exterior decoration and interior structures. For future work, considering a collection of ceramics that have linear-shaped tempering materials (e.g. shell, fibre, or more elongate minerals) that might align in accordance with manufacturing techniques (see Figure 6.21), might enable more robust conclusions about the techniques used by potters. However, the Arkona collections were still a valuable case study because of their unique position within a borderlands culture, and micro-CT scan data was able to add insight into the complex communities of practice at work there, as will be discussed in detail in Section 7.2.

Recent studies, including that completed by Kozatsas and colleagues, use micro-CT data to answer questions not only related to primary manufacturing techniques, but also to discover and define unique "individualized craft behaviors" (Kozatsas et al. 2018:104), or the gestures and motions undertaken by potters' hands and bodies while practicing their craft. They use micro-CT scan data to answer research questions about social stratification and evolving household units by sampling from one house over differing time periods (Kozatsas et al. 2018:105). Because they had a directed research question, and the resolution to identify individual techniques and variation within these techniques, they could identify both different production sequences within deposits that represented only a few generations, and those that remained the same over the course of several centuries (Kozatsas et al. 2018:117). Here micro-CT data allowed the authors to say something about how individual artisans were engaging with tradition and innovation and what it tells them about social structures: a perfect example of what micro-CT analysis can bring to the table. Similarly, in the Arkona Cluster sample I examined, I could identify individualized craft behaviours in the form of error-correcting and tendencies in finishing techniques. Using micro-CT scanned data, I could also identify craft gestures or behaviours that were used over the course of the several generations represented by the Arkona Cluster sites, such as folding and applying clay to rims, and mixing clay fabrics to meet certain inclusion volume requirements. The engagement of Arkona potters in tradition and innovation is discussed more in Section 7.2.

The lesson to be learned from these examples is that selection of collections for scanning should be made with care, as the time and money involved in scanning and analysis means micro-CT scanning is not the best method for answering all research questions. For example, if the research questions have to do with the provenance of ceramics and relating them to the local or non-local landscape, petrography is currently the better technique. Or if the archaeologist is examining collections with the purpose of placing them within temporal or spatial chronologies, basic visual classification of attributes and use of a suite of dating techniques might be a better use of research funds. However, research questions related to learning, practice, identity, tradition and innovation in potting all suggest micro-CT analysis is a strong source for information, and it is worth the time and effort that goes into the analysis. Since micro-CT can examine the interior structures of ceramics, including the nature of clay fabrics and the void structures that are left behind by gestures and movements used in forming and finishing pots, it is one of the strongest techniques for direct interpretations of these steps in potting practice. Undoubtedly micro-CT is one of the best techniques for understanding ceramic manufacturing and forming techniques in the past, allowing for interpretations about the transmission of potting knowledge and practice over space and time.

Depending on how fine-grained the research question is, an X-radiography or a CT study may be able to answer simple coiling versus slab built primary manufacturing questions. However, micro-CT generates higher resolution images at a higher fidelity, allowing for the investigation of more nuanced questions about variation within techniques, artisan gestures, and idiosyncratic quirks, permitting more insight about artisans' engagement with innovation and tradition. Nonetheless, that resolution comes at the cost of time and budget. Micro-CT analysis should be considered as part of an integrated program of ceramic analysis, including both macro and micro techniques. In this way, it can further improve our understanding of the process of vessel manufacture in the archaeological record.

7.2 Ceramic Craft in the Arkona Cluster

This section will explore what the results from micro-CT scans can tell archaeologists about the craft of ceramic manufacture and the artisans in the Arkona Cluster of sites. These insights include the choices potters in the Arkona Cluster were making concerning ceramic fabric recipes, rim manufacturing techniques, improvisation, and building ceramics while practicing the craft of potting to make vessels. The micro-CT scans allows for an exploration of how pots were made at and across sites in the cluster. It also briefly discusses how these manufacturing choices relate to decorative attributes on the exterior of pots, and the implications this has for how archaeologists need to change their current thinking about Woodland ceramics in Ontario. This section will illustrate how these Arkona artisans were working within communities of potters, and what insights might be gleaned about ceramic making across this cluster of sites and material borderland.

7.2.1 Preparing Clay at Arkona

Potters make many choices while preparing clay to be used in the manufacture of pots. These choices encompass learning and tradition, contemporary innovative approaches to the craft, their degree of experience and life learning at the point of preparing a fabric, the agency of the materials they engage with, the contingencies of domestic spaces and landscape places, season, and balancing other tasks when obtaining and preparing clay fabrics (e.g., Michelaki et al 2015). The primary aim when making these choices is to achieve a level of workability and texture of the fabric that "feels right," is "good enough," or otherwise informs the potter through their preparation and handling that the fabric is ready for forming. The choices the potter makes range from clay sourcing, acceptable levels of clay lumps or accidental inclusions, and ratios of temper to clay and clay to moisture; all tested against expectations informed by learning and previous preparations (Rye 1981). Potters have a good idea of what the clay is supposed to feel like, and they may also have tested the fabric in a number of ways while mixing it. This material interaction between the potter, clay, and inclusions is thus a complex experiential negotiation and decision-making throughout the preparation stage that variously is captured in the resultant archaeological record of vessel sherds.

The ability to access this decision making in sherds is limited when using macro examinations. At the same time, petrographic analyses can profile and characterize fabric makeup, and the range of fabrics present in a given assemblage. In particular, Braun (2015) has argued accessing potter/material engagement and craft decision making can be best understood in terms of interior fabric volumes (clay, inclusions, voids), not counts, as volumes more readily speak to how potters were making these choices and evaluating the understood rightness of the fabric being prepared. If this is the case, then micro-CT analysis of vessel fragments in 3D allows us to further advance research on inclusion and void volume percentages within the clay as expressions of potters' choices to get fabrics right.

Inclusion volume percentages for the vessels scanned ranged from 2-20%; however, 77% of those 67 specimens fell within a 5-15% inclusion volume, and more than half (55%) of the 67 specimens fell within a 5-10% inclusion volume. There was little variation between sites in the cluster. There are few comparable studies, but those that do exist from petrographic work (Braun 2010, 2015; Weglorz 2018) suggest a typical inclusion volume that is higher: in the 20-40% range. This difference may simply be a variance due to methodology, as seen in Section 6.6, or it is possible potters in the Arkona Cluster were using less temper than later Ontario late Woodland Tradition potters. There are, of course, other factors that could have accounted for this relatively low inclusion volume including the local landscape and the depositional context of the clay (Michelaki et al 2015). The variation in the amount of inclusions generally noted across Ontario Indigenous ceramic assemblages range by 25-30% (Braun 2010, 2015; Weglorz 2018), while the Arkona inclusion percent range is only 18%. I would argue this pattern indicates Arkona potters worked to a similar recipe and had a clear goal in mind when adding temper to ensure success in vessel firing and use.

Potters in Arkona were adding temper intentionally to clay, as exhibited in the discussion on textural analysis and grain-size distributions on the seven samples that underwent that type of analysis. All of the Arkona vessels sampled had medium sand-sized or smaller particles, and these categories collectively represent the vast majority of inclusions in the clay fabric. But the full range of inclusions observed in the micro-CT scans encompasses both unintentional (i.e., natural inclusions that remained after filtering clay, as well as accidental additions picked up from the working environment), and intentional additives (i.e., temper), which likely were created for the purpose by crushing rocks into fine particles to be added to the clay for workability. I suspect that finer particles visible in the scans were mostly natural inclusions simply not filtered out of the clay in the slaking and sieving preparation process. In other words, the smaller end of the spectra of inclusion volumes probably represent an overlapping of natural, accidental, and some intentionally added particles, all mostly beneath awareness and not a concern for artisans.

At the other end of these spectra of inclusion volumes by category were the larger inclusion volume categories, which make up only a small portion of all inclusions (below 99% of all inclusions). Notably, these very steep drop offs in frequency almost all occur somewhere in the coarse sand category (Table 7.1). To me, this pattern suggests that the spectra of material potters selected for use as tempering additives ranged in size from the medium sand category into the very fine gravel category (Table 7.1) and makes up the bulk of the visible, non-clay material in fabrics. In addition, given the extremely limited frequencies of fine gravel-sized inclusions (samples level off to lower than 0.05% of all inclusions in the very coarse sand category between the 1.30 mm^3 and 2.5 mm^3), I suspect items at this largest end of the volume spectrum more generally represent accidental inclusions. These items likely were picked up in the work environment, or overlooked when the potter was preparing/selecting their preferred additives. If this is the case, these larger volume inclusions also points to where the limit of "tolerable" was in the mind of potters.

In particular, though it was impossible to determine with certainty which inclusions were a natural part of clay fabrics or accidental pick-ups, and which were intentionally added temper, the textural analysis allows for an educated guess. I would further suggest that potters were mostly aiming to work with particles the size of coarse sand (0.0654-0.524 mm^3) and very coarse sand (0.524-4.19 mm3) as tempering materials. As well, given the likelihood that some or all of this temper was being prepared by crushing fire cracked rock to create temper particles of varying sizes (Linda Howie personal communication 2017), it is reasonable to expect that some portion of this material fell above and below the "typical" size preference for temper. The sphericity data for the seven sampled sherds, while not conclusive on its own, also supports the notion that the smallest inclusions are the most spherical, and most likely to be natural, while larger inclusions are less spherical, which might be result of crushing tempering materials. These notions align well with the arbitrary distinction that was used by Braun (2010:72), in which "inclusions below 0.5 mm were considered to be naturally occurring, and those above 0.5 mm were considered to be added as temper." In other words, while micro-CT scan data could not replicate distributions noted in petrographic studies, scan data does provide novel and additional insight into the logics and ranges of choices potters were making while preparing clay fabrics to preferred recipes.

Table 7.1. Table illustrating the volume categories used for micro-CT textural analysis. The "presumed source" column represents my attempt at accessing the intentionality of inclusions of various volume categories. *The scan of Specimen 011 failed to record frequencies of the smallest inclusions.

2D diameter	Adjusted Volume Categories	Volume categories for micro-CT data	Point where inclusion frequencies in specimens drop to below 1% of all inclusions	Presumed source
62.5-125µm	0.000128-0.00999mm^3	Very fine/Fine sand		Natural
125-250µm				Natural
0.25-0.5mm	0.01-0654mm^3	Medium sand		Natural and/or Temper
0.5-1mm	0.0654-0.524mm^3	Coarse sand	0.2-0.29 mm^3- 1 0.3-0.39 mm^3- 3 0.4-0.49 mm^3- 2	Temper
1-2mm	0.524-4.19mm^3	Very coarse sand	0.90-0.99 mm^3- 1*	Temper
2-4mm	4.19mm-33.51mm^3	Very fine gravel		Temper and/or Accidental
4-8mm	33.51-268.08mm^3	Fine gravel		Accidental

As highlighted in Figure 6.11, medium sand is the largest volume category for five specimens (024, 050, 061, 070 and 011), while very fine/fine sand is the largest category for two specimens (038, 042). It is worth noting that Specimens 038 and 042 both come from AgHk-42, the Bingo Pit village. With only seven specimens undergoing textural analysis, it is possible these results were simply a coincidence, but AgHk-42 is the last and largest site in the Arkona Cluster sequence, noted for a much more substantial settlement pattern and material culture than seen elsewhere in the cluster (Ferris 2018). This distinction might hint that potters at AgHk-42 might have been making a finer-grained ceramic fabric than what was preferred at other sites in the cluster, and perhaps engaging in a slightly different potting community of practice. More analysis comparing samples from this site to others in the cluster is needed to see if this difference is an artifact of my sampling choices, temporal changes over the life of this craft within the Arkona Cluster, or suggestive of possible social innovations playing out across communities within this material borderland.

The data on inclusion volume percentages, textural analysis of the ceramic fabric, and grain-sizes allowed me to access how the potters at Arkona might have been preparing and engaging with the materials needed to make pots. It hints at a recipe potters understood and a tactile, distinct knowledge of what to expect when preparing clays for vessel formation. This knowledge was taught and experientially perfected over time, and reinforced as the expert understanding of clay material properties to achieve in preparation trans-generationally.

7.2.2 Vessel Manufacture and Technological Gestures

Void volume percentages obtained from micro-CT analysis were uniformly low in the Arkona specimens scanned, with 79% of the whole sherd specimens falling between 1-3% void volume. Compared to petrographic analysis of later Ontario Late Woodland Tradition vessels (e.g. Braun 2015; Weglorz 2018) that have estimated void volumes up to 15%, the maximum void volume of 7% at Arkona is low. This discrepancy could be due to differences in methodology (micro-CT versus petrography See Section 6.6), the nature of the material (type of clay), as well as potters’ practice in time or space. This consistently low void percentage overall for Arkona vessels may represent the intensive working of clay, including techniques like paddle and anvil, to force most of the air space out of pot fabrics. Increased void volume can also result from air pockets forming around large inclusions in the fabric, so it is possible the Arkona pottery has relatively low void volumes compared to later vessels in part due to the use of relatively small temper. More comparative studies from across Ontario would need to be conducted to see if this is the case.

Despite there being a variety of vessel body and neck shapes present in the specimens sampled for this study, and in the Arkona assemblages as a whole (Cunningham 2001; Suko 2017a; Watts 2008), there was little variation in the void structures below the rim portion of vessels when neck and body sections were present in the specimens scanned. Planar voids parallel to vessel walls, and vughs around inclusions, were present in all vessel necks and bodies. There was, however, a difference within specimens between voids in the neck/body portions of specimens and rim portions. As an overall pattern, I noticed slightly higher void volumes in the rim area of the Arkona vessels, and slightly less void volume generally below rims. The paddle and anvil technique used to form the body of some vessels has been known to produce many small voids, both elongate and around inclusions (Braun 2015; Rye 1977) which were seen in the Arkona sample. However, the much larger joining voids formed by folding clay and adding clay to the rim portions of these vessels resulted in overall higher void percentages in of the rim portions of vessels scanned. Both these slightly higher void volumes within rims, as well as the notable frequencies of correctives visible on rims, likely speak to the increased attention potters gave to that portion of the vessel while forming vessels.

When creating the rim portion of vessels, potters used a range of gestures to create similar vessel profiles within the Arkona Cluster. There was a relatively even distribution of rim forming techniques observed across samples from all sites in the cluster. There were only a few minor variations in rim forming techniques between sites, including slightly higher frequencies of plain rims at AgHk-52 and AgHk-54, and an absence of rims with just added clay at AgHk-54. These differences probably have more to do with my sampling than actual variation in potters' techniques. As outlined in the results, folding rims was the most common rim formation technique used at all of the Arkona sites. Folded rims, alone or in combination with added clay, make up 64% of my sample, while rims with added clay or in combination with folding make 42%, and plain rims make up 13%. In short, 87% of rims were, in one way or the other, thickened in the finishing of the vessel top. This method is consistent with the broader temporal pattern of a thicker rim or "pseudo collar" (Ferris and Murphy 1990) used across southwestern Ontario at this time.

The potter's aim to create castellations probably helped influence the use of these rim formation techniques in Arkona. I found a correlation between rims that used folding as a forming technique, especially when combined with added clay, and the presence of castellations. That suggests folding clay over towards the exterior of the rim was a part of the preferred method used to create castellations on these vessels. Even on specimens where castellations were not present on specimens, it is apparent that thickening rims by folding clay over at the lip or adding clay was a common technique within the Arkona Cluster of sites. Sometimes rim formation methods were visible by simple visual examination of the exterior or broken edge of sherds. However, more often, it was not possible to determine rim formation method by eye. These technological gestures and their frequency in the Arkona collection only became apparent when I could view vessel rim internal structures through micro-CT scans.

That these rim manufacturing techniques are fairly evenly distributed across the sites examined suggest this was the preferred set of practices followed by potters across the sites of this cluster and time, collectively sharing and perfecting methods taught by the previous generation. This resulted in a limited range of rim forming techniques in the vessels left behind. The repeated use of these technological gestures, folding rims and adding clay to rims, suggests a collective or trans-generational knowledge of ceramic vessel forming at work here. These rim forming techniques were commonly shared "tools of the trade" these potters relied on.

Some of these rim forming techniques used by the Arkona potters were more widely shared throughout the region in the twelfth and thirteenth centuries. Comparable micro-CT data that examines rim forming techniques does not exist, but "incipient collars" or slight collar development is noted for both the thirteenth century Ontario Late Woodland (Williamson 1990:298) and the Western Basin Tradition (Murphy and Ferris 1990:203).

As well, other sites in southwestern Ontario and generally dating to this time period exhibit primarily vessels with incipient collars and collars of varying sizes showing up in in around 2-20% of site assemblages (e.g., Lennox 1982:36; Noble 1975:18; Timmins 1997b:133). The trend towards collared vessels really emerges through the fourteenth century (e.g., Martelle 2002; Williamson 1990:298). Perhaps the thickened rims or incipient collars noted more broadly were created using similar techniques to that reflected in the micro-CT data from the Arkona Cluster, and temporally presages the development of formal rim collar formation later in time.

Morphology of the rim, lip and neck in the Arkona sample also followed trends noted more broadly in twelfth and thirteenth century assemblages, with a predominance of lips that are flat, rim profiles that are concave, and necks that are short and curve out at the shoulder (e.g. Lennox 1982:37; Timmins 1997b:133; Williamson 1990:298), though variability in rim shape is also noted in some assemblages (Noble 1975:18; Wright 1966:28). There were certainly some differences in neck and rim profiles noted within the Arkona Cluster, with more vessels with short necks and concave rim profiles at AgHk-54, while there were more rims with straight profiles and elongated necks at AgHk-32. This may reflect a change in practice at Arkona over generations since AgHk-32 is the earliest site in the sampled cluster, and AgHk-54 is later. This change could reflect an increased influence on Arkona potters of ceramic trends to the east, where Ontario Late Woodland Tradition vessels exhibit shorter, more constricted neck profiles during this time (Watts 2006:91), distinct from the elongated neck profiles found to the west (Murphy and Ferris 1990:202). These shared morphological traits may represent the potters at Arkona engaging with more widely used practices, and in the future, more through comparisons between this community of practice and others might reveal constellations of practice across the lower Great Lakes in the Late Woodland. Based on the broader trends in vessel morphology, potters appear to share at least some gestures and practices with wider communities than those which existed within the Arkona Cluster. Again, complete assemblage analysis would reveal if neck shape change over time at Arkona is an actual trend or just a result of my sampling strategy.

7.2.3 Vessel Finishing and Decorative Elements

Micro-CT scans revealed that there were relatively few vessel forming practices followed by potters who were also employing generally similar fabric recipes, across the life of the Arkona Cluster of sites. However, finishing, especially the application of decorative techniques and composition of decorative motifs, are much more diverse and subject to variable execution (e.g., Cunningham 2001, Suko 2017a, Watts 2008). In a sense, the relative uniformity of fabric recipes and vessel forming practices may reflect a conservativism to fabric recipes and vessel forms in time and place, i.e., tradition, while finishing methods and decorative motifs may reflect an openness to artisan variation, i.e., innovation.

Stamped obliques appeared most commonly on the exterior of the sampled Arkona vessels I scanned, accounting for 88% of exterior motifs, which is in line with larger trends across southwestern Ontario ceramics in the twelfth and thirteenth centuries, where stamping and oblique designs predominate assemblages (e.g. Lennox 1982:39; Timmins 1997b:136; Williamson 1990:298). Generally, there was little correlation between rim manufacturing techniques and the type of rim decoration used by potters. Exterior decorative techniques varied slightly across sites within the cluster, with perhaps a slight preference for alternating obliques (56%) at AgHk-54, and a similar slight preference for right obliques at AgHk-42 (55%). Overall, the distribution of exterior decoration suggests potters across time and within the cluster were engaging with the widespread “variability in both motif and technique” that is a hallmark of early Late Woodland ceramics through the thirteenth century (e.g., Murphy and Ferris 1990:228; Williamson 1990:298).

Decorative elements on the neck of the vessel were usually different than the rim motifs in the Arkona sample, switching from the common oblique elements on the rim to horizontal lines, horizontal combinations of elements, or elaborate triangle or diamond motifs on the neck. As opposed to overall exterior decoration, where incising made up only 6% of the main finishing technique used, on necks at Arkona incising was the main technique on 44% of necks, and was used in combination with stamping on 19% of necks. As with the use of stamped obliques on vessel rims, both incising and stamping decorative elements on necks was a common decorative practice more widely in southwestern Ontario, though variation is notable. For example, at the earlier Ontario Late Woodland Tradition Van Besien site, incising was predominately used on necks (Noble 1975:20), while the later Calvert site exhibits primarily stamped neck motifs, with only 21.2% incised and 5.1% combination of incised and stamped elements on necks (Timmins 1997b:137). At the primarily twelfth to thirteenth century Western Basin Tradition Bruner-Colisanti site, incised and stamped techniques were used equally on necks (Lennox 1982:34).

Neck motifs were also varied in the Arkona sample, with triangle shapes and horizontal neck motifs making up the largest percentages recorded. More generally, ceramic assemblages from southwestern Ontario are noted for a wide range of stamped horizontal, oblique and vertical decorative bands, and incised hatched and horizontal motifs (e.g., Lennox 1982:34; Noble 1975:18). Incising tends to occur more frequently in later assemblages (Williamson 1990:298). The variability in form and application of neck decoration suggests this form of expression, in particular, may have been where potters could exercise individual choice.

There was some correlation between neck motifs and the shape of necks in the scanned Arkona sample. While elongated necks only account for 24% of the sample, triangle motifs appear on elongated necks 55% of the time. These "elongated" necks are a regular, though not exclusive, form found in Western Basin Tradition site assemblages through the eleventh to fourteenth centuries (e.g. Cunningham 1999:35; Murphy and Ferris 1990:201; Lennox 1982:30; Watts 2006:87). These neck forms can serve as sites for elaborate incised or stamped decorative motifs, including the triangle and diamond motifs mostly dating between the eleventh to thirteenth centuries. These neck forms and distinctive motifs are not typically associated with Ontario Late Woodland Tradition sites. At Arkona, at least in the scanned sample, the association with elongated necks and complex neck motifs seems to be the case, suggesting that potters had these motifs in mind when creating longer necks. Lennox (1982:34) proposed that the limits of the length of a stamp versus the limitless length of a motif created by incising might account for the differences in neck motif, though stamped examples were noted from Arkona.

Within the scanned Arkona vessel sample, slightly more triangular motifs appeared in the vessels sampled from the Van Bree site (AgHk-32), the oldest site in the cluster, which also had a higher proportion of elongated necks than average. Triangular neck motifs and elongated necks may have become less common over time in the Arkona Cluster, which is a general trend noted through this period (Murphy and Ferris 1990). But this trend also indicates there were local potters imagining and creating vessels in the Arkona community in new ways between generations of potters, underscoring how tradition and innovation are negotiated in the doing and learning.

Punctates are a finishing attribute that micro-CT scans provided additional insight on. Interior and exterior punctates, and the bosses created by punctates, are a frequent attribute present on vessels in southwestern Ontario from this period. Nonetheless, current literature suggests Ontario Late Woodland Tradition ceramics trend towards interior punctates and exterior bosses (Watts 2006:213; Williamson 1990:298), while Western Basin Tradition ceramics trend towards exterior punctates usually without interior bosses (Murphy and Ferris 1990:228; Watts 2006:88). At the Calvert site, for example, 43% of vessels exhibited interior punctates, 37% exterior bosses, and only 8% exterior punctates with 7.5% interior bossing (Timmins 1997b: 133). Of the 67 Arkona vessels sampled for scanning, 31 (46.3%) had exterior punctates, of which 23 (34.3%) had interior bosses, while 21 (31.3%) vessels had interior punctates, of which 18 (26.9%) had exterior bosses. These percentages reflect a fairly even distribution of interior and exterior punctates and bosses opposite 75% punctates (opposite 74% of exterior punctates, and opposite 86% of interior punctates). These percentages might trend towards Western Basin Tradition practices because of the greater tendency towards exterior punctates, though these were frequently bossed, which was not “typical” of Western Basin Tradition trends through this time. The split at Arkona between interior and exterior punctates and the frequent presence of both interior and exterior bosses suggests a flexibility in punctate and boss application that may have been pulling from multiple decorative traditions (as suggested by Suko 2017a and Watts 2006). As with other applications, such as neck motif, punctates and bosses may have been a way in which Arkona potters engaged and innovated from distinct sets of ceramic practices they would have been aware of over their lives and across generations.

Punctates appeared on between 70-100% of the vessels scanned from each site. The lowest percentages were from the largest number of samples taken from AgHk-52 and AgHk-42. From the scanned sample used for this study, potters throughout the cluster were using both exterior and interior punctates, usually with bosses opposite them, as a finishing method.

The directionality of punctates seen in micro-CT scans also allows for some observations about practice and the handedness of artisans at Arkona. While slight variation in application is notable within specimens, the majority of punctates on any given specimen were either straight, left angled or right angled. Left and right angled punctates were not found on the same vessel. I also observed some tendencies for artisans to apply straight punctates more often on the interior of vessels, while exterior punctates were more often angled in one direction or another. This observation allows me to access the gestures of potters, as it is suggestive of a more careful effort being used to reach into the pot to create interior punctates. These patterns of punctate directionality also could suggest artisan handedness.

Research on handedness in pottery making (e.g. Sassaman and Rodolphi 2001; Uomini 2009; Wallaert-Pêtre 2001) suggests that the identification of particular movements and tools preserved in clay is still in its infancy. Nonetheless, the directional categories I could record in this study clearly reflected the direction of the tool impression made by the potter. I also assume the potter was decorating the pot with the vessel orifice pointing upwards, at least for rim finishing, which is where punctates appear (almost all punctates were noted above necks, and interior punctates could have only been applied with the vessel oriented this way). In terms of handedness, then, right directionality likely relates to the potter using their left hand to make the punctate, while left directionality likely relates to the potter using their right hand to make the punctate. For punctates applied straight on it is not possible to determine handedness. Note that the presence of left and right directionality also suggests vessels were not rotated for every punctate applied and thus the potter had to reach to some degree to insert the tool. If that was the case, reaching also would explain variation in the degree of angle seen across a row of punctates for a single vessel (e.g., Figure 6.59 A); i.e., a sharper degree of directionally hinting at a longer reach. I am also assuming that aligned handedness (i.e., left directionality by left hand or right directionality by right hand), which would have required the artisan to twist their wrist over, was not a preferred gesture.

Based on the relatively small sample (52 vessels with punctates) from Arkona, I found a relatively high frequency of what I interpret as left-handed directionality in the application of punctates. Contemporary meta-analyses of handedness suggest anywhere from 9.3-18.1% of populations worldwide are left-handed, with the best overall estimate being 10.6% (Papadatou-Pastou et al. 2020). Also, it should be noted that handedness can be influenced by cultural factors, so these numbers should be taken with a grain of salt (Papadatou-Pastou et al. 2020). That being said, 25% of vessels punctated in this Arkona sample suggested left-handedness. Of the vessels scanned at AgHk-52 (Figura), that number is closer to 50% of punctates indicating left-handedness. Sassaman and Rodolphi (2001), examining potting communities in the American Southeast, noted that the long-term, non-random distribution of left-handedness among potters is a trait impacted by maternal influence. If so, the relative higher frequency in the Arkona collection, and in particular at AgHk-52, might indicate successive generations of potters learning from left-handed family members at these sites, or a limited number of potters, some of whom were left-handed, contributing to more of the vessel population at Figura and subsequent Arkona sites. With more micro-CT scanned assemblages from a wider variety of sites, the directionality of punctates has the real potential to further our understanding of the demographics of a community of potters at any one locale, or the multi-generational influence of potter families over the ceramic trends seen across a sequence of sites.

7.2.4 Adaptive Irregularities and Improvisation at Arkona

So far, in this summary, I have reviewed the systematic steps taken when producing ceramics, which implies that craft producers worked in a regular sequence, from preparation to finishing, every time they made something. This process captures both the underlying logics of production followed by artisans, and the technological sequence used throughout this research. Likewise, I would argue that the way people made pots was governed by a range of routines and rhythms that went along with this production sequence. Almost any ethnographic study on potters will underscore that there are repeated, often unconscious or non-discursive steps in manipulating clay that craft producers use to ensure success (e.g., Deal 2011; Dietler and Herbich 1994; Gosselain 2016; Gosselain and Livingstone-Smith 1995; Roddick 2016). Archaeologists studying craft production have repeatedly noted that motor skills, posture, and gestural movements resist change as artisans work in regular ways to establish rhythms (e.g., Dobres 2000; Forte 2019; Gosselain 1998; Hagstrum 1985; Michelaki 2008; Roddick and Hastorf 2010; Stark 1999). Throughout this research, I have used these conceptual understandings of production to argue that communities of artisans, individuals, and the relationships between them can best be understood by focusing on these regular gestures and ways of doing things accessible through micro-CT scans.

But the micro-CT scanned data for this research has also regularly revealed the material traces of a kind of artisan drift or improvisation in practice. The scans revealed occasions when potters, as they engaged in the practice of potting, used adaptive irregularities (Sennett 2008:134) to adjust to the conditions of potting, and respond the task at hand. These irregularities and improvisations are the skilled potter's response to the push back of the material, as the ongoing interaction between maker and material unfolded. For this section, I focus on when regular rhythmic vessel production steps and gestures required improvisation on the part of the potter, sometimes with the use of gestures that were adaptive to the situation. Considering these instances of improvisation allows me to explore the notion that producers work in messy, complex, distracting, real-world environments. Moreover, it allows me to identify where artisans themselves recognized that some effort was required to negotiate and "follow the forces and flows of material" (Ingold 2010:97) to bring about the vessel form, rather than scrapping the effort entirely and starting over again.

When we talk about the craft of making clay objects in a non-industrial, Indigenous residential setting, we are referring to an activity that is part of the day-to-day social lives of people who make clay vessels while interacting with their families, neighbours, and communities. These craft producers were not usually working in a pristine workshop set apart from the broader daily rhythms and activities of their settlement. Making pots also meant finding the opportunity, alone or with other potters, to prepare clay, and form and finish vessels, while balancing, or not, the multitude of other priorities, tasks, concerns, and daily aspirations these individuals negotiated for themselves, their families, and their communities. Furthermore, the materials artisans worked with had their own properties and limitations, lending a material agency complimenting or constraining the potter's efforts to manipulate the clay, temper, water, and the tools used in production. Place, time, and physical properties were thus an interaction between these materials and the craftsperson. Micro-CT scanning offers a new way to explore this process of interaction between materials and craft producers, allowing us some insight into the engagement and entanglements between them, the contexts these interactions were occurring within, and what happened when things did not work quite as planned.

For example, the clay smoking pipes scanned for this study readily revealed irregularities. Borehole retries seen in the scans of pipe stems and bowls did not adjust the overall shape of the pipe, as they related to easy "fixes" or adaptations achieved by simply creating a second (or third, fourth, or fifth) borehole in the pipe. McCartney (2018:57) argues that half of a clay pipe recovered from AgHk-52 is an example of a "juvenile" or learner pipe, because it was not extensively fired, and in the longitudinal cross-section the "…initial stem borehole that was placed at a misdirected angle had to be corrected." However, two of the five pipes I scanned showed this same pattern of misdirected boreholes. Neither of these specimens could be considered "juvenile" or novice pipes. This distinction in interpreting irregularities in gestures used in borehole placement underscores the strength micro-CT scan data can provide in contextualizing interpretive notions of "failure" or "not good enough" beyond the analyst's eye.

Turning to ceramic vessels, I was struck by the limited range in forming techniques present across all samples examined across the Arkona Cluster, and the relatively limited variation in vessel form. This limited range of material expression suggests that potters were repeating the steps and gestures required to form pots (Bleed 2008; Forte 2009; Kuijpers 2017; Sennett 2008), and that perhaps many of these pots were created by potters who were skilled at potting and had developed a "repertoire of learned gestures" (Sennett 2008:178). The effort that artisans clearly focused on getting rims "right", through both repeated gestures and adaptive irregularities, underscores how, to the potter, this part of the vessel was a focus of the formation stage. This is one of the most difficult parts of the pot to form, and in some contexts is viewed as “technical signature” of the potter (Roddick 2016:140). The extra attention paid to the rim portion of the vessel is visible not only in the extensive decoration found on the exterior of most rims, but also in the care potters took in achieving a rim shape that included castellations.

The ongoing interaction and engagement between material and craftsperson sometimes called for improvisation. Notably, 13 rim sherd scans revealed the addition of clay on top of a fold. In addition, another six sherd scans exhibited evidence of last-minute adaptive irregularities in the form of smaller, more ephemeral added bits of clay on rims and lips. This total of 19 sherds exhibiting evidence of improvisation makes up 30% percent of specimens. Examples of these instances are found at all sites in the cluster with more than one vessel scanned, and are found slightly more often at both AgHk-42 and especially at AgHk-40 (Table 6.21). While the number of scanned samples may or may not be representative of whole vessel patterns or broader site assemblages, higher percentages of adaptive irregularities might indicate these measures were used more often at the later sites in the cluster. This pattern might suggest ceramic craft changed over time to incorporate more adaptive irregularities to achieve a finished pot, or that a broader number of potters who relied on improvisation more often made up the community of practice at these sites.

I would argue the adaptive irregularities evident in the rim formation on ceramic vessels was completed not to improve pot functionality, but to achieve a more consistent shape to a vessel’s lip and rim form around the vessel orifice. These adjustments to rim form seem to suggest potters at Arkona were fully engaged with their hands, eyes and brains, using learned habitual gestures and making judgement calls while practicing their craft (Sennett 2008), adjusting the emerging physical shape of vessel form when they perceived there was a need to. . This negotiation might not end with “perfection,” but instead with a physical form that was a result of the material interaction that the potter could deem was a “good enough” approximation of a pot based on parameters learned and passed down within their community of practice.

That adaptive irregularities appear throughout the cluster suggests there was a commonly shared conception of what rim form needed to embody. As well, the techniques to make rims both engaged with the conventions of what a rim form should look like that was predominant across the broader region during the eleventh through thirteenth centuries, and was internalized locally by potters working in the communities of the Arkona Cluster. In fact, that the earliest sites in the cluster tended to have lower percentages of adaptive measures, while some of the later sites had higher rates of these irregularities, suggest this conception of what a rim and lip should look like might have become more firmly defined over time at Arkona. This could also be a physical manifestation of the development of skill through repeated gestures at the later Arkona sites. These adaptive irregularities show that material is not simply manipulated, but negotiated, to create a form that both the material allows for and that the artisan deems acceptable. That potters adjusted their regular gestures when forming rims and lips shows the agency of the material and vessel in this process (Gosden 1999; Knappet and Malafouris 2008; Watts 2006:2), and shifts the focus to the physical traces left by the techniques and gestures that potters were using to transform matter (Knappet et al. 2010; Watts 2006:44).

Documenting these adaptive irregularities allows us to begin to access what potters' thought was "good enough," and their expectations for the emerging vessel form they were making. Presumably "not good enough" pots were scrapped, while others were found to be nearly "good enough" and needed relatively minor adjustments, while pots without irregularities or adjustments were "good enough" on their own. Though I do not know if un-scanned portions of the vessels examined for this study did or did not contain adaptive irregularities, the specimens I examined that did not show evidence of these adaptations can be thought of as reflecting a rim form that did not need fixing. In other words, these unadjusted rim forms can be thought of as reflecting a mutually acceptable outcome in the negotiation between potter and material, within a given context of production (Ingold 2010; 2013; Watts 2006:44). Thus, identifying the adaptive irregularities visible by micro-CT scans offers a whole new way of exploring material artisan engagement and how ceramics can give insight into tradition and innovation at work in a community of practice.

Finally, I would also suggest that, given potters across the Arkona Cluster used these adaptive and improvisational gestures and techniques, they also are indicative of enculturation across the generations of potters who practiced their craft here. This tradition of improvisation in the "fixing" of rims and lips using particular gestures in these precise ways speaks to the fact that these potters not only taught the next generation of potters the regular repeated motions and gestures used to form rims, but also "tricks of the trade" to adjust that rim taking shape if it was drifting too far from the learning framework, during the practice of potting. There is a shared knowledge of negotiation conveyed by these adaptations, and within the constraints of the material, captured by smoothing or fixing lips, rims, and castellations by using repeated techniques.

The potters at Arkona were concerned with how the rim portion of these vessels looked; they were using repeated gestures and improvisation while forming them and using techniques to add depth, shape, and distinct design expression onto this portion of the vessel. The human-clay interaction and entanglement played out in all stages of vessel construction at the rim, and is visible in the micro-CT results. These potters were giving clay fabrics agency, and were given agency by that clay in the rhythmic, itinerant continually changing relationship between maker and material (Ingold 2010:99).as they worked in their community of practice – in time, in place, and across generations - to create pots that made sense to them within the context of the Arkona Cluster.

7.2.5 Different Makers

Though based on extremely small samples (five clay pipes and three miniature or learner vessels), micro-CT scans provide for some preliminary observations on the differences between ceramic makers within the Arkona Cluster sites. While the full-size vessels sampled here suggest a cohesive community of practice, there are notable differences in production between those vessels and the small learner vessels and the pipes that were scanned that are worth considering here.

Learner vessel scans exhibit several differences from the full-size vessels. For example, the three vessels scanned have a lower inclusion volume than recorded for full-size vessels, exhibiting between 1-3% inclusion volumes, while full-size vessels typically have between 5-15% inclusion volumes. Moreover, the variation in inclusions for learner vessels included two vessels that likely lacked temper (Specimen 012 and 014), because the inclusions present were rounded and relatively small. The third learner vessel had large inclusions as well as a web of planar and tubular voids that appeared to be left from organic material (Specimen 013; see Figure 6.76), both of which might have been intentionally added or were simply present in the clay deposit used, and not sieved out. In Braun's study of Iroquoian clay objects organic temper was found in small vessels, clay lumps and smoking pipes, but not in full sized pots (2015:116), suggesting the process of preparing clay for small pots versus large pots was different both at Arkona and elsewhere.

These differences in inclusions suggest the forming may have not relied on prepared clay fabrics to create these smaller pots. It may also have been the case that the individuals making these pots were practicing forming or finishing gestures on the clay, either as a casual act, or more formally as a learning experience. If so, these individuals would not have needed, or not have had access to, formally prepared clay fabrics, or were making these pots at a time other than when large vessels were made.

These small pots did not exhibit obvious visible forming techniques in the scans, though I do not have a good reference for what a pinch pot might look like in scans. All three pots did exhibit clay added, either to form rims (Specimen 012 and 014), or by folding over the rim to the interior so that the fold was added to the interior (Specimen 013). These were not the neat folds or added clay techniques that were a mark of most full-size vessels, but these miniature pot makers were clearly familiar with the dominant practices used for rim formation, and for correcting rim formation. The decorative elements on these miniature pots also suggest a familiarity with commonly used rim and neck decoration on the larger vessels, with bands of oblique and vertical design elements appearing on the rims and what appears to be an attempt at incised triangular motifs on Specimen 013 (see Appendix A for images of miniature vessel exteriors). I would argue this suggests the makers of these pots were practicing or learning the gestures and repertoire of vessel making, perhaps as novice or apprentice potters, watching, learning, and doing, by participating in the craft of pottery making alongside the more established potters in the Arkona Cluster.

In his petrographic work on ceramic objects from a fourteenth century Ontario Late Woodland Tradition village, Braun (2015) suggested pottery vessels were made by a smaller group of experienced craftspeople, using a restricted palette of materials and techniques. He also argued that smoking pipes were made by larger numbers of people of differing skill levels, using a wider range of materials. McCartney (2018:40) builds on Braun's work, and that of Creese (2016), by suggesting clay pipe manufacture in the Arkona Cluster was "…idiosyncratic, utilizing a wide variety of base clays and tempers in addition to individualistic decorative choices." From the limited scans I completed, I can at least confirm that, within the Arkona Cluster, the smoking pipes scanned exhibited obvious differences from Arkona ceramic vessels, and perhaps at least some of the smoking pipes scanned were made by individuals who were not also making vessels.

The clay pipes scanned had a variable inclusion volume range, with percentages between 2.2% and 7.1%. The two pipes with higher inclusion volumes (Specimens 086 at 6.7%, and Specimen 088 at 7.1%) may be tempered, based on my visual examination of the fabric, while the other three (all with inclusion volume percentages of 2.2% or 2.3%) do not appear to be tempered. Though based on a small sample, this variation suggests either less of a concern for tempering properties within smoking pipe fabrics, or perhaps some pipe makers were not as versed in clay fabric recipes as vessel makers.

Within the clay pipe collection from the Arkona Cluster of sites, there is a fair degree of variability in both manufacture and decoration (McCartney 2018:93). McCartney (2018:94) noted, "The Arkona Cluster pipe assemblages reveal a striking diversity of morphological and decorative attributes across sites, despite their geographic and temporal proximity." He also noted differences in pipe assemblages and their deposition between sites (ibid), suggesting that these differences may indicate different sets of pipe makers at each locale (McCartney 2018:97-8). In the sample of scanned pipes I examined there was variability in manufacture, with joining voids visible between pieces of clay that were used to build the pipe stems and bowls, and the use of corrective boreholes in two specimens. With a larger sample, further variability and patterning within the cluster and between sites might emerge. Certainly, the context for the use of smoking pipes differs from that of vessels, and that difference may also suggest smoking pipes were produced as a more individualistic practice (Braun 2015; McCartney 2018).

Micro-CT scan data provides a new opportunity to examine the making of smoking pipes and explore distinct dimensions of that craft. At the very least, the variation of inclusion volumes across even a small sample does suggest clay mixing was not as important a dimension to pipe manufacture, or that they were made by a wider set of individuals. Knowledge transmission systems amongst makers for clay pipes and makers of pots were thus likely distinct across the Arkona Cluster.

7.2.6 Toward a Community of Practice in the Arkona Cluster

In this section I focus on “communities of practice” and “communities of potters.” These notions offer a way to think about potters and the communities they worked within to produce ceramics, and have been embraced by many archaeologists and ethno-archaeologists (e.g.; Bowser and Patton 2008; Cordell and Habicht-Mauche 2012; Crown 1999, 2007; Gosselain 1992; Huntley 2006; Peelo 2011; Michelaki 2008; Roddick and Stahl 2016; Sassaman and Rudolphi 2001; Stark 2006; Van Keuren 2006). The concept of a community of practice draws on Lave and Wenger’s (1991) “situated learning,” in which members of a community are created based on their participation in the same tasks (Joyce 2012; Wegner 1999). In the case of a community of potters, this community would be the social group that participates in the task of harvesting raw materials, preparing them, and making pots (Arnold 2005). A community interacts with each other distinctly from broader members of the settlements they are a part of, and are insulated from other communities of potters who produce similar but not identical products (Arnold 2005:16). These communities, are defined by a shared history of practice, learning frameworks and regularities of production and use but are not homogenous or bounded (Eckert 2008; Gosselain 2016; Roddick 2016).

When we are talking about the craft of ceramic making in an Indigenous, non-industrial, village-level setting we are talking about an activity that is part of the day-to-day social lives of people interacting with their families, neighbours, and communities. Each potter likely began learning their craft at a young age, either from observing or direct contact with closely related potters within their community (Crown 2014), whether that community be a loosely knit extended family or a more structured, long-house setting. These open-hearth fired pots may have been communally fired with several group members producing pots at one time, or may have been fired in a one-off setting by an individual, depending on the context. At Arkona, the community of potters could potentially encompass pot makers who interact with other potters at a particular site, or generations of potters across the life of the cluster, or interact with pot makers beyond the cluster and across the region. This framework shifts ceramic focus onto the makers of pots, the choices they made, and their engagement with material tradition and innovation.

It is important to stress that my study was focused on scanning a sample of vessels from the Arkona Cluster of sites. As such, these results are not representative of a complete analysis of all site ceramic assemblages. Nonetheless, the findings presented here clearly engage with and further research on the Arkona Cluster of sites and specifically on those ceramic assemblages, while offering new insights into this community of practice operating in an archaeological material borderland between the twelfth and thirteenth centuries CE.

There were different ways of doing things within and across this cluster of sites, as is readily evident materially and in settlement form (Ferris 2018; St. John and Ferris 2019; Suko 2017a). The micro-CT scan data further contributes to exploring this range of expression. Findings noted vessels with lower or higher than average percentages of inclusions and differences in the range of rim forming techniques used. But general similarities in the ways pots were created also suggest potters across this cluster were familiar with and working within regional ceramic trends seen for this period, including variable ceramic traditions to the east and west. Moreover, fabric recipes, rim forming strategies, adaptive irregularities, and the likely role of small learner vessels in trans-generational learning across the duration of this diversity of settlements also suggest potters were participating in a distinct community of practice. The nature of this community has been examined in previous ceramics-focused research on this cluster of sites (Cunningham 2001; Watts 2006; Suko 2017a), and the micro-CT findings presented here offer additional insight.

Cunningham's 2001 analysis of ceramic decorative and morphological features from AgHk-32 (the Van Bree site), which is the earliest of the documented sites from the Arkona Cluster, was conducted before the full extent of this cluster was discovered and investigated. Cunningham concluded that the Van Bree ceramics were produced by two different potter traditions that spatially sorted out across the site between a "West" and "Central" cluster. He also suggested that these two vessel clusters reflected distinct ceramic traditions, as local culture history frameworks have framed these (i.e., Western Basin Tradition and Ontario Late Woodland Tradition), but were not highly structured. Micro-CT scans of Van Bree vessels tend to suggest a single potting community made these vessels, despite "tradition" variation in decorative attributes. Notably, of the ten vessels scanned, folded rims (4), added clay rims (4), and folded rims with added clay (2) were all present at Van Bree, and did not separate neatly between Cunningham's spatial clusters. Likewise, vessels that had been identified by Cunningham as "Western Basin," had rims constructed using different techniques. If there was a co-occupation of the site represented by spatial distribution of ceramic attributes as Cunningham suggested (1999, 2001), we might expect the community of practice from one tradition to rely on one rim forming technique, while the other community of practice rely on another; however micro-CT analysis revealed this was not the case.

More recently, Suko's (2017) analysis of a later site in the Arkona Cluster, AgHk-54 (Inland West Location 3), suggested that the ceramic vessels from this site may reflect a single, localized pottery-making community. Suko (2017:263) interpreted the ceramics as reflecting a shared local identity and knowledge of craft, incorporating potting practices from the east and west to shape a local, pluralistic material "borderland" expression. In my study, nine vessels from this site were scanned. Vessels included five whose rims were made by folding, two by folding with added clay, and two that were plain. From this sample potters appear to have relied heavily on the folding technique, a method that remained popular throughout the duration of the Arkona Cluster. These findings further suggest that the potters at here were also connected to a trans-generational community of practice that was larger than the spatial or temporal limits of the site, reflecting the shared local potting tradition of the Arkona Cluster.

Watts (2006:195-196), based on a broader examination of ceramics from within and to the east and west of the Arkona sites, found that the two predominant archaeological ceramic traditions across that wider region embodied distinct sets of practices. He noted in particular that prevalent vessel shapes suggest both groups were governed by an intuitive understanding of "proper" vessel form designs, and that vessel forms were conservative to change. He also argued that decorative practices and symmetry were less structured or adhered to across assemblages from the material tradition to the west ("Western Basin Tradition") than they were for the material tradition to the east ("Ontario Late Woodland Tradition"). In the examination of the Van Bree (AgHk-32) assemblage, in particular, Watts (2006:190) argued that there was no co-occupation at the site by discrete potting traditions, but rather a "syncretic social form" expressing a "ceramic hybridization," with elements of both traditions being used by potters on some of the vessels.

The morphological data presented in Chapter 6 suggests potters in the Arkona Cluster were producing vessels, and forming them, from a taught learning framework of acceptable forms: one with short necks (76% of all vessels where neck form could be determined), and one with elongated necks (24% of all vessels where neck form could be determined). Across these two forms the majority of the vessels sampled had flat lips, and concave or straight upper rim profiles. Decorative elements examined also suggested there were broad consistencies in practice (e.g., stamped obliques making up the majority of the rim motifs). But there was also clear variation in form and finishing. The neck portion of the vessels sampled reflected the use of both incising and stamping, and motifs were more varied than on rims. While oblique motifs made up 88% of the upper rim decoration, for example, the largest category of decoration on the neck, triangular motifs, only accounted for 43% of neck decoration. While these triangular motifs on some necks, and the slightly higher frequency of exterior punctates suggest a "Western Basin Tradition" influence at Arkona, the overall morphology of vessels, the prevalence of bosses, and the frequent use of stamped obliques on the rim portion of vessels also suggests an "Ontario Late Woodland Tradition" influence. These observations reflect the kind of pluralistic mélange of approaches previously noted for these sites (Suko 2017a; Watts 2006). Micro-CT data adds the observation that folded, added clay, plain rim forms were all used on both long-necked and short-necked vessels, and across the diversity of decorative motifs noted for these specimens.

Some of the patterning seen in the Arkona vessels sampled could be due to temporal differences between the sites within the cluster (see Ferris 2018 and St. John and Ferris 2019 for further temporal sequencing; see also Figure 2.3). As the trans-generational community of potters negotiated tradition and innovation through this material borderland over time, there are slight changes that could be seen both with and without micro-CT data. Though limited grain-size analysis hinted that potters might be using smaller temper at the last site in the cluster (AgHk-42, Bingo village), generally rim manufacturing techniques, inclusion and void volumes, and other attributes only seen through micro-CT were not markedly different between sites within the cluster.

However, a number of the morphological and finishing attributes visible on the sampled specimens trended through time at Arkona. Overall, Van Bree (AgHk-32), which is the earliest site in the cluster, seems to have the most attributes that differentiated it from the other, later dated sites in the cluster, with higher percentages of both elongated necks and triangle neck motifs, and a higher percentage of interior punctates. Potters at AgHk-32 used diverse upper rim profiles, and this was the only site that exhibited straight rather than concave rim profiles as the most common form (60%), which makes sense given that concave rim profiles tended to go hand in hand with short curved necks. The elongated necks and triangle motifs present at Van Bree suggest there may have been a stronger Western Basin Tradition influence within Arkona potting practices earlier on. However, the use of more interior punctates at Van Bree (and at AgHk-54) runs counter to this trend, since interior punctates are supposedly an Ontario Woodland Tradition trait at this time. Though playing with a mix of attributes from distinct potting traditions at Van Bree is consistent with the ceramic hybridization noted by Watts (2006), and the pluralistic material expression observed by Suko (2017).

Micro-CT data suggests exterior and neck decorative motifs and neck shape have very little correlation to the forming techniques used to create the rim of the vessel. However, neck motif and neck shape did correlate: 79% of elongated necks had triangle motifs while only 27% of short necks had triangle motifs. There was clearly a link in the potters' minds at Arkona between the elongated neck form and the range of decoration that could be used to fill them. However, potters who were decorating necks with the "hallmark" (Murphy and Ferris 1990:205) Western Basin Tradition diamond or triangular neck motifs were forming the rims of these vessels in the same way potters decorating their necks with more typically Ontario Late Woodland motifs were. However, it is worth noting that in this study a relatively high portion of the elongated necks from Figura (AgHk-52) (1 out of 3) and Bingo (AgHk-42) (2 out of 4) were considered somewhat exceptional vessels, with glyphs drawn in the open panels of the triangles (see Specimens 065, 066 and 068 in Appendix A; Archaeologix Inc. 2012; Ferris and Wilson 2010; Golder 2012b). While the elongated necks made up 50% of the vessels at Van Bree, perhaps at the later sites these vessels became a sort of specialized form that could be pulled out of a potter's repertoire when they needed a larger canvas for a decorative expression of tradition.

There were fewer notable differences between the remainder of the sites, although some slight variations were noted. One such example was AgHk-42 and AgHk-40 having a higher instance of adaptive irregularities applied to the rim. Other slight variations within the cluster were noted, such as rounded lip forms being more common in the AgHk-52 sample than elsewhere. AgHk-54 differed slightly because of its high percentage of short necks (89%), 100% concave rim profiles, and lack of rims formed using added clay. Exterior decorative elements differed. Notably samples from AgHk-42 (Bingo Village) and AgHk-54 (Inland West Location 3) had oblique motifs appearing on necks while they were absent at AgHk-52 (Figura), perhaps suggesting the former two sites are more closely linked to one another than to Figura, either temporally or with a more closely overlapping community of potters.

While not conclusive, the combination of the increase in adaptive irregularities at later sites, the decrease in the number of elongated neck shapes, and the fact that these elongated necks at later sites were sometimes used for what archaeologists have classed as “exceptional” vessels, may collectively indicate a drift over time at Arkona to a more rigid idea of what a “typical” pot should look like. On the other hand, despite variation found in neck shape (particularly at AgHk-32), the flexibility of punctate and boss use, and neck decorative elements seen throughout the sample, and the methods of manufacturing rims, all remain the same across space and time. Folding rims was the most common method used, and applying clay to rims the second most common. The adherence to only one or two ways of forming rims, and the fact that these techniques are consistently in use for generations, suggest that this community of practice at Arkona shared a common tradition of pottery making. This tradition was informed by broader potting practices to the east and west, and those broader temporal and regional trends became incorporated elements practiced within this localized craft expression.

Micro-CT analysis allows us to see decorative variation as just that, variation within the final finishing steps along the broader process of making. Perhaps finishing is the most ephemeral and variable step in this process by potter inclination, depending on adherence to tradition, innovation or playfulness. But it is also a stage in production that perhaps does not tell us as much as vessel forming does about how potters learned their craft and their community. While finishing elements reflect tradition, they are also clearly open to innovation and choice, and so tell us something different about potters and their community. It is only when we access all of the steps in this process of potting that we can begin to think more robustly about the communities of practice in which individual potters participated. Micro-CT data allows us to investigate the learning process and broaden the focus of pot making from an emphasis on finishing attributes.

Primary forming techniques are only externally visible to the analyst’s eye if secondary forming techniques have not obscured them, so they have not been previously studied at the Arkona Cluster. The micro-CT analysis from this study has shown that over a few generations, Arkona potters used a range of shared practices between sites, but also that their practice shifted over time.

From the micro-CT data it was evident that differing sections of vessels revealed more or less about forming practices. For example, paddle and anvil use likely minimized void patterning and other manufacturing techniques lower down the body of vessels. More generally, ceramic vessel manufacturing techniques do vary between vessel sections and even within them (van der Leeuw 1993, 1994). Various manufacturing techniques are regularly combined in the construction of a single vessel (e.g., Kozatsas et al. 2018), which was readily evident here in rim forming gestures followed in creating castellations. Distinct construction zones of a vessel may or may not have been how the potter conceptualized pot form as they were making them, but it is clear from the micro-CT scans that rim forming did require secondary steps during manufacture, and thus was a useful focus to explore potter practice at Arkona.

Despite clear decorative variability and engagement with broader regional trends east and west, as well as use of variable neck forms, there is little evidence from the micro-CT analysis to suggest two distinct and separate potter communities of practice were at work at Arkona. Rather, and furthering Suko (2017:42) and Watts (2006) interpretations, these findings reflect a localized ceramic practice that incorporated manufacturing and design elements from multiple ceramic craft traditions. Given these findings, the Arkona ceramics appear to be the expression of a distinct artisan community that was sustaining tradition and innovation in practice, one that archaeologically captures a material borderland at that time and in that place.

At Arkona, the community of practice, which I argue existed and persisted over the 270 year life span of these sites was a multigenerational potting community that articulated and passed along a set of clay preparation and rim forming practices. Relatively stable ratios of inclusions to clay and the prevalence of rims which have been folded over, or which have had clay added to them, suggest a shared knowledge between potters at Arkona. The differences seen in the pots from Van Bree, suggest some of these practices may have shifted over time, and that potters at the other sites, who were practicing potting within the last half century of occupation at Arkona (from around 1200-1270 CE), were interacting with each other in a more immediate way. It seems likely that the potters from sites that were more closely connected generationally may have been participating in the craft of ceramic making at the same time, using shared techniques and practices. The regularity and context of practice would have impacted their potting habits, and the variation seen in the finishing of pots at Arkona may reflect the fluid borderland context in which they were being produced. Making pots was a skill which was learned locally and formed a local identity, and local identity tensions may have played out in the Arkona Cluster. However, potters were not potting in isolation but had connections both within and beyond the Arkona Cluster. Finishing attributes are reflective of larger constellations of practice that span the Woodland period in the lower Great Lakes. The consistency of learning frameworks over generations indicates a fairly tight community of practice at Arkona, while changes in this practice, like those seen between Van Bree and the later sites, may indicate some members in the community introduced new ways of doing things, possibly from further afield.

Next steps could include research of this type at a larger analytical scale, looking at how pots were made beyond Arkona. A larger study could examine whether there are in fact constellations of practice throughout the Late Woodland. This is not a closed space but one where people were aware of larger trends in potting practice throughout time and space. Morphological attributes at Arkona tend to reflect the broader regional context in which these potters were working, as does the application of decorative elements such as stamped obliques and punctates. The thickened rim is a trait found beyond this cluster of sites; achieved through one set of learned gestures within the Arkona cluster one way, and achieved through a different learned practice elsewhere.

"Identity" across this Arkona Cluster and archaeological borderland was maintained through human practice, not inscribed on the pots. But the materiality of practice (ways of making pots) captured in those artifacts does indicate a belonging to community, and expression of a potter's identity. Through micro-CT scans we gain further insight into how pottery-making knowledge and tradition was learned, remembered, and negotiated through the doing of potting in this setting. Further micro-CT research on ceramic practices from a broader region, similar to the scope of the study undertaken by Watts (2006), would more clearly document and trace the local trajectories of tradition and innovation, and the boundaries of interaction between distinct communities of practice across southwestern Ontario, and through this period.

7.3 Conclusions

This section offers some conclusions regarding what I feel this research has achieved. It will explain what micro-CT adds to archaeological ceramic analysis and the greatest strengths I see for micro-CT-driven analyses of ceramics, including further discussion on how this method can be incorporated into a broader ceramic research strategy. It will cover my final evaluation of this method for ceramic analysis, including a discussion of what I would have changed in this research were I to go back and do it again. Potential directions for future work are also discussed.

7.3.1 The Value of Micro-CT in Archaeological Ceramic Analysis

The greatest strength of micro-CT-based analysis in archaeological ceramic research is that it gives the archaeologist the ability to explore, in 3D and non-invasively, potting communities and access to methods of vessel manufacture that cannot be accessed otherwise. By providing the archaeologist with a link to the gestures and individual artisan choices that were involved in ceramic manufacture, micro-CT data gives us a glimpse into the interactions, engagements and negotiations that occurred between materials and ceramic craftspeople in the past. What it really allows us to explore is the innovation of individual artisans working within a much larger tradition of ceramic making.

Micro-CT scanning, in effect, allows us to access artisan and material agency beyond simple ceramic artifact descriptions. While conceptual frameworks emphasizing material agency and focusing on technology and gestures (e.g. Gosden 1999; Knappet and Malafouris 2008; Knappet at al. 2010; Watts 2006:2) are good in theory, accessing these gestures and material-human interactions in the artifacts left behind is difficult to achieve. These vestiges available to the archaeologist for study are fragments of a finished product, and the artisan’s various actions and correctives along the way to production are often covered up, smoothed over, or wiped away in finishing the vessel, or masked subsequently through the post-production use, destruction, and disposal of the object. I would argue that micro-CT scanning offers a new and transformative way to access this process of interaction between materials and craft producers, allowing us some insight into the engagement and entanglements between them, and the contexts these interactions were occurring within.

While undeniably an innovative method for ceramic analysis, whether conducting a micro-CT-based study is worth the effort depends on both the goals and budget for a research project. As with any technique, micro-CT has limitations and inherent problems that researchers must discover and correct for, where possible. As discussed previously, micro-CT scanning is a challenging method to employ, one with a steep learning curve to become familiar with the hardware and software, running a scan, conducting image analysis, and obtaining meaningful results. Ideally, to both master the technology and frame robust research designs, I would suggest having an experienced technician run the scans and be involved in the design of the research project to support the researcher and ensure that scans can best service research questions. My experiences suggest, at least, that inexperience substantially adds time to a project, and makes it difficult to anticipate what will or will not work beforehand. There are also issues with the upkeep of the machine itself, and the need for a technician rather than an archaeologist to troubleshoot when things go wrong.

Once the scans were created, the next challenge was to translate these remarkable, high resolution, non-invasive images into meaningful, explicable data: both qualitative and quantitative. A large part of this dissertation work involved the process of researching and determining methods of 3D image analysis that would be useful for recognizing distinctive features related to production and manufacturing techniques and developing novel analytical protocols. As such, considering image analysis software that can best aid the needs of the research project is an important step in micro-CT research. This was a challenge for this project since micro-CT studies of low fired earthenwares was in its infancy when I began, and analytical software options were limited. From where I am now, had Dragonfly image analysis software been available at the beginning of this research, I would have relied heavily on it. After all, as the designer’s state, Dragonfly was “designed for researchers and engineers in the fields of material and life sciences, geology, nanotechnology, and the environment" (Object Research Systems 2020; see: https://www.theobjects.com/dragonfly/index.html). I also would have been able to take a direct training workshop in the image analysis program that I was using, rather than trying to self-teach myself from limited manuals. Such training was not an option for VG (a European based company), but Dragonfly (based in Montreal Québec) provides both online workshops and in person training. However, this is an after the fact regret I only raise in retrospect: Dragonfly was released by ORS partway through my research (in September 2016: See Appendix F for my research timeline), after I had already become familiar with VG, and at the beginning of this project. When I started, I believed VG was the best option for the type of analysis I was conducting.

Micro-CT analysis might also be prohibitively costly and as such, may best be used after initial radiography studies are undertaken (Middleton 2005; Greene et al. 2017). Certainly, conducting a lower-cost radiography study on a larger number of sherds might be a good method for deciding which ceramic specimens to scan in a micro-CT machine. However, some of the minute details visible in micro-CT scans would be missed in an initial X-ray screening. Sample selection is also important. Certain types of ceramics will be more applicable to micro-CT research. For example, low fired earthenwares made by hand or wheel will contain voids, inclusions and temper. But micro-CT scans may not provide interpretive value for more refined earthenwares or porcelains, or mass-produced ceramics. Because each technology has its own strengths and weaknesses, it is probable that micro-CT analysis will not replace visual examination, X-radiography or petrography, but will become a vital, complimentary technique used in the material science study of ceramic materials.

A critical contribution of micro-CT research specifically, and micro studies generally, is that these techniques broaden the focus of ceramic analysis significantly away from solely classifying visible decorative attributes, which certainly has been the primary focus of Late Woodland analyses for the entire history of the discipline. Micro analyses allows researchers to more directly think about the potter and the choices they were making in the production of vessels and all stages of the *chaîne opératoire* of ceramic manufacture. Micro-CT data allows archaeologists to access the potter beyond decorative styles and traits, and contributes to a broader discourse on communities of practice, learning and knowledge transmission.

There is no point of scanning ceramics just for the sake of making scans, but with a specific research question, a budget to complete the project, and a careful research design in mind, micro-CT analysis is an exciting and useful tool for ceramic analysis. By conducting a micro-CT analysis on the Arkona Cluster ceramics, I hope I have contributed to the research of pottery manufacture, and recognition of the individuals and communities who were making ceramics and the complex negotiations and decision making processes that potters put into the production of every vessel as a part of their daily lives.

Research on micro-CT analysis of archaeological ceramics is also relevant to the increased use of digital imaging and 3D models in archaeology generally. Many anthropologists and cultural heritage institutions are using 3D models and digital collections as a means of disseminating knowledge (e.g. Able et al. 2011:878; Bruno et al. 2010; Evans and Daly 2006; Keene 1998; Lynch 2002; Waibel 2014). In fact, micro-CT images from this dissertation were used in a Museum of Ontario Archaeology exhibit entitled: Earth and Fire: The Craft and Form of Ontario Earthenware Pottery Traditions (http://archaeologymuseum.ca/visit-us/exhibits/past-exhibits/), will feature in future museum exhibits, and has been featured in blog posts by the Museum of Ontario Archaeology (https://archaeologymuseum.ca/potters-in-the-past-micro-computed-tomography-of-archaeological-ceramics/).

Many recent studies have begun to assess digitization methods and attempts are being made to increase their efficiency for documenting archaeological collections. In Ontario (and elsewhere), boxes of artifacts are accumulating due to the increase in cultural resource management (CRM) work without value added studies being undertaken to further learning anything new from this record (Ferris and Cannon 2009). These collections (whether from CRM or museums) are inaccessible to researchers, students, and the public, especially with regards to Indigenous and descendant communities (e.g., Ferris and Welch 2014). Micro-CT scans have the potential to make collections more accessible, by providing a detailed high-resolution view of the exterior and interior of ceramics, and the identification of decoration, fingerprints, and morphological characteristics, without any unnecessary handling of fragile collections (Clark et al. 2001; Keene 1997:303; Lu and Pan 2010:213). In this way, the non-invasive nature of micro-CT may allow for analysis of previously un-examined collections, especially those of a culturally sensitive nature. Likewise, micro-CT scanning has the potential to supplement traditional destructive techniques currently in use in ceramic studies. Furthermore, the digitization of archaeological material may allow for wider reaching dissemination of material and make these ceramics accessible to descendant communities and researchers outside of Ontario.

7.3.2 Future Directions for Research

Recent articles such as those by Kozatsas et al. (2018) and Sanger (2017) have highlighted the potential for micro-CT and CT methodologies to add to the field of ceramic analysis. These studies, much like this dissertation, both emphasize the remarkable ability of CT scans to highlight the steps in craft production that are hidden by subsequent actions in that production sequence. The ability to tease out individualized craft behaviours will be the greatest strength of micro-CT (Kozatsas et al. 2018). The focus to date has been primarily on the qualitative analysis of CT images to explore the correlations between ceramic fabric features and manufacturing techniques or forming operations (Kozatsas et al. 2018; Sanger 2017), rather than quantitative data. These recent studies, and this dissertation, are beginning to suggest protocols for scanning ceramics and for the description and quantification of the features that can best be identified in micro-CT images. This research is also starting to define and develop a language for how these features relate to the unique manipulations potters are putting on clay, adapted in part from previous archaeological and ethnographic work. Kozatsas et al. (2018) focused far more on the nature of the joins in clay than I did, which is something I would incorporate into future work.

One of the areas of greatest promise that was not explored in any depth during this research is the development of a non-invasive, 3D petrography. Many archaeologists have recognized the potential for micro-CT to be used as a tool for exploring the recipes of clay fabrics used to construct ceramic vessels. While this is an avenue of research that has not yet been undertaken using micro-CT technology, refinement of the scanning process and analysis might allow for mineral identification in the future. Dual energy techniques and the use of calibrated scans could aid in identifying minerals based on their density (Friedman et al. 2012; McKenzie-Clark and Magnussen 2014). Scanning smaller specimens at higher resolutions would be useful for recognizing individual mineral shapes and angularity, while providing larger sample sizes than manual petrographic techniques. Furthermore, micro-CT technology and image analysis software will continue to be refined over time and may allow greater potential for a 3D petrography, and notably for overcoming the limitations of singular, 2D petrographic profiles.

Thin section petrographic analysis undertaken by Dr. Linda Howie of HD Analytical Solutions on a sample of the Arkona sherds on behalf of Dr. Ferris, funded through his SSHRC research grant, was intended to further advance my comparative research. Unfortunately, that work was not completed in time to be included in this study. Nonetheless, preliminary, informal reporting (Howie, personal communication, 2017), noted the likelihood that Arkona potters regularly used fire-cracked rock as a temper source in vessels from across this cluster of sites. This observation is furthered by the shape and angularity of crushed rock, which should be different than uncrushed rock, and this could be seen in 3D volumes. Other more recent studies (e.g. Hawkins et al. 2019; St. John et al. 2019), underscore the capacity of the two techniques to be complementary. In these studies, micro-CT scans provides a big picture view of ceramic fabric preparations and information on rim manufacturing techniques, while petrography provides detailed information on ceramic fabric preparation and identifies the materials within that fabric.

If, in the future, we are able to determine mineralogy of temper materials or inclusions in the clay, as Carr and Komorowski (1995), McKenzie-Clark and Magnussen (2013) and Middleton (2005:82-83) all suggest, using micro-CT scanning will have several advantages over traditional thin sectioning, since it is non-invasive, and it can provide a more representative sample of the inclusions and voids in a sherd. Within the scope of this dissertation it was not feasible to use the micro-CT scans to determine what specific minerals made up the inclusion and temper portions of the ceramics.

With regards to the provenance of clay sources and mineral identification, micro-CT scans are not as useful as thin section petrography at this point in time (Lamontagne 2018). When working with micro-CT data, we do not have the colour and reflective properties of minerals to work with, both of which are keys to petrographic analysis (Quinn 2013). Micro-CT scans, however, have proven useful for visualizing and even identifying plant species used by potters based on voids left by vegetative fibre temper (Kahl and Ramminger 2012; Sanger et. al. 2013), and exploring hair or fur temper in ceramics from the Canadian Arctic (Moody 2018). With future studies that focus on this aspect of ceramics, micro-CT analysis may be able to answer some of the same questions that current ceramic petrography does; but the reality is that micro-CT analyses see the internal architecture of ceramics in an entirely different way than petrography analyses do, pointing to future complementary strengths between these two approaches.

In this research I conducted a small scale study on experimental clay slabs (see Chapter 6), and others have conducted both radiography (Berg 2011) and CT studies (Sanger 2016) using experimental vessels and slabs to determine how manufacturing traces are manifest in micro internal ceramic structures. Future work could include compiling these results and making them available in a manufacturing technique database including both experimental and ethnographic pots (e.g., work by Danielle Crecca and Andrew Roddick at McMaster's Lab for Interdisciplinary Research on Archaeological Ceramics https://socialsciences.mcmaster.ca/lab-for-interdisciplinary-research-on-archaeological-ceramics-lirac/current-research; and some preliminary micro-CT scans of vessels created by potter Richard Zane Smith https://www.facebook.com/groups/591089374391661/permalink/1243541102479815/). Such a database would be an extremely useful resource for archaeologists examining microstructures in archaeological ceramics since "the specific microstructures induced by different forming techniques is still debated and therefore, not a straightforward form of analysis" (Weglorz 2018:58). An experimental and ethnographic manufacturing technique database would allow for allow greater insights into low fired earthenware ceramics both locally and globally.

While this case study of vessels from the Arkona Cluster provided insight into ceramic manufacture at one particular time and place in the Late Woodland, future research could explore Ontario Indigenous pottery manufacture over a greater geographic and temporal expanse. This research could include scanning more vessels from the sites included in the non-Arkona scans for this research, and from other Ontario Late Woodland contexts. With larger datasets of pottery and pottery manufacturing techniques in use throughout the Late Woodland, we could better understand how potters participated in larger technological and methodological trends through time and space, and how these were differently internalized within local communities of practice. Based on my limited scans of specimens from the Late Woodland I suspect potters were engaging with larger trends but also making sense of those trends internally - constructing pots and mixing clay in the ways that were based on how they learned to do so from those closest to them.

When we place this research in the wider context of ceramic manufacture in Ontario and the Northeast, there is little existing comparative data. Recent collaborative work that I have participated in with the Huron-Wendat Nation featured micro-CT scanning of 74 ceramic specimens as one part of a multi-method approach to uncovering ceramic communities of practice (Hawkins et al. 2019; St. John et al. 2019). This study was focused on a different time and place than the Arkona Cluster, specifically focusing on high collared pottery from pre-existing archaeological collections found across the lower Great Lakes, St. Lawrence Valley, and northern Ontario and Québec from the fifteenth and sixteenth centuries. The micro-CT analysis I conducted presented readily observed commonalities and differences between techniques used by these different populations of Late Woodland potters. I noted that rim forming through folding was not observed in any Huron-Wendat vessels. Further, the Huron-Wendat vessels exhibited a coiling or stacking technique in collar construction in 19 of 74 (26%) vessel specimens, which was not observed in any Arkona specimens. However, both communities of potters were using applied layers of clay in various ways to achieve a collared effect. In the Huron-Wendat sample, 55 of 74 (74%) rims were made using layered or applied clay, while at the Arkona Cluster 28 of 67 (42%) vessels had added clay to the rim portion of the vessel. Applying coils or layers of clay to form castellations seems to be a technique used by Huron-Wendat potters more widely (Weglorz 2018:57).

The observations from micro-CT scan data on rim manufacturing techniques underscore that Arkona potters and the Huron-Wendat potters were each part of distinct, closely knit communities of practice. At the same time, these potting communities from different times, places and ways of living were both engaged in the larger craft tradition of potting in the Northeast. Future work employing micro-CT scanning on more Woodland ceramics from a greater spatial-temporal range might reveal more “tools of the trade,” and how broadly ones I have been able to document, like folding over rims and using applied layers of clay to create thickened rims, were shared across Woodland potting tradition.

7.3.3 Final Thoughts

As we build on these initial micro-CT ceramic studies and attempt to develop a methodological and theoretical program for the use of micro-CT in archaeological ceramic research we must keep both the potential and the limitations of this method in mind. There was a steep learning curve to the process. In hopes of decreasing that curve for future researchers there are a number of “best practices” I posit here for the micro-CT scanning of ceramics going forward, based on lessons I learned over the course of this research. Firstly, if the intent of the study is to closely examine the size, shape and amount of inclusions and voids in a ceramic fabric the specimens should be scanned at a constant voxel size to eliminate discrepancies and allow for consistent cut off points at to eliminate noise at the smallest end of the spectrum. If material characterization is the goal, calibrated scans of ceramics need to be perfected and dual energy techniques explored. Future work on material characterization should employ direct comparisons between micro-CT scans and petrographic thin sections of the same materials. In all research, whenever possible, depending on the condition of the machine, users should employ consistent beam energy (kV) and beam current (µa) settings (for the Nikon XTH 225 ST system I suggest about 130-140kV and µa of between 67-70). When the characterization of forming techniques and voids is the goal, vessel sections that have been mended should be avoided, since segmenting actual voids in the fabric from voids between mended sherds is difficult. Finally, when selecting samples for scanning, a simple X-ray technique could be used before deciding which samples to micro-CT scan.

Sanger’s (2017) method of visualizing many sherds on the live viewing screens, but only reconstructing a portion of those, could be easily replicated.

There has been excellent research examining decorative and morphological features on the exteriors of pots, and how these reflect the communities and constellations of practice that potters are working within and research involving the compositional analysis of ceramics has furthered these undertandings. Research conducted using ethnographic analogy to contextualize communities of practice and ceramic production in the past has added greatly to archaeologists’s understandings of these communities. But I think what micro-CT adds is a far greater understanding of the community of practice producing pots in a given setting. It takes away the need to rely on analogy or assumptions about how potters were manipulating clay and lets the archaeologist directly see the resulting joins and void structures that are caused by the repeated hand motions and gestures of the potters. As archaeologists, we talk a lot about the embodied knowledge in communities of practice, but in reality this is hard for us to access. We can easily measure changes in vessel form or changes in decoration across time and space, and we can access production through geochemical analysis and petrography. Micro-CT, however, allows us to access the craftsperson’s gestures used to form pots and the ongoing improvisation inherent in the craft of potting through traces hidden within the vessel walls.

Micro-CT scanning has the potential to reveal many aspects of the practice of pottery making not accessible or only differently accessible previously. With a greater database of scans we may be able to trace interactions between groups based on pot making, and potentially how communities sourced and prepared their temper and clay. We can trace potting traditions based on minute variations in potting techniques and shift the focus in ceramic analysis to include all of the steps involved in making a pot. Through micro-CT scans we can gain further insight into how pottery making knowledge was learned, taught, and remembered through the circumstances of potting over the course of generations. Most importantly, this innovative technology allows the archaeologist to interact with, and appreciate, the ancient potters of this place, and the ways they engaged in and negotiated with their craft and their materials, within the contexts of their daily lives.

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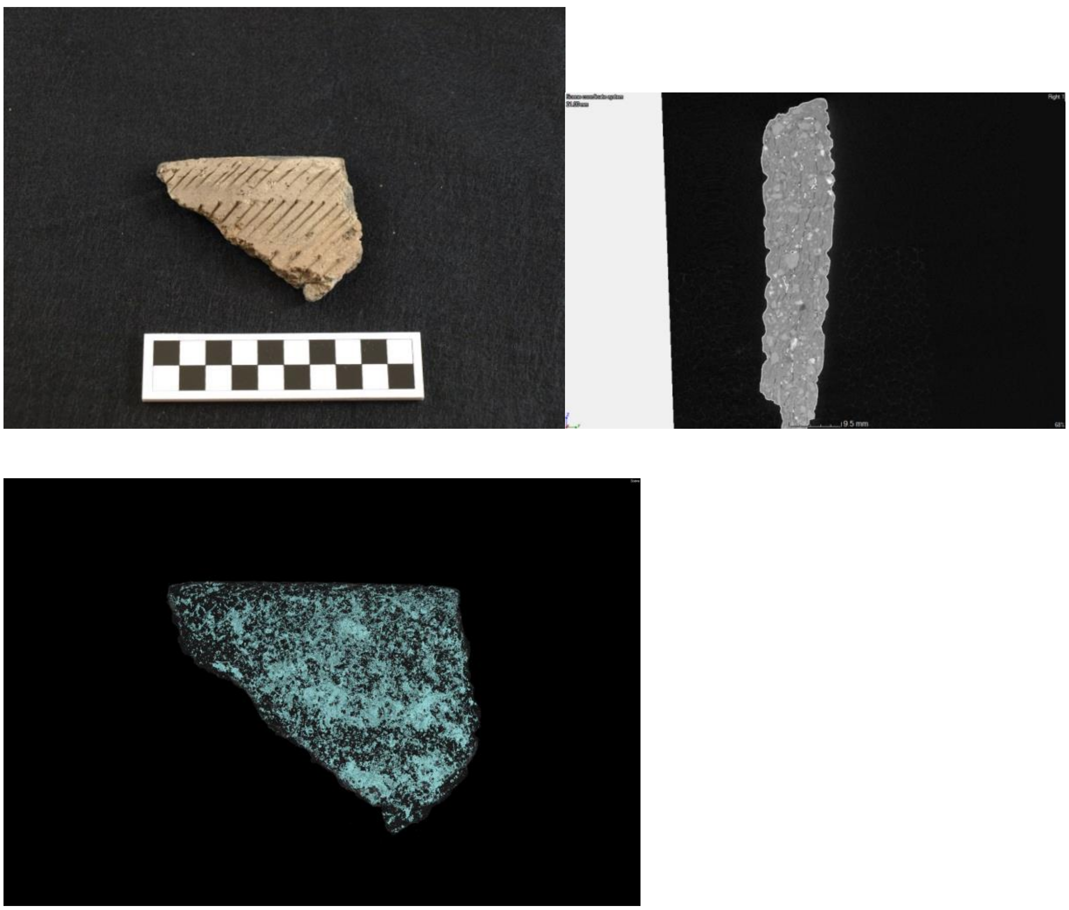
Appendices

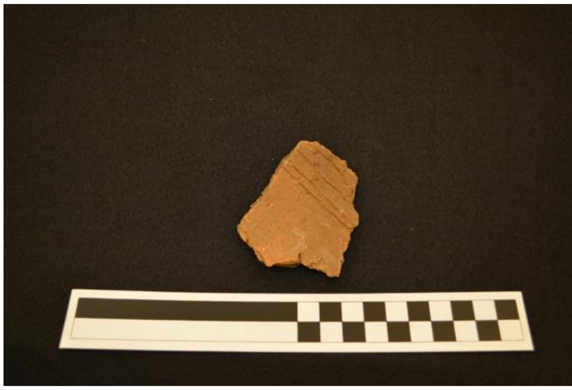
Appendix A: Photographs and Micro-CT images of all Specimens

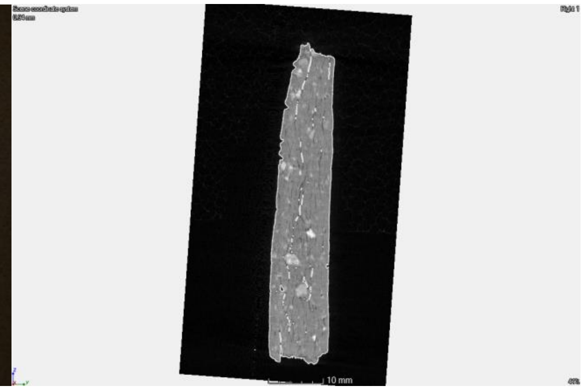
The Appendix includes a photograph and X plane slices of all samples. Borden numbers of sites and rim manufacturing techniques are listed in the image captions. In some cases an additional slice on the Z plane is included. Where excellent 3D images of void structures and/or inclusions could be obtained, they are also included. Voids are rendered in light blue or light green and inclusions are rendered in orange throughout.

Arkona Vessels:

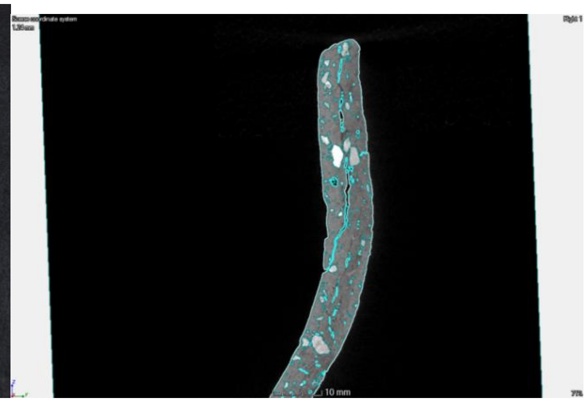


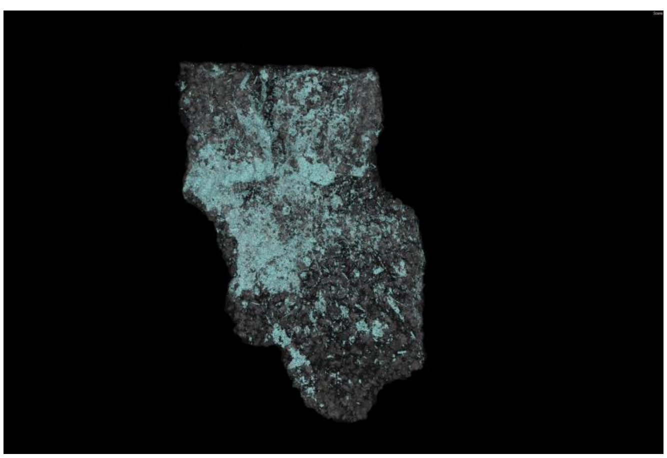
StJohnCT004 AgHk-32 Folded.



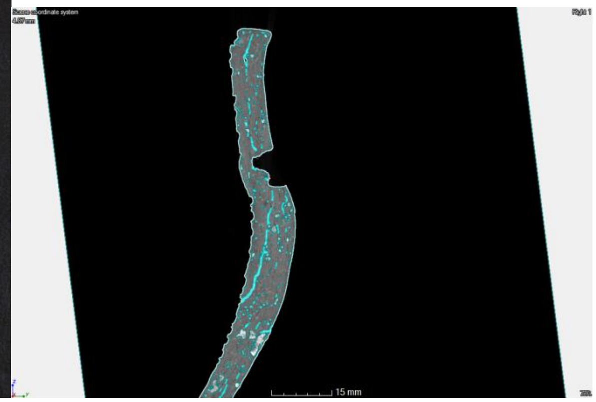


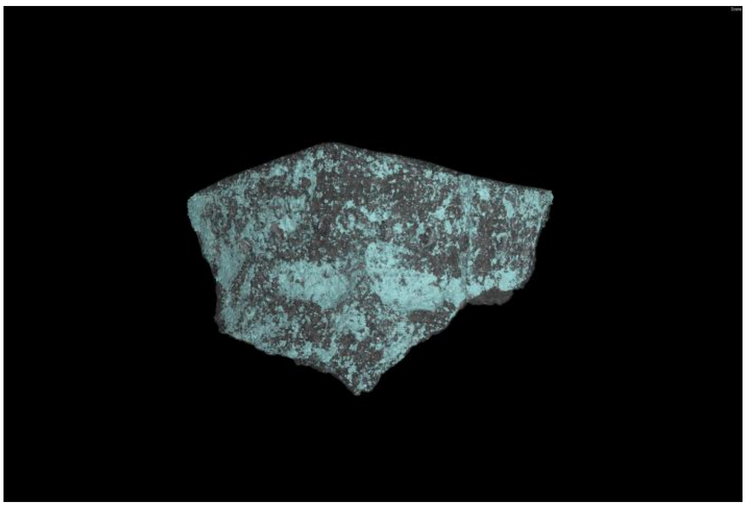
StJohnCT005 AgHk-42 Unidentified



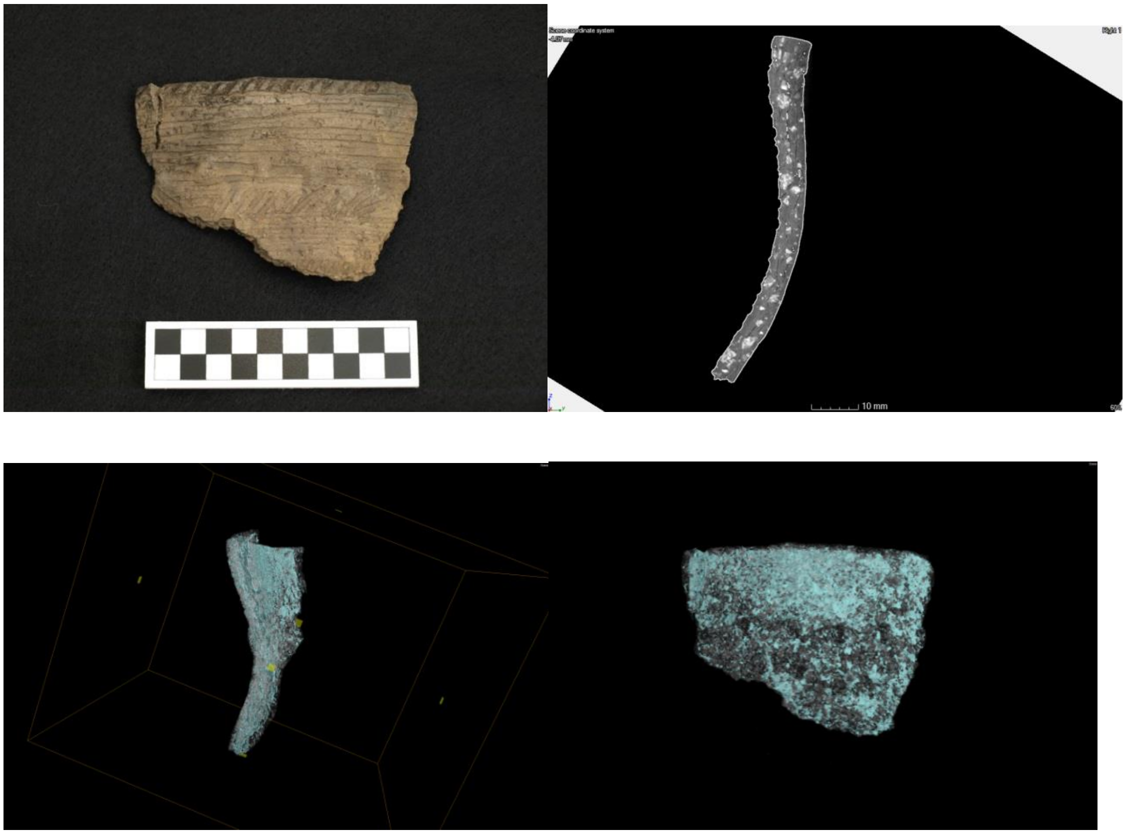


StJohnCT006 AgHk-32 Added clay

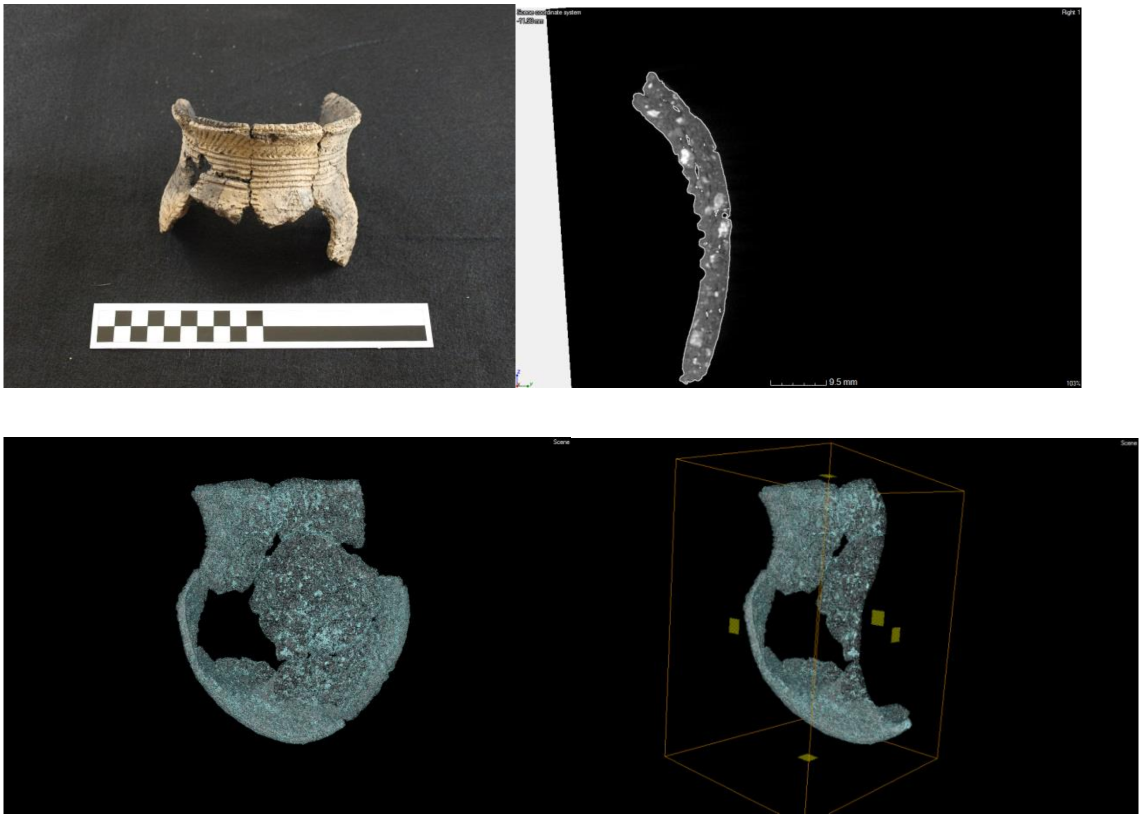




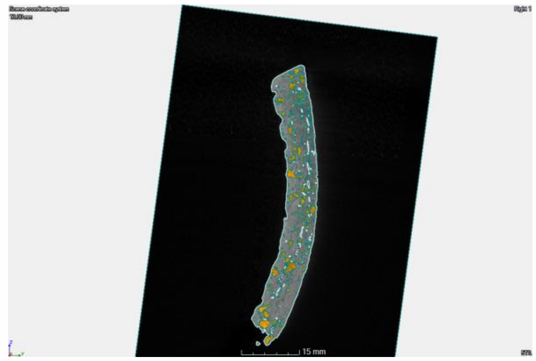
StJohnCT008 (same vessel as StJohnCT055) AgHk-32 Added clay

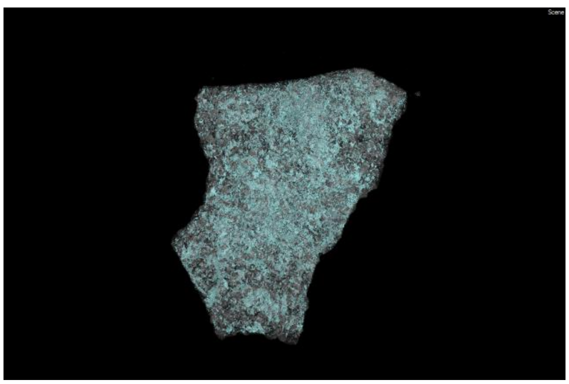


StJohnCT055 (same vessel as StJohnCT008) AgHk-32 Added clay

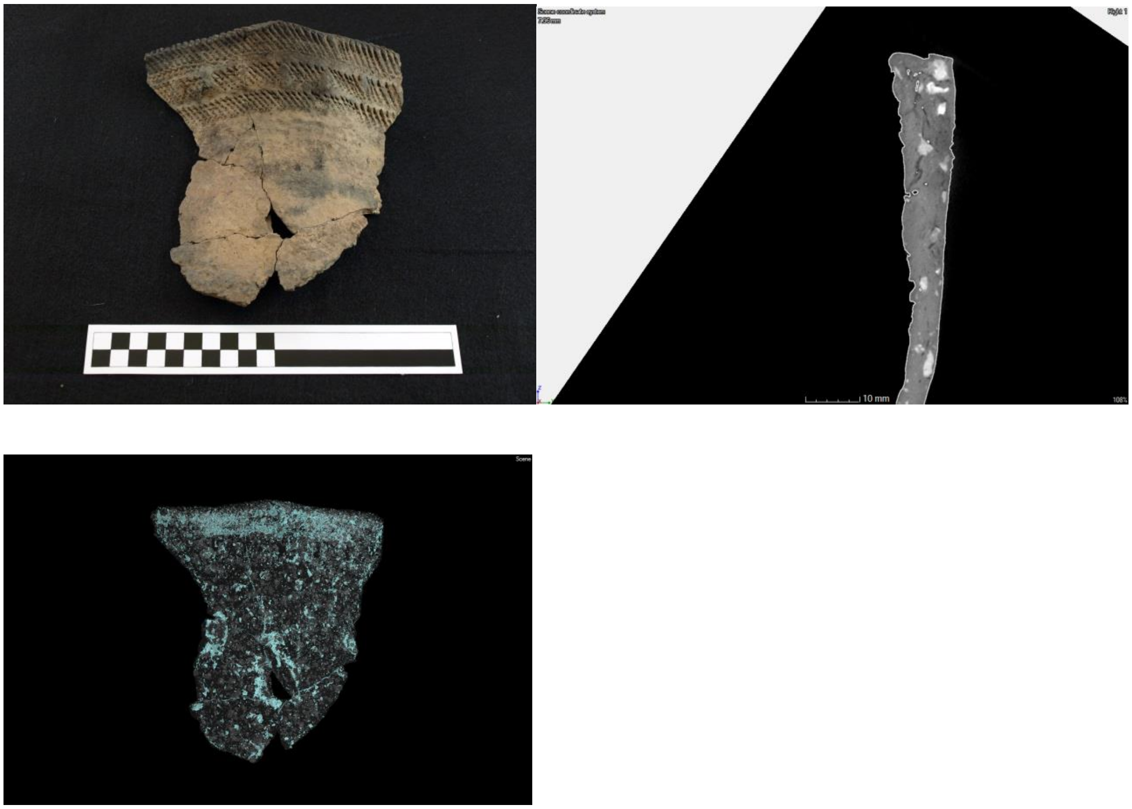


StJohnCT009 AgHk-54 Plain



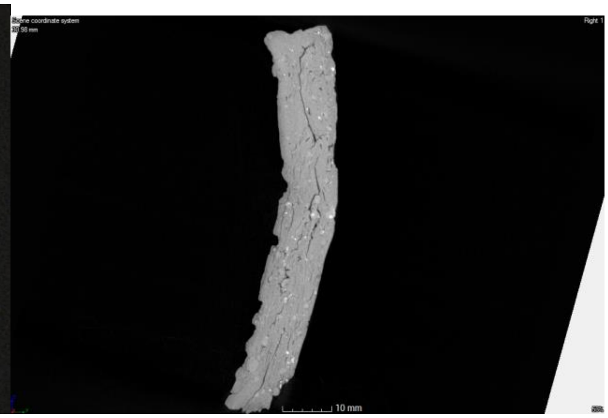


StJohnCT010 AgHk-54 Folded (Photo Golder Associates 2012a)

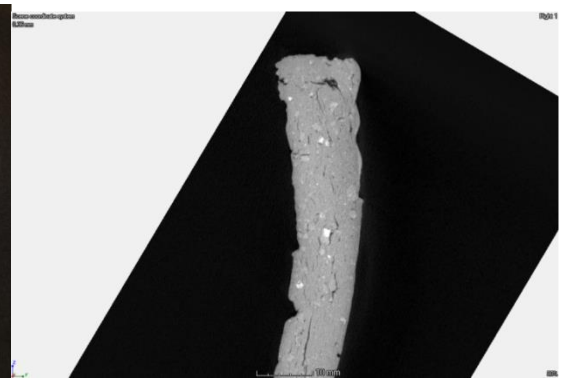


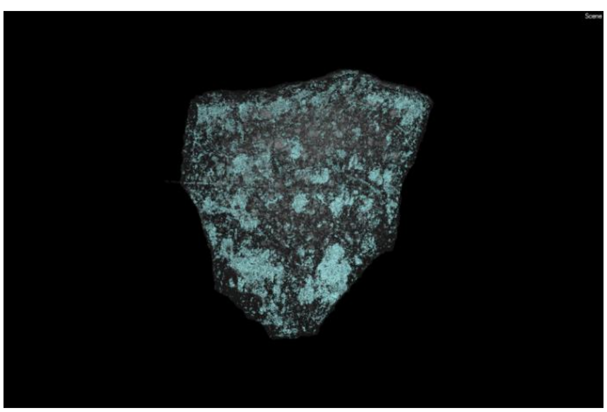
StJohnCT011 AgHk-54 Folded

StJohnCT016 AgHk-54 Plain

StJohnCT020 (same vessel as StJohnCT070) AgHk-52 Folded

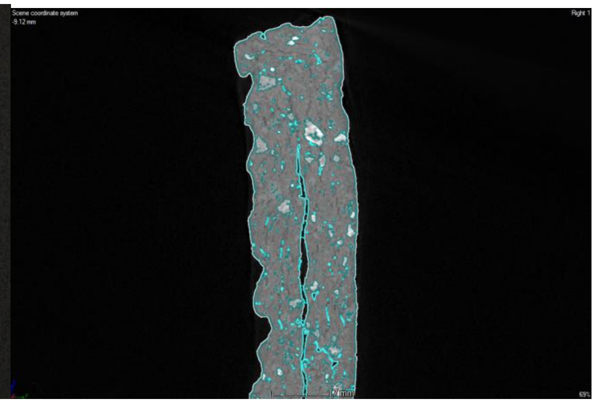
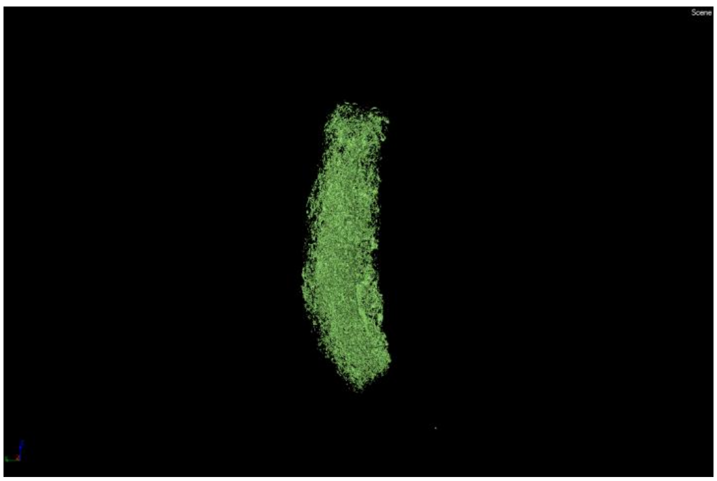





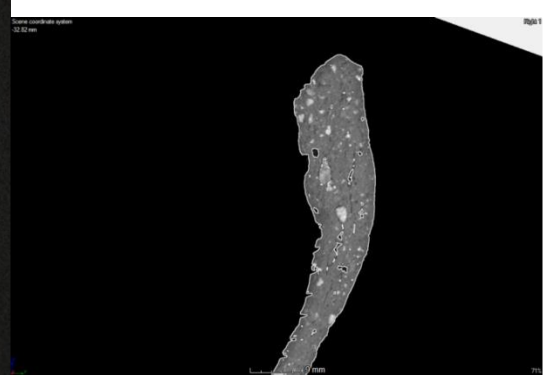
StJohnCT070 (same vessel as StJohnCT020) AgHk-52 Folded

StJohnCT021 AgHk-52 Plain

StJohnCT022 AgHk-52 Folded

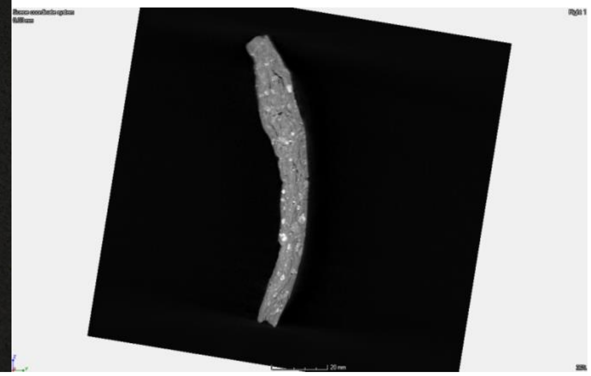
StJohnCT023 AgHk-52 Folded

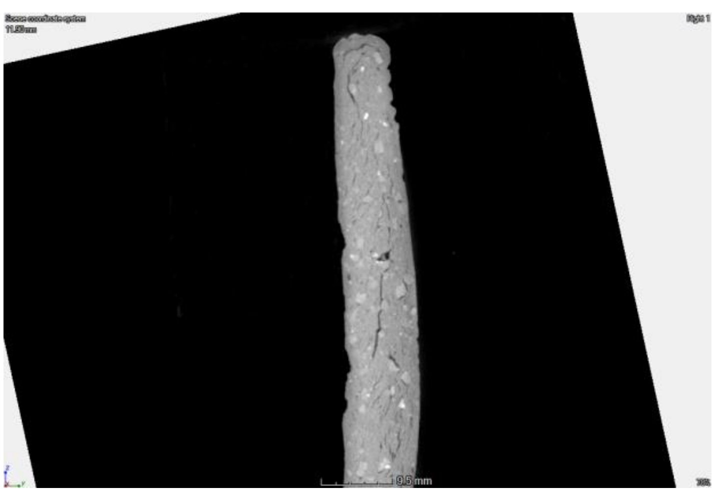
StJohnCT024 AgHk-52 Added clay

StJohnCT025 AgHk-52 Folded

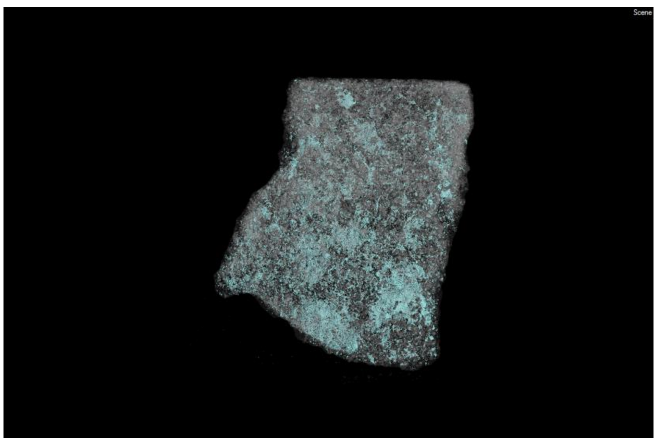
StJohnCT026 AgHk-52 Plain



StJohnCT027 AgHk-52 Plain

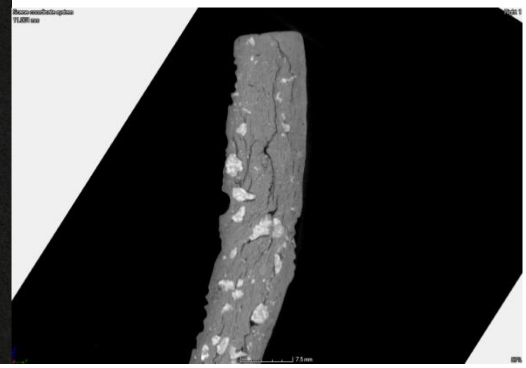
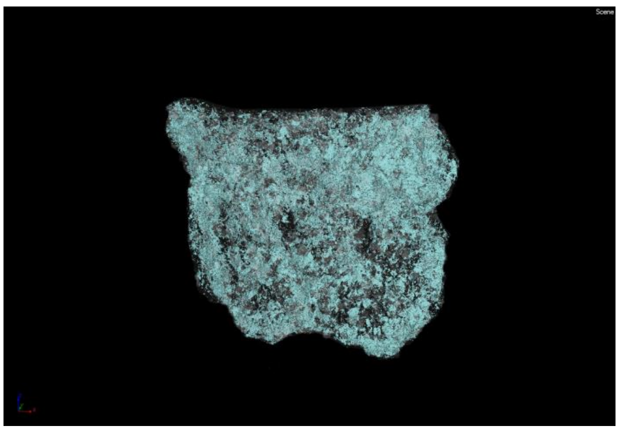


StJohnCT028/96 (same vessel as StJohn090) AgHk-52 Folded with added clay

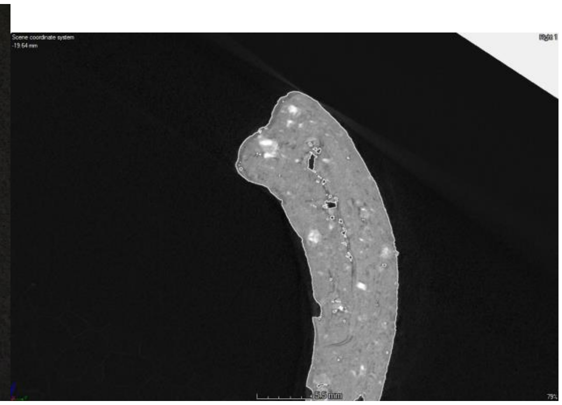


StJohnCT090 (same vessel as StJohnCT028/96) AgHk-52 Folded with added clay

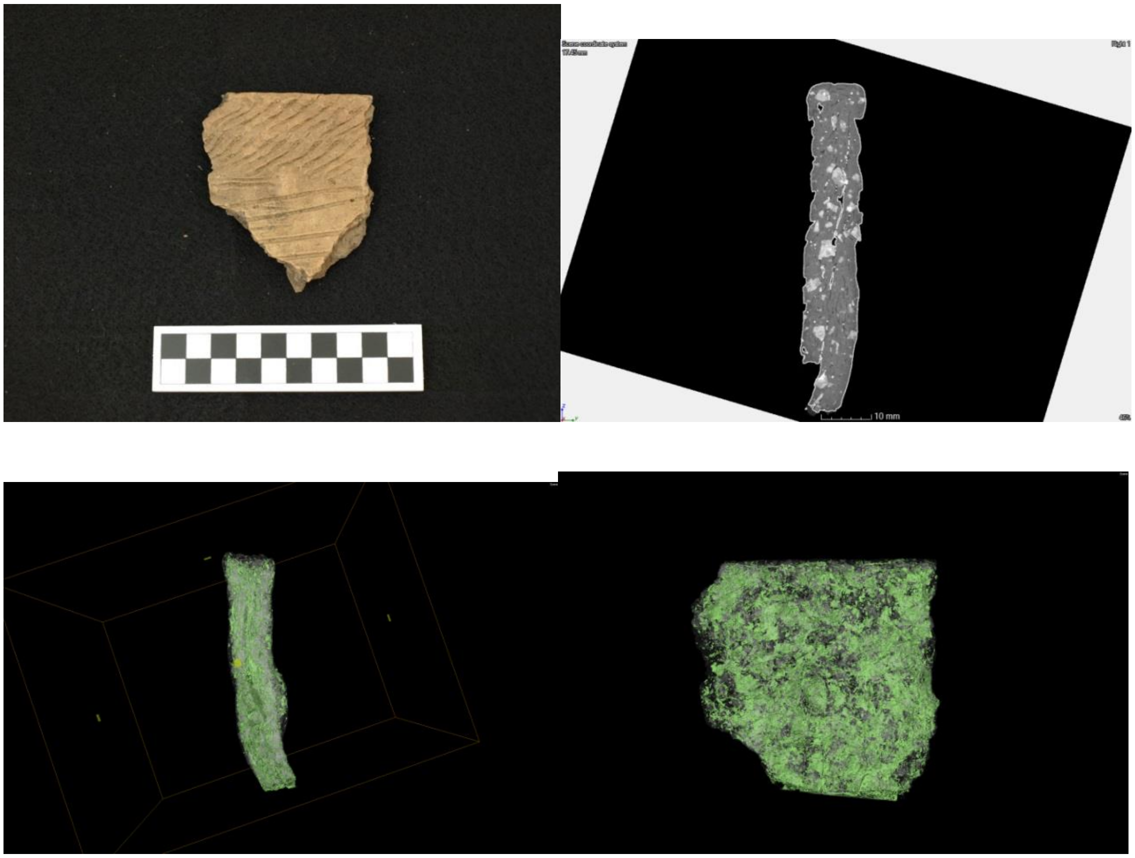
StJohnCT029 AgHk-52 Folded

StJohnCT030/93 AgHk-42 Added clay

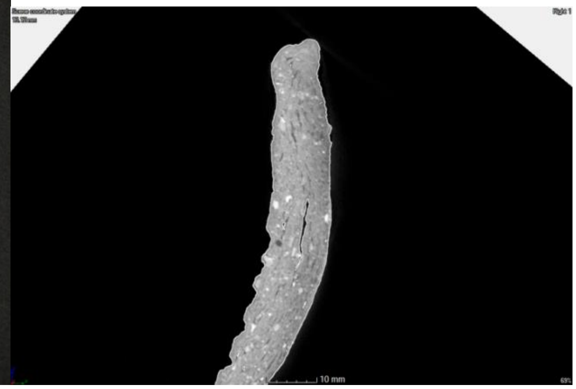
StJohnCT031 AgHk-42 Folded

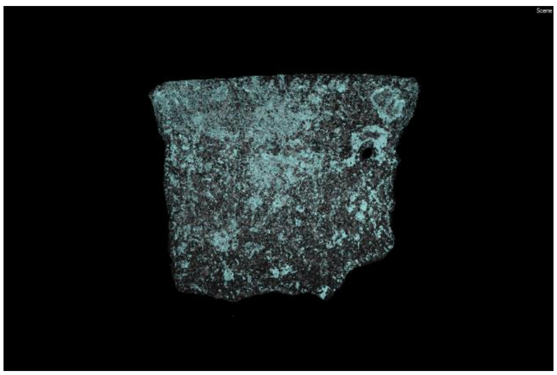


StJohnCT036 AgHk-42 Folded

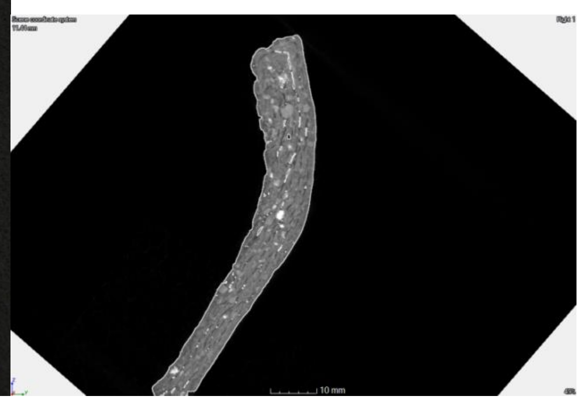
StJohnCT038 AgHk-42 Folded with added clay

StJohnCT039 AgHk-42 Added clay

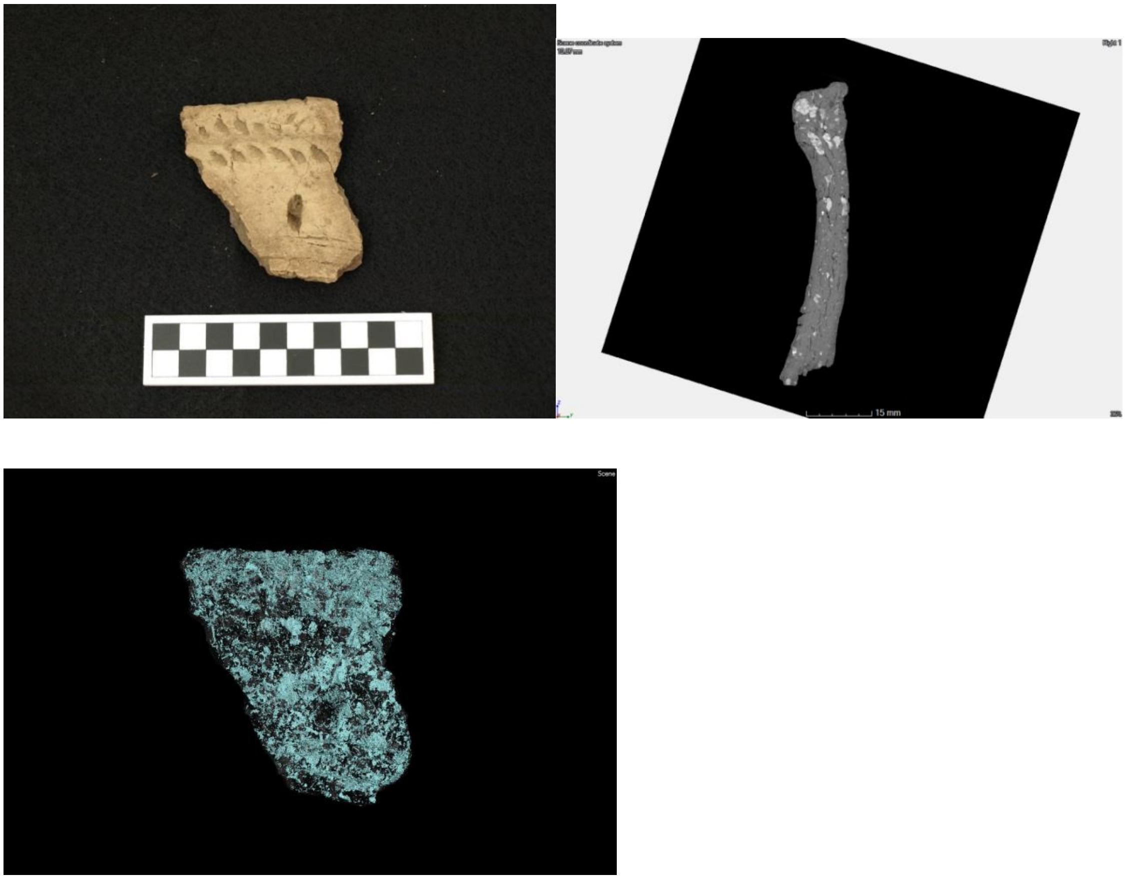




StJohnCT040 AgHk-42 Folded

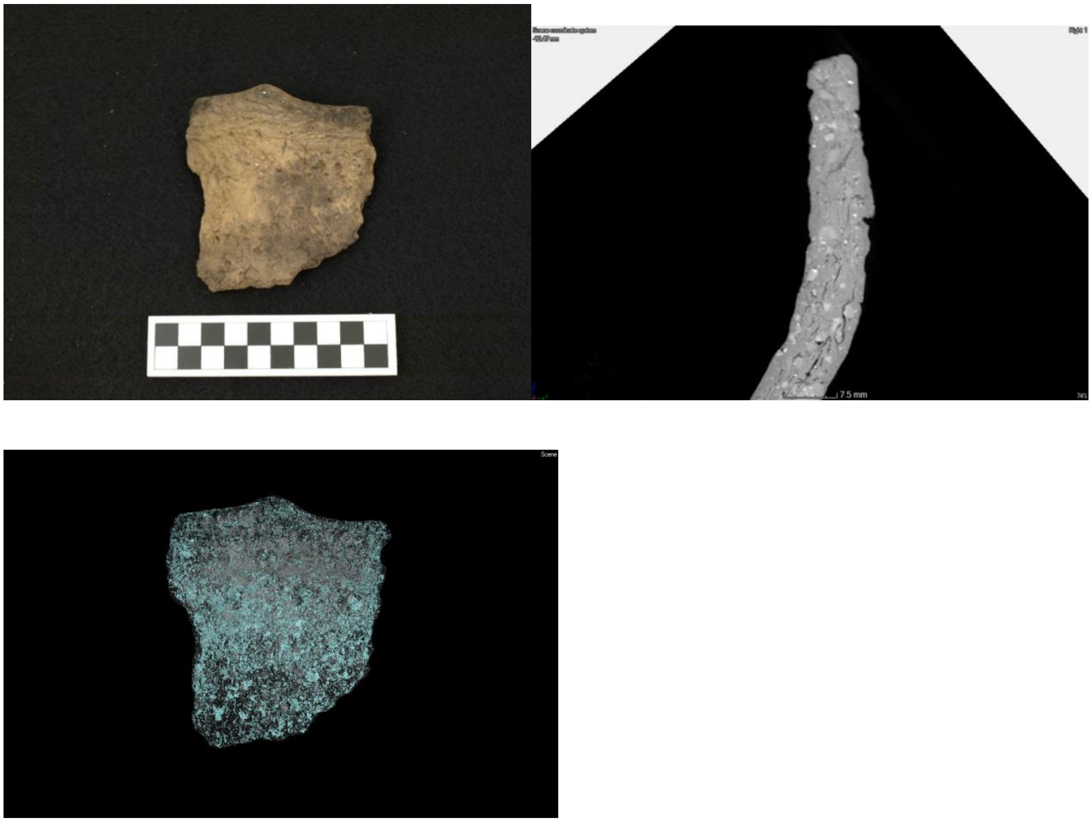


StJohnCT041 AgHk-42 Folded



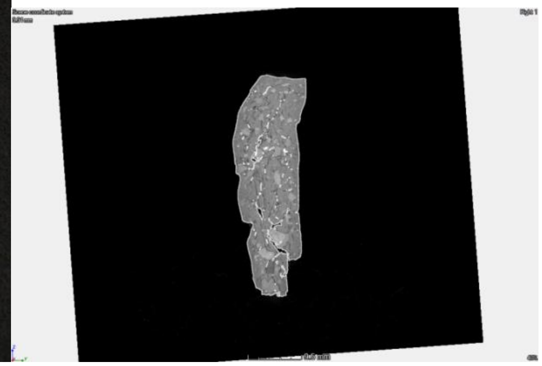
StJohnCT042 AgHk-42 Added clay

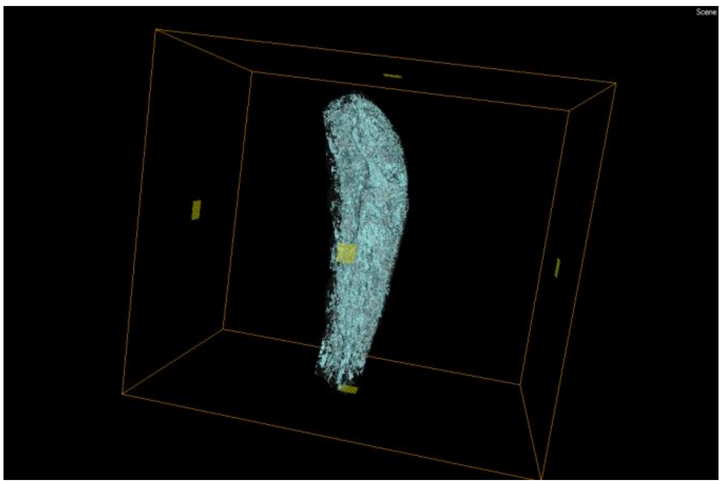
StJohnCT043 AgHk-42 Folded with added clay



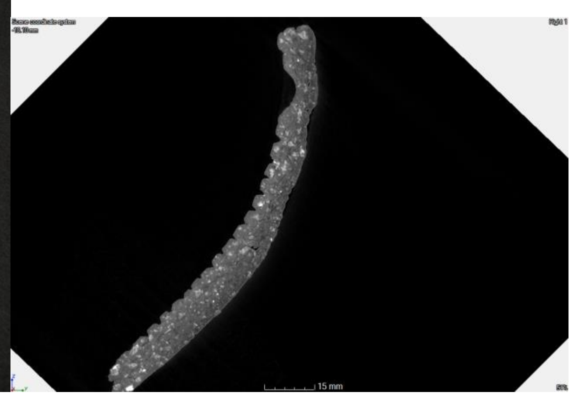
StJohnCT044 (same vessel as StJohnCT101) AgHk-42 Folded

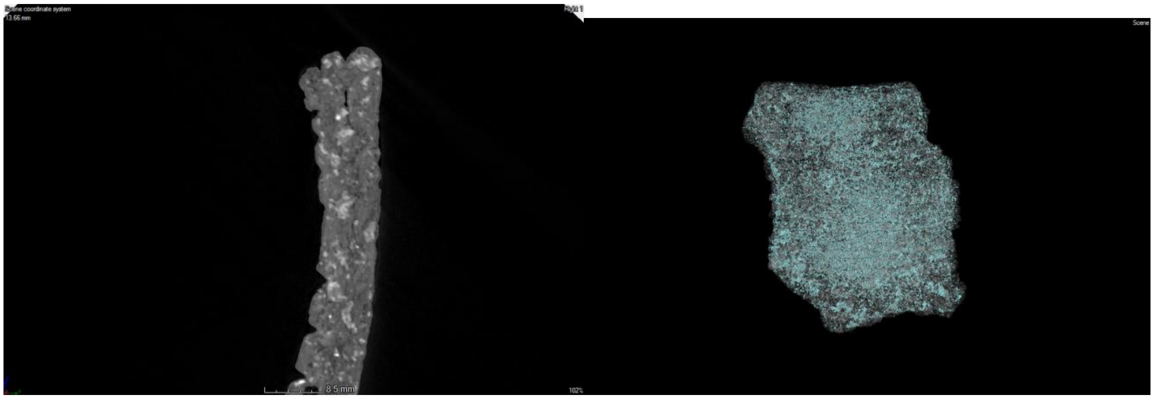
StJohnCT101 (same vessel as StJohnCT044) AgHk-42 Folded



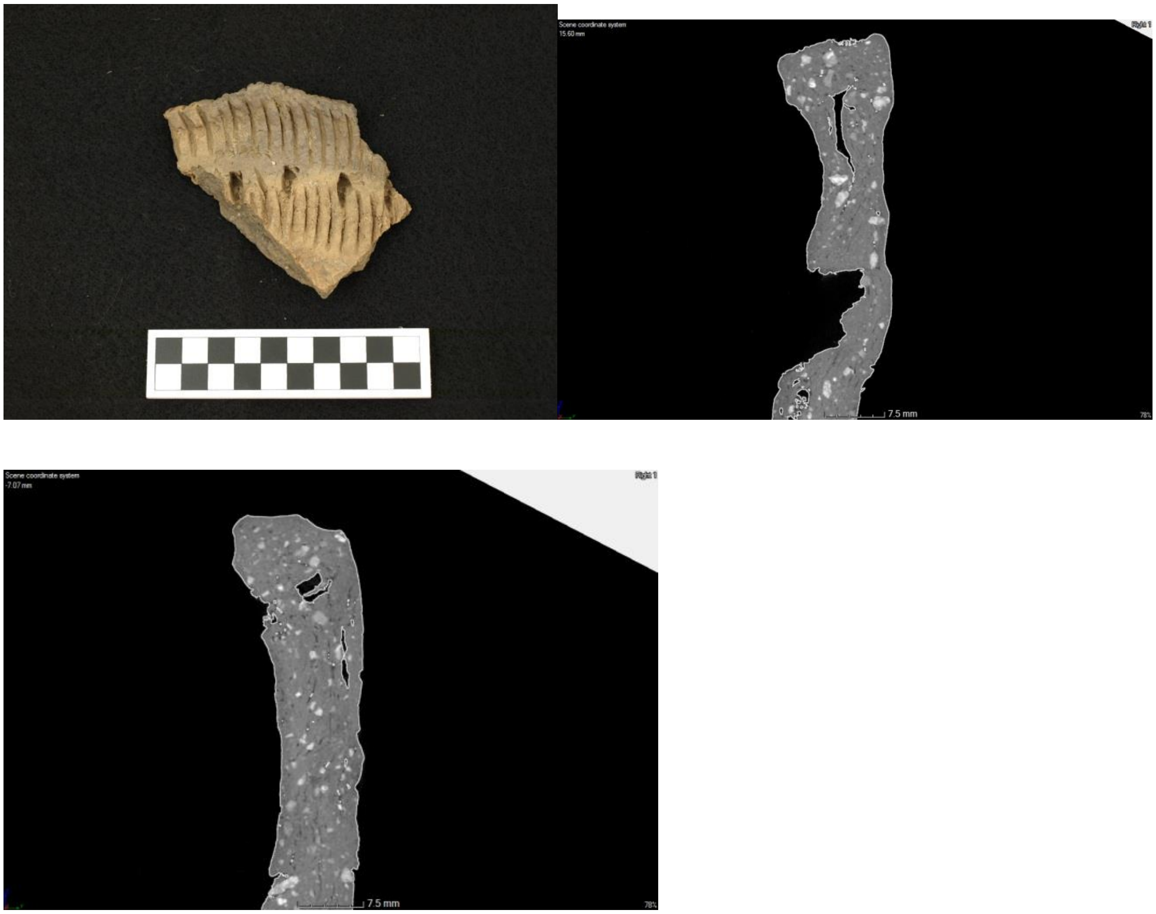
StJohnCT045 AgHk-42 Folded

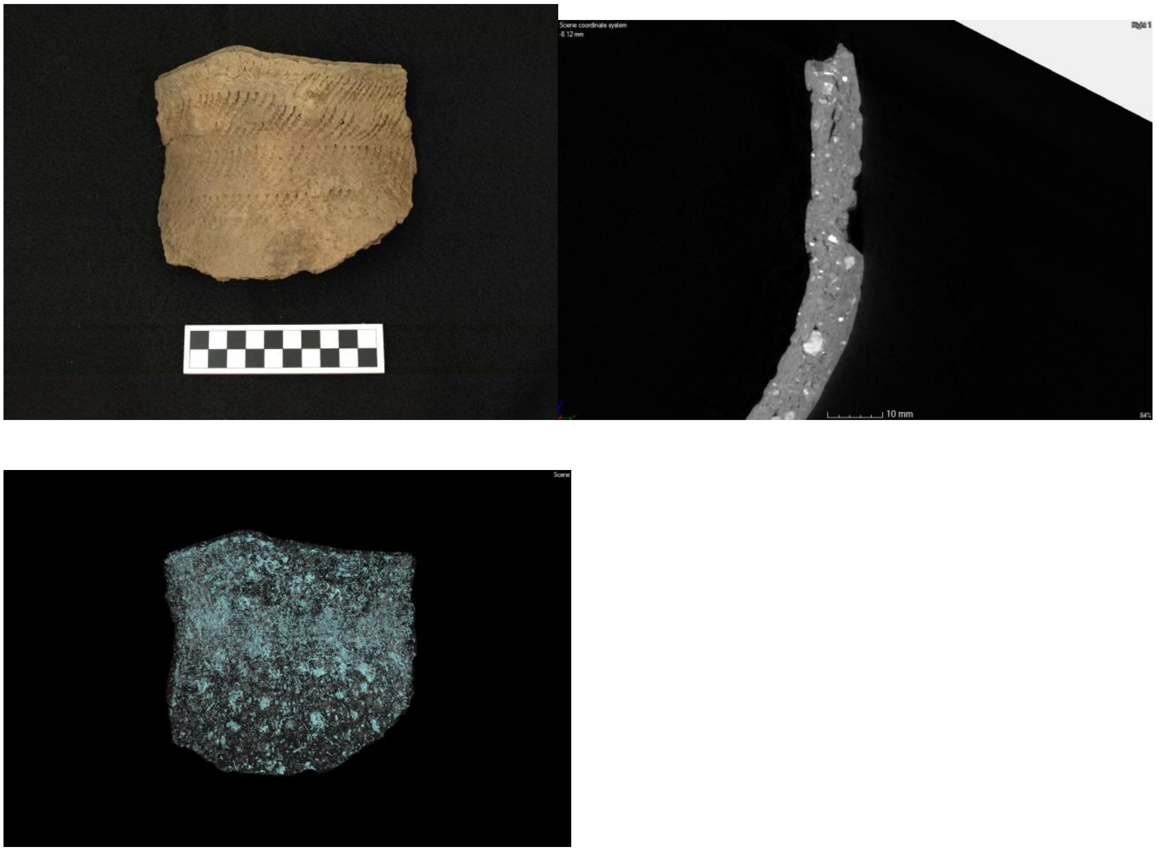


StJohnCT046 AgHk-42 Plain

StJohnCT047 AgHk-42 Plain

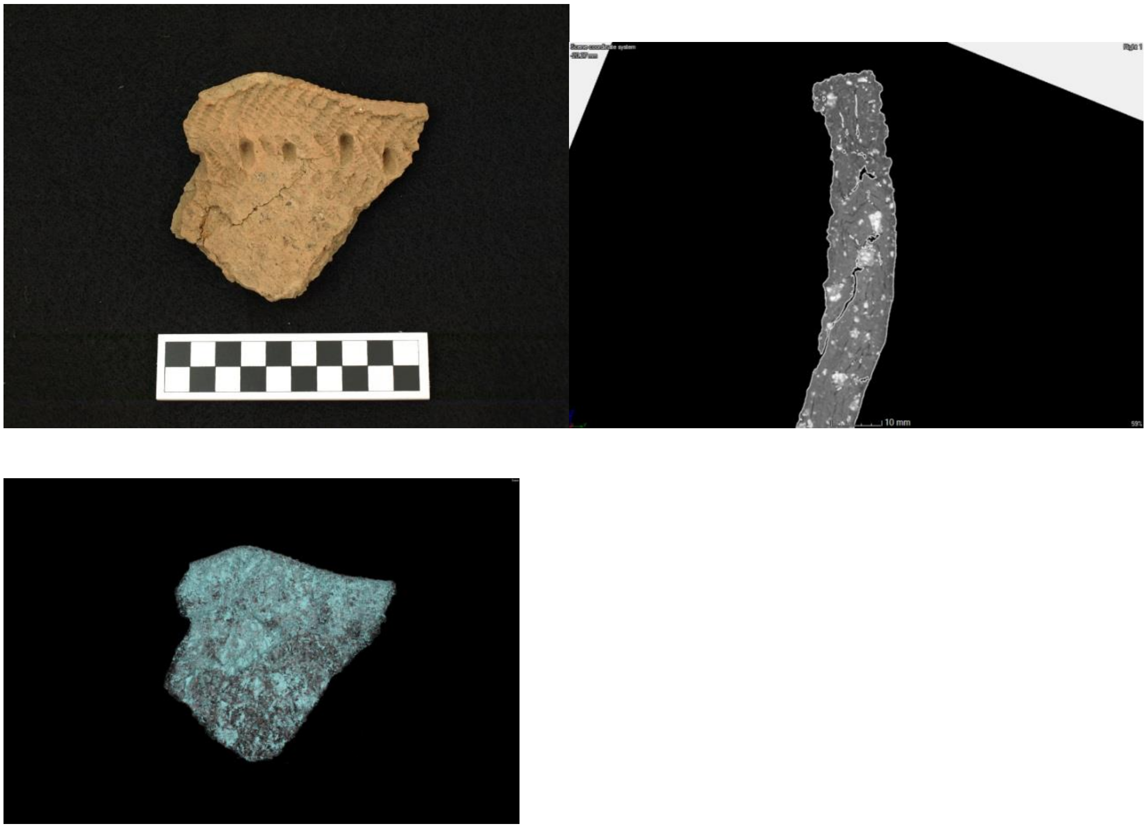


StJohnCT048 AgHk-40 Folded with added clay



StJohnCT049 (same vessel as StJohnCT102) AgHk-40 Folded with added clay

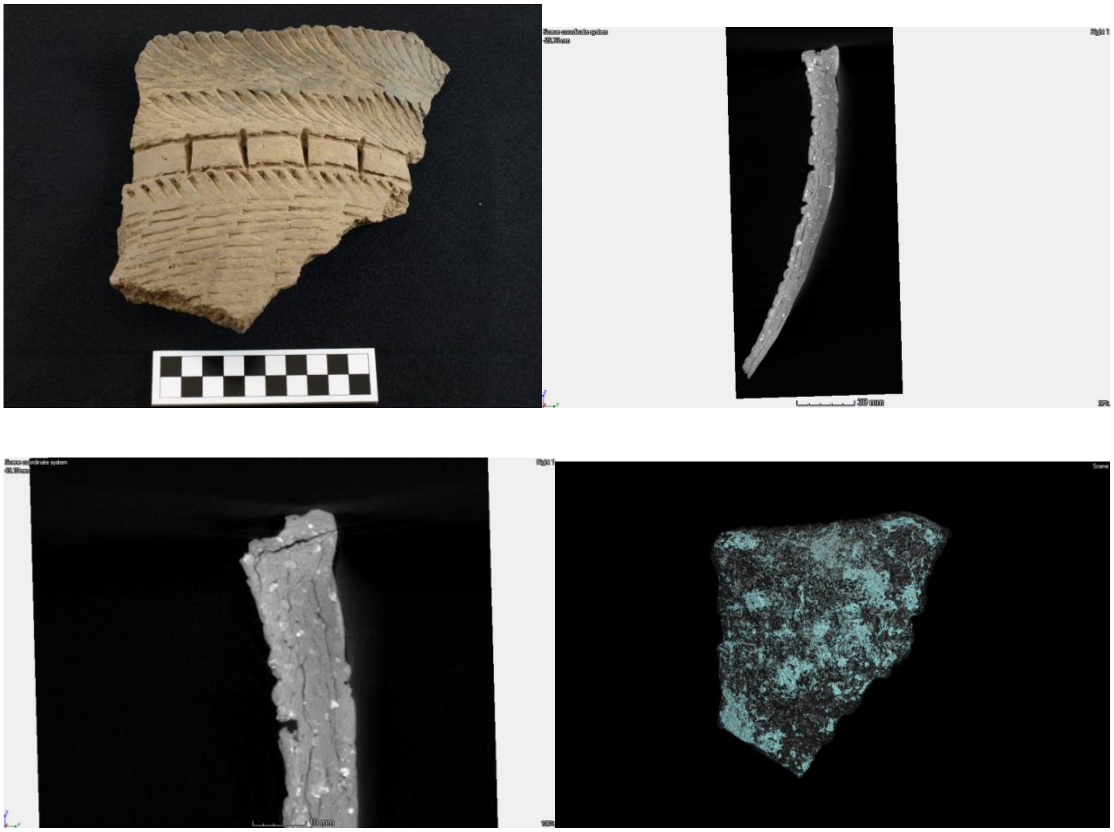
StJohnCT102 (same vessel as StJohnCT049) AgHk-40 Folded



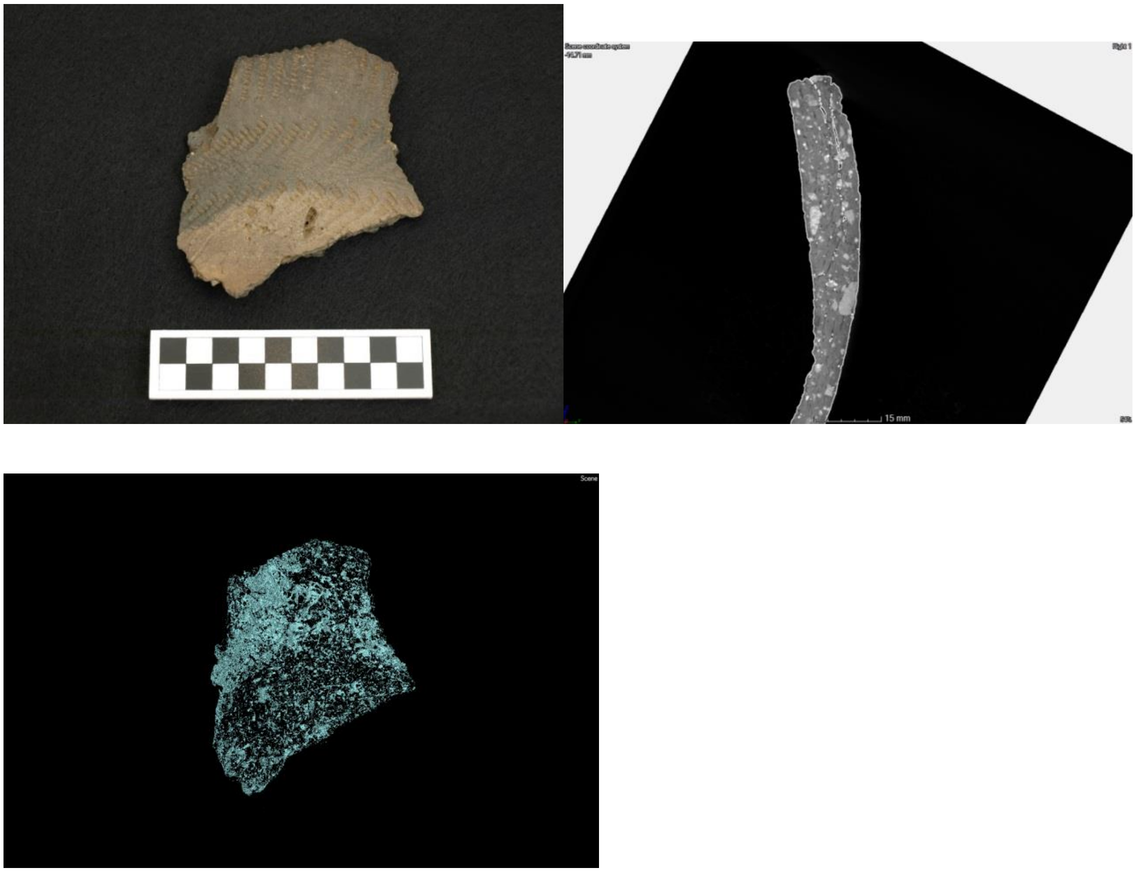
StJohnCT050 (same vessel as StJohnCT097) AgHk-40 Folded with added clay

StJohnCT097 (same vessel as StJohnCT050) AgHk-40 Folded with added clay

StJohnCT051 (same vessel as StJohnCT100) AgHk-40 Added clay



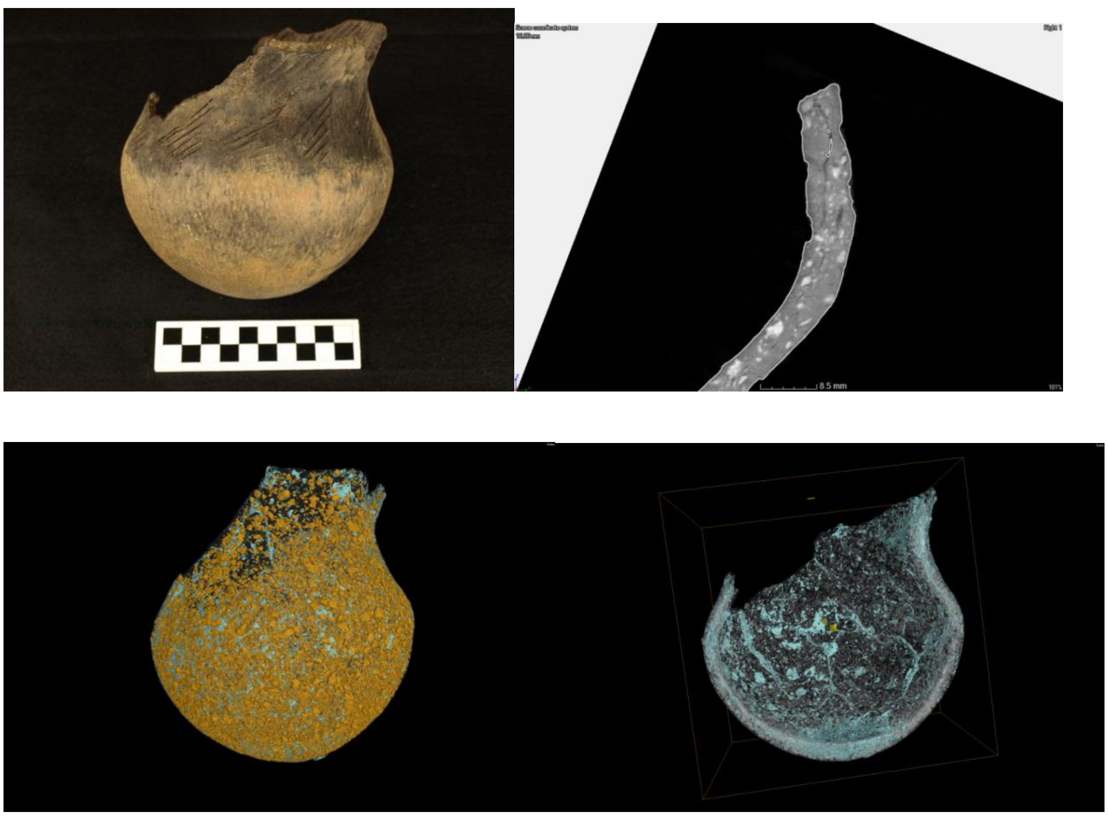
StJohnCT100 (same vessel as StJohn051) AgHk-40 Added clay



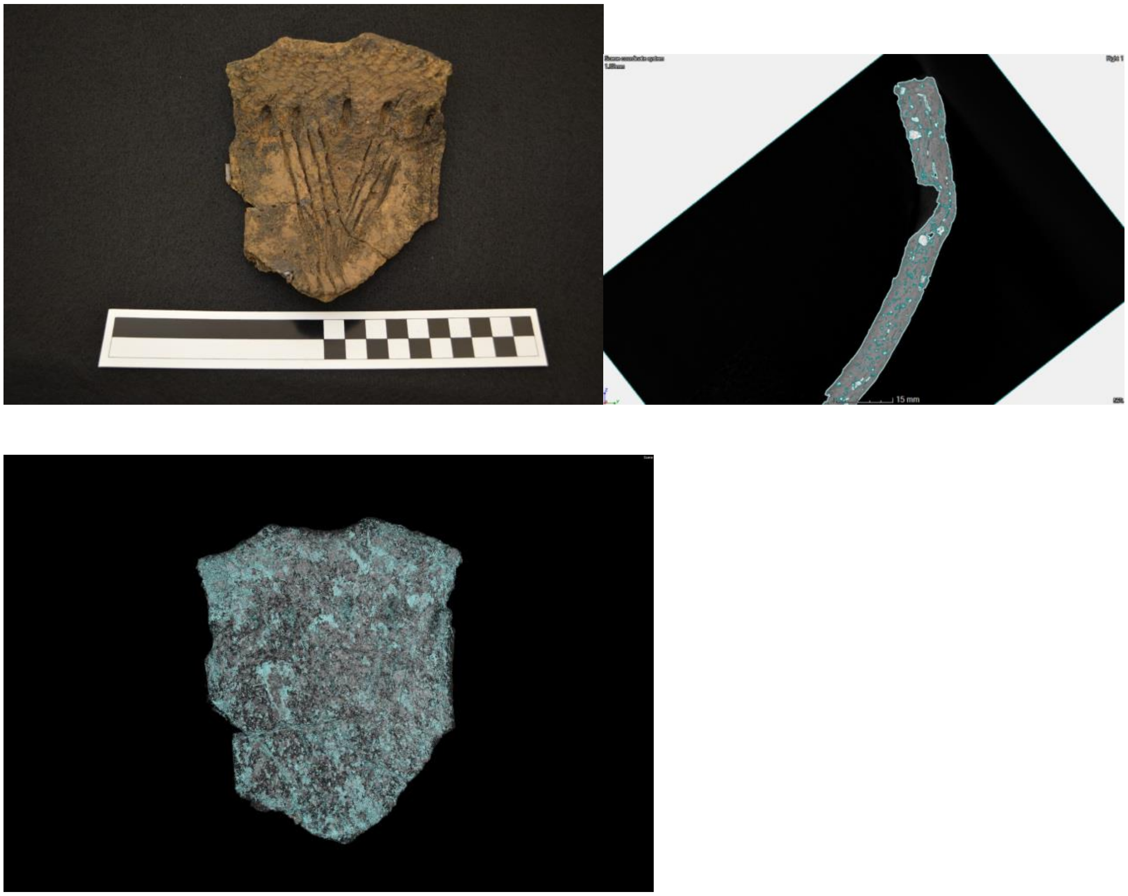
StJohnCT052 AgHk-52 Added clay

StJohnCT053 AgHk-56 Unidentified

StJohnCT054 AgHk-32 Folded



StJohnCT060 AgHk-42 Added clay



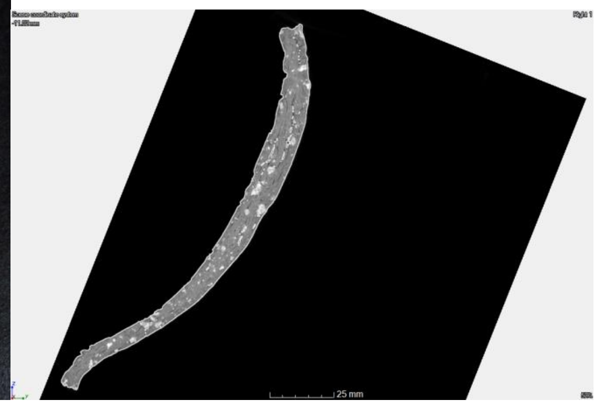
StJohnCT061 AgHk-32 Folded

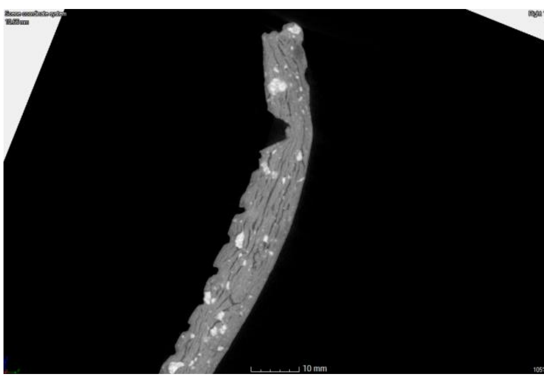
StJohnCT062 AgHk-32 Added clay

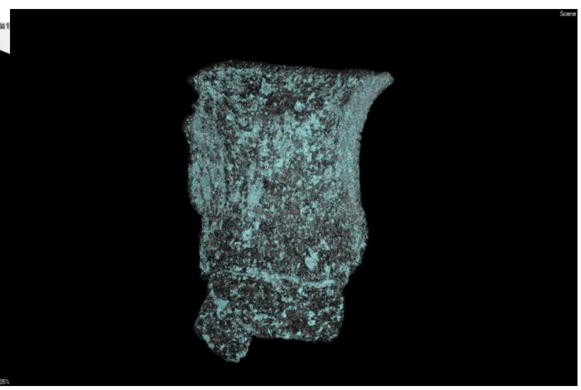
StJohnCT063 AgHk-40 Folded

StJohnCT064 (same vessel as StJohnCT098) AgHk-32 Folded

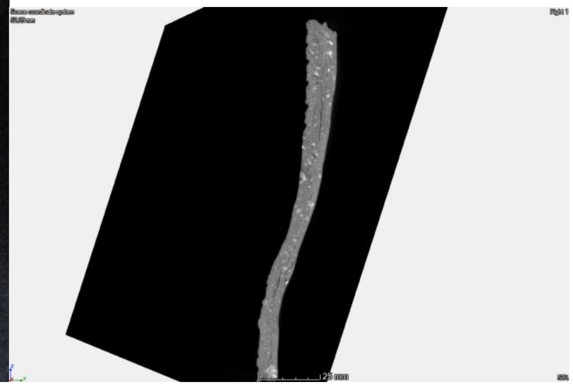
StJohnCT098 (same vessel as StJohnCT064) AgHk-32 Folded with added clay

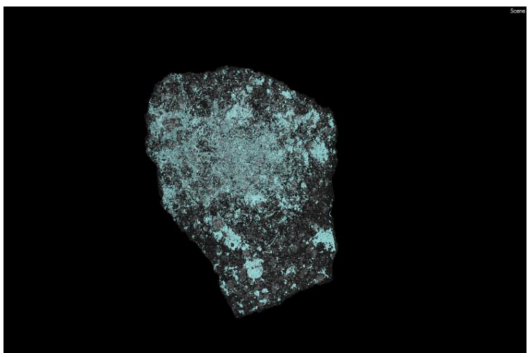




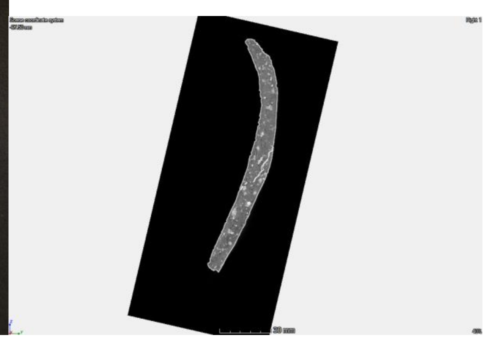


StJohnCT065 AgHk-52 Added clay

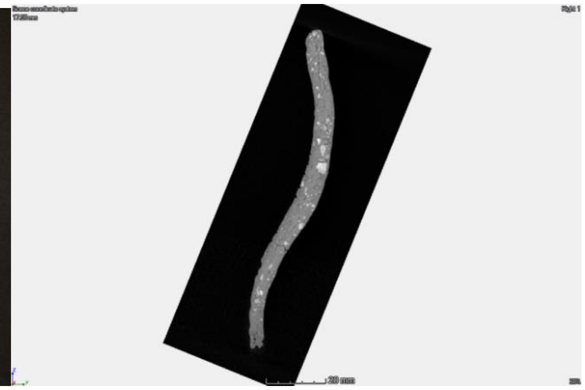
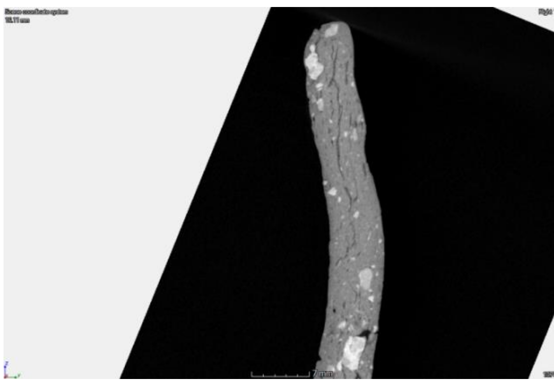
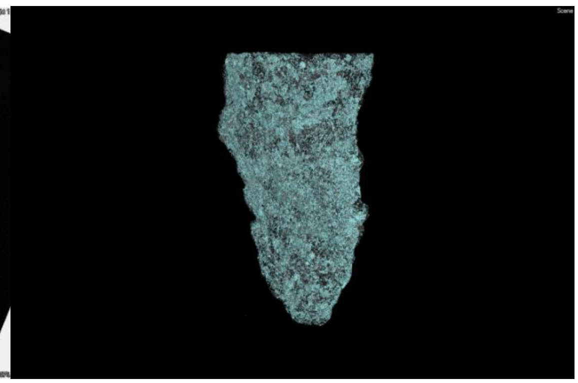




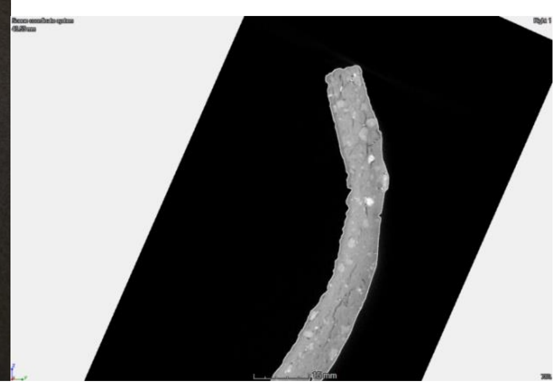
StJohnCT066 AgHk-42 Folded with added clay



StJohnCT067 AgHk-42 Unidentified

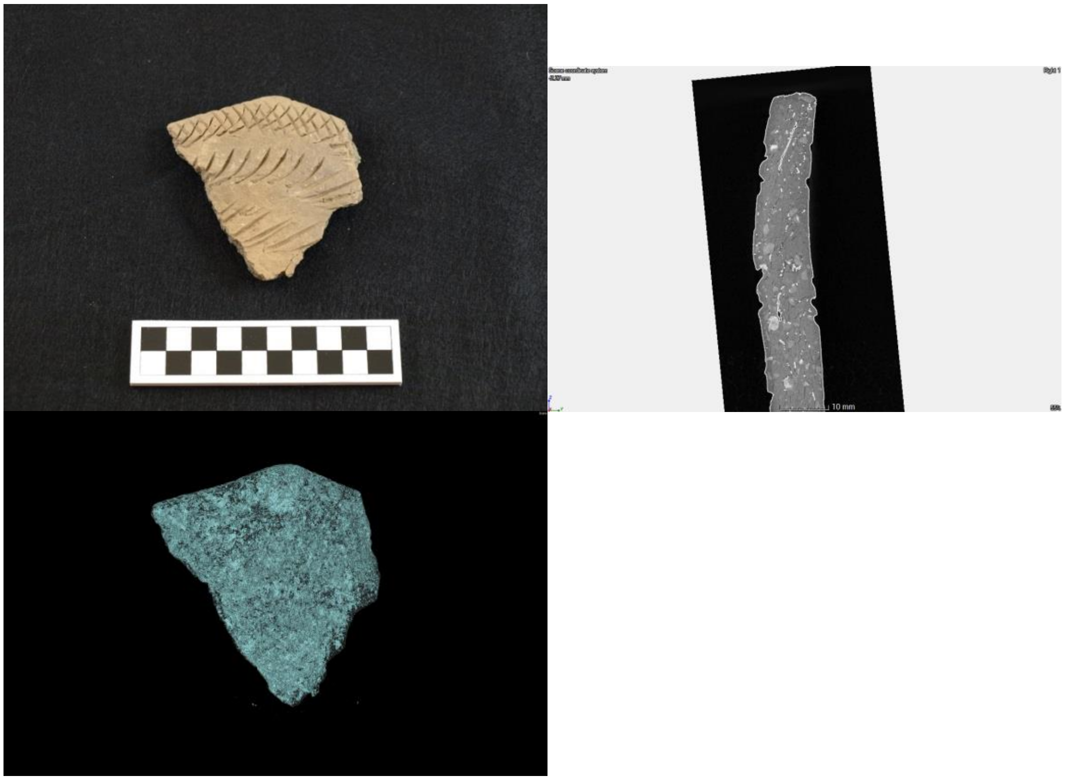
StJohnCT068 AgHk-42 Folded to exterior

StJohnCT069 AgHk-42 Added clay

StJohnCT071 AgHk-52 Unidentified

StJohnCT079 AgHk-32 Folded to exterior



StJohnCT085 AgHk-32 Folded to with added clay

StJohnCT091 AgHk-52 Added clay

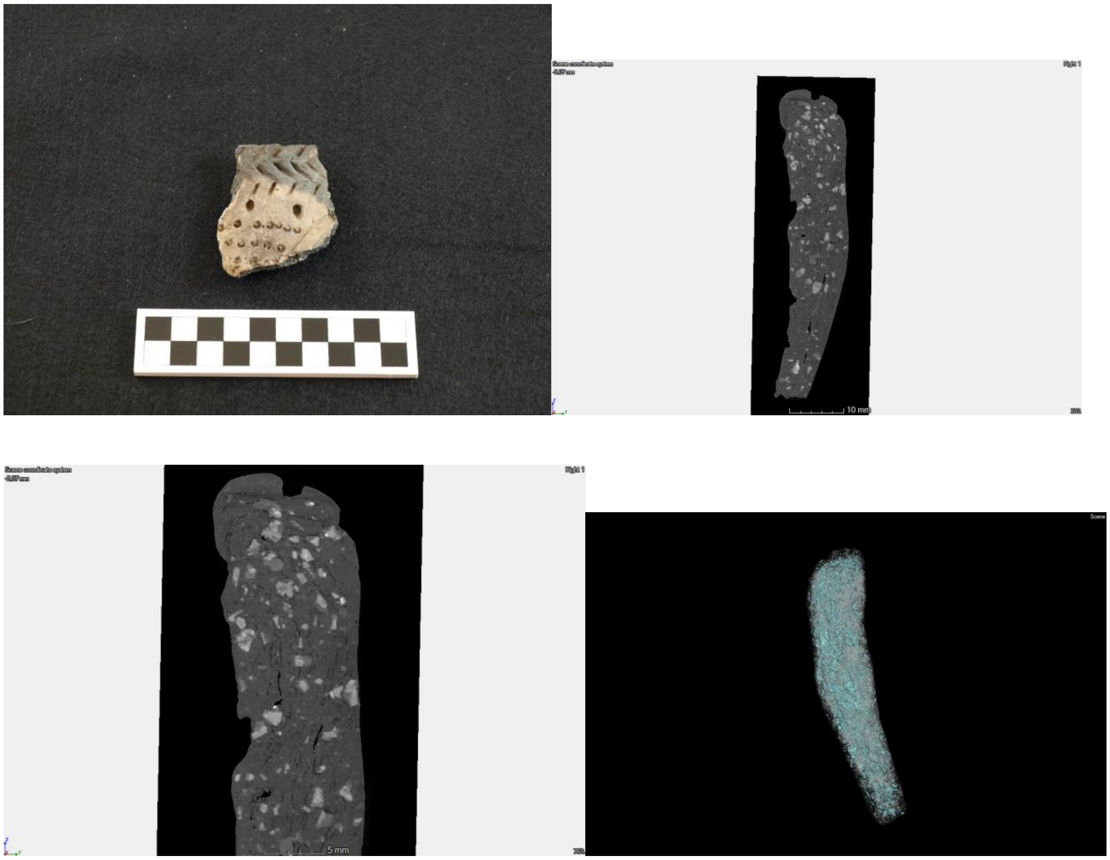
StJohnCT099 AgHk-42 Folded

StJohnCT105 (same vessel as StJohnCT106) AgHk-58 Folded

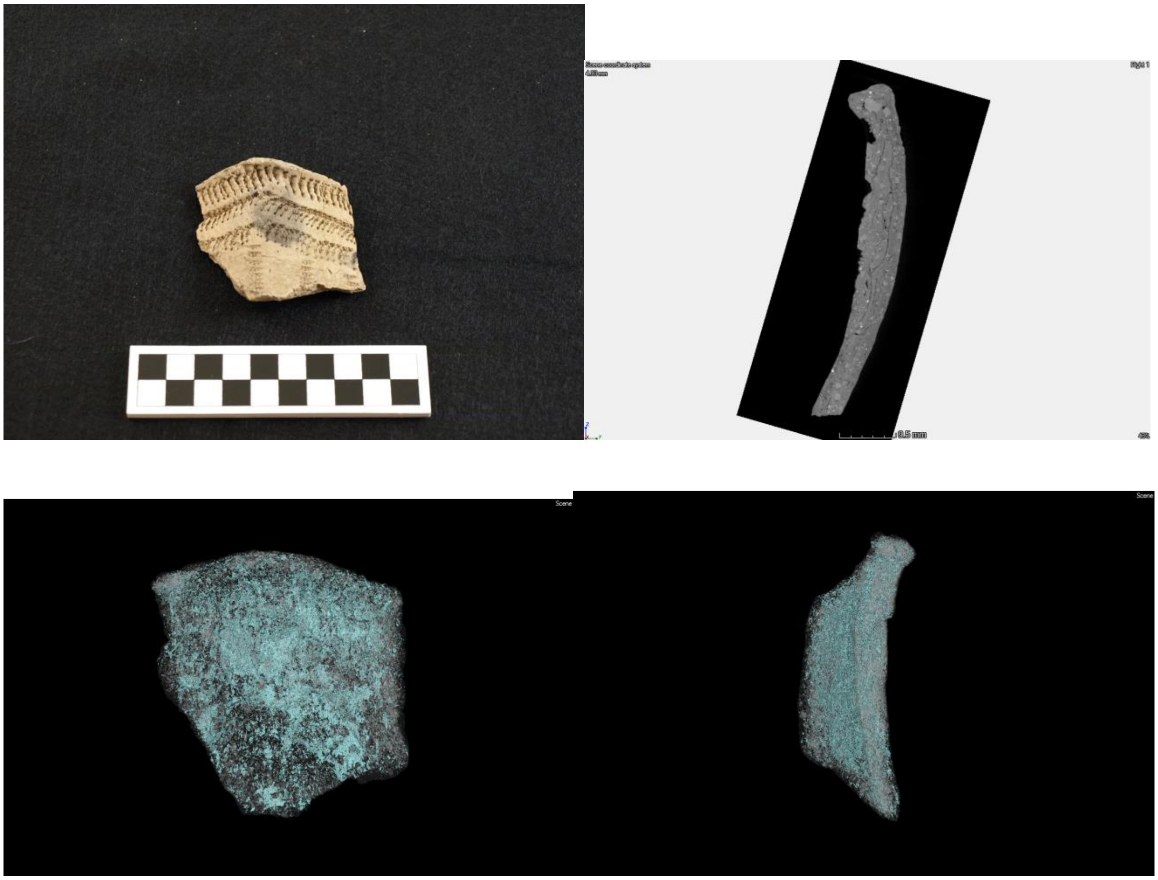
StJohnCT106 (same vessel as StJohnCT105) AgHk-58 Folded

StJohnCT107 AgHk-58 Added clay

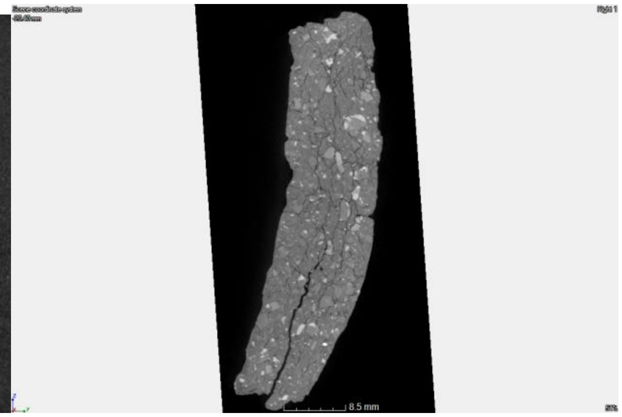
StJohnCT109 AgHk-58 Plain

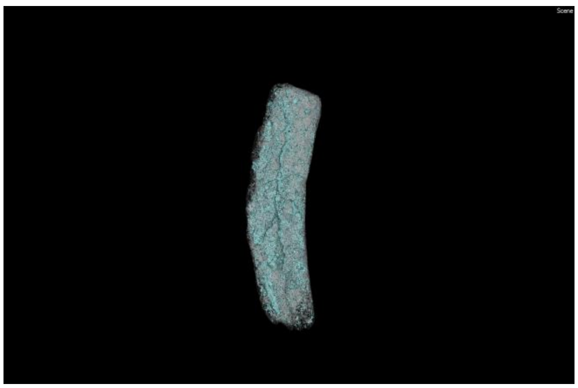


StJohnCT110 AgHk-58 Folded

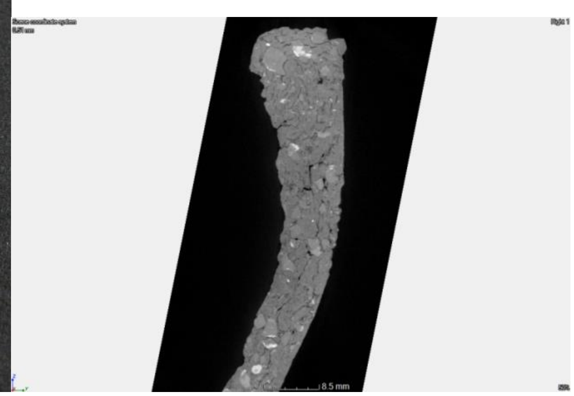


StJohnCT111 AgHk-58 Folded with added clay

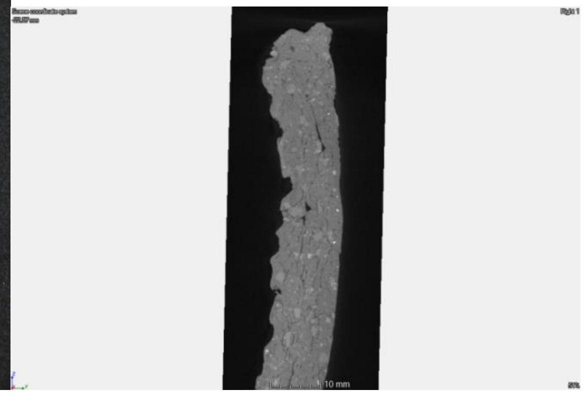


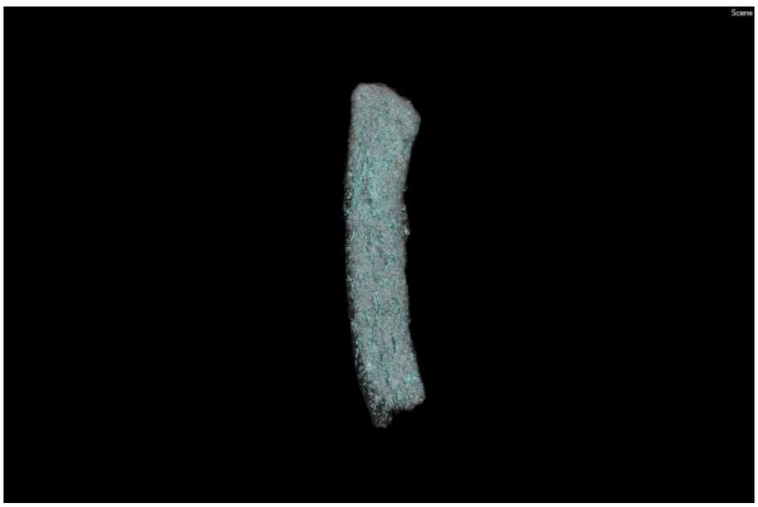


StJohnCT112 AgHk-58 Folded

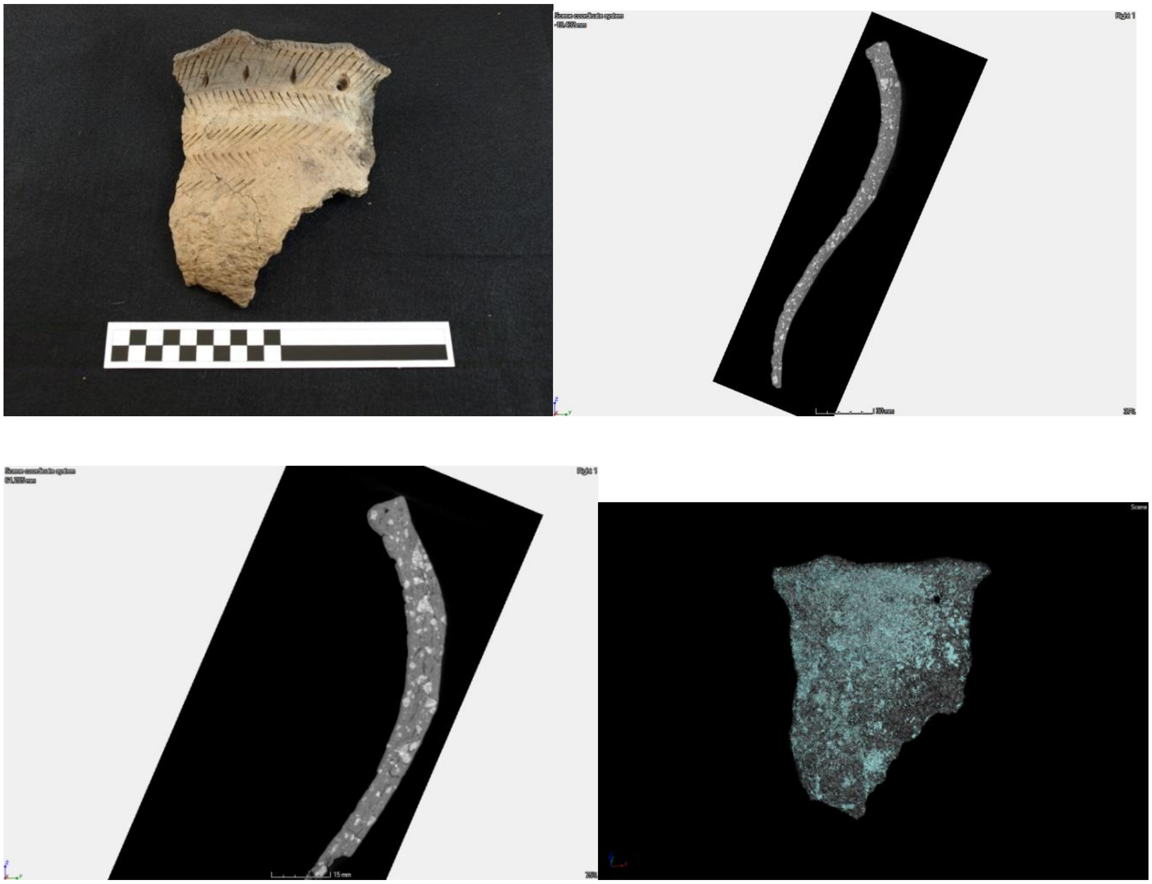


StJohnCT113 AgHk-58 Folded with added clay

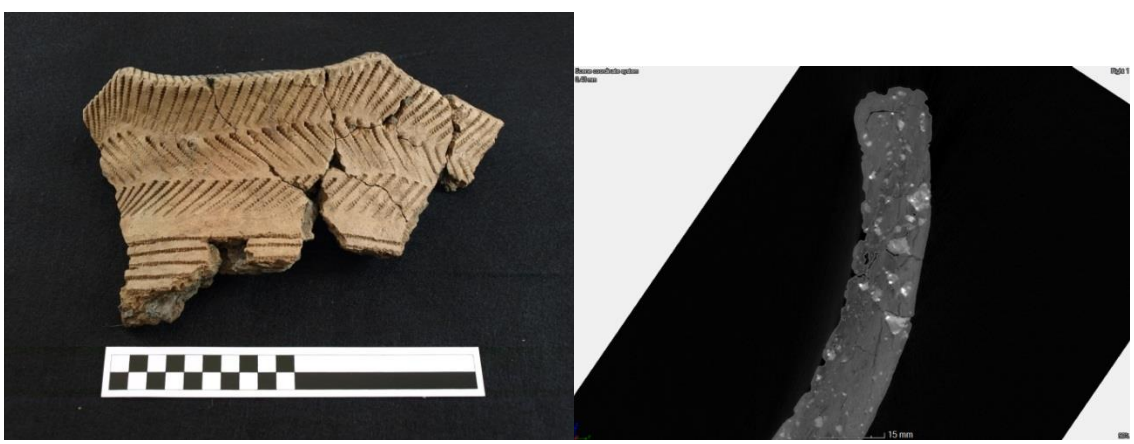




StJohnCT114 AgHk-54 Folded



StJohnCT115 AgHk-54 Folded

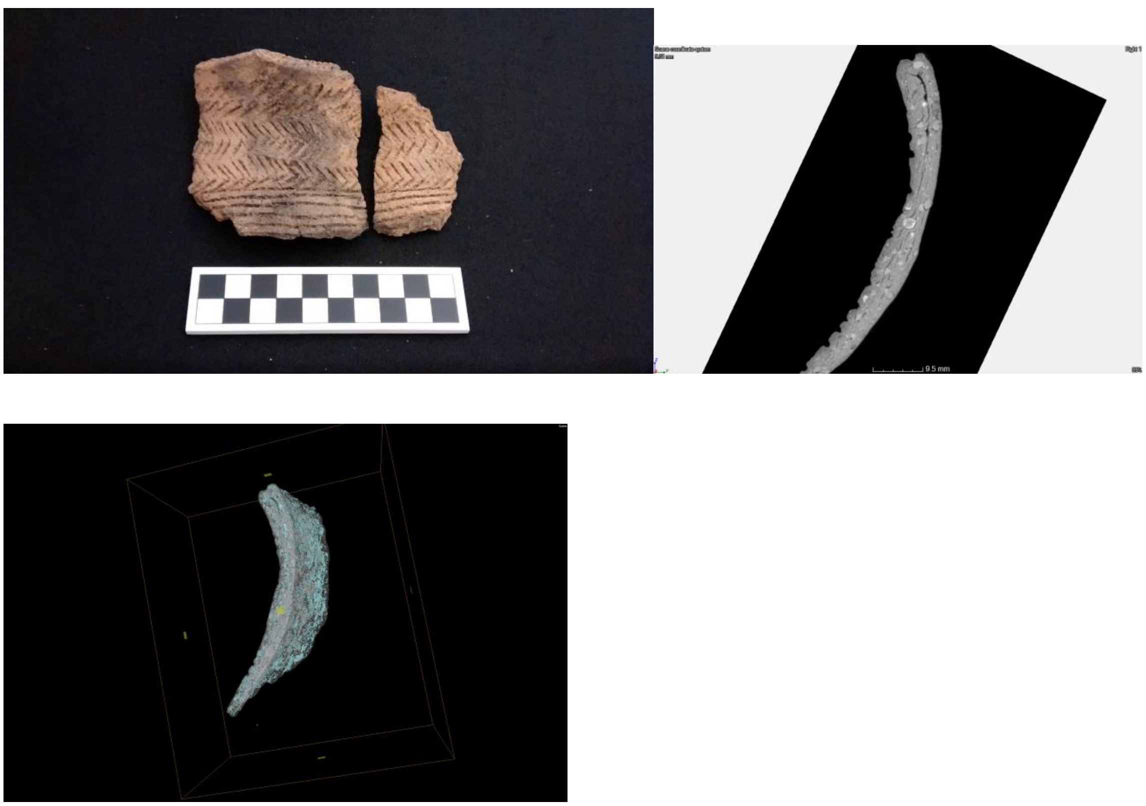


StJohnCT116 AgHk-54 Folded

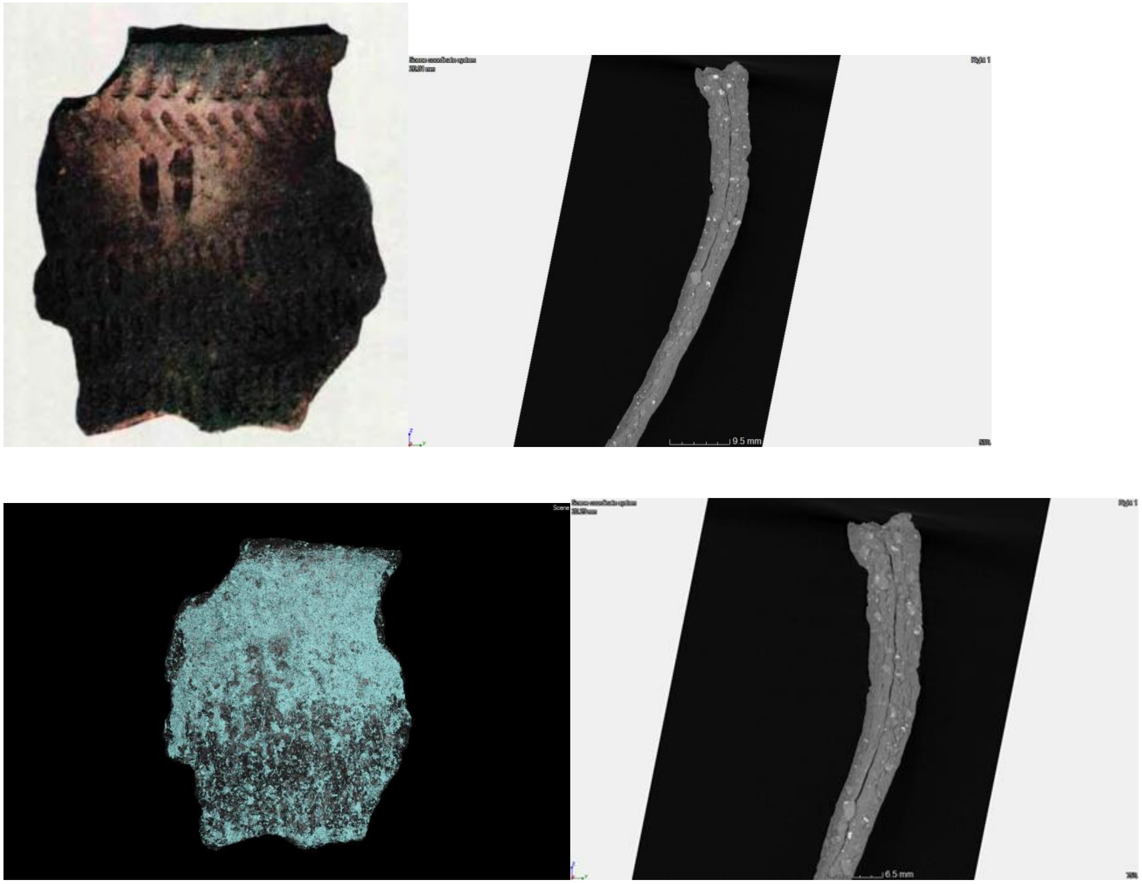
StJohnCT117 AgHk-54 Folded with added clay

StJohnCT118 (same vessel as StJohnCT119) AgHk-54 Folded

StJohnCT119 (same vessel as StJohnCT118) AgHk-54 Folded with added clay



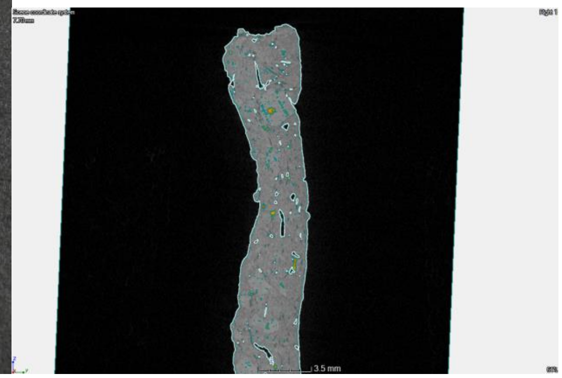
StJohnCT132 AgHk-52 Folded

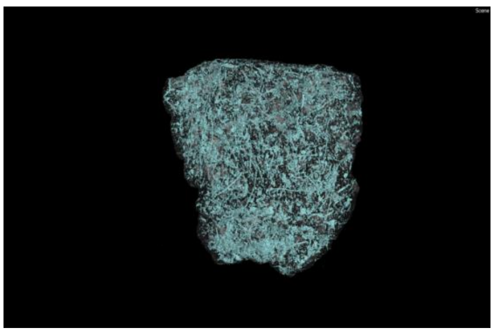


Ferris Vessel 36 AgHk-32 Added clay (Photo from Archaeologix Inc. 1998)

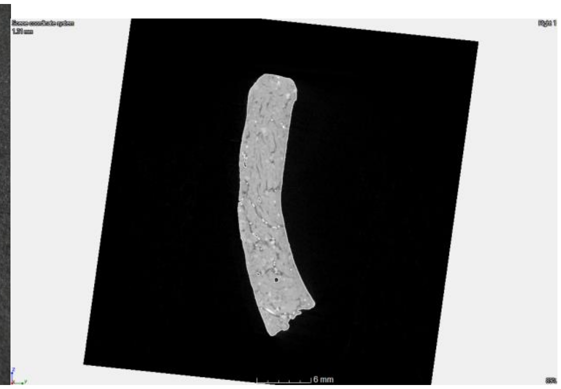
Arkona Learner Vessels

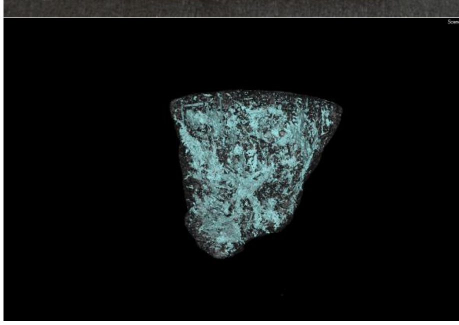
StJohnCT012 AgHk-54





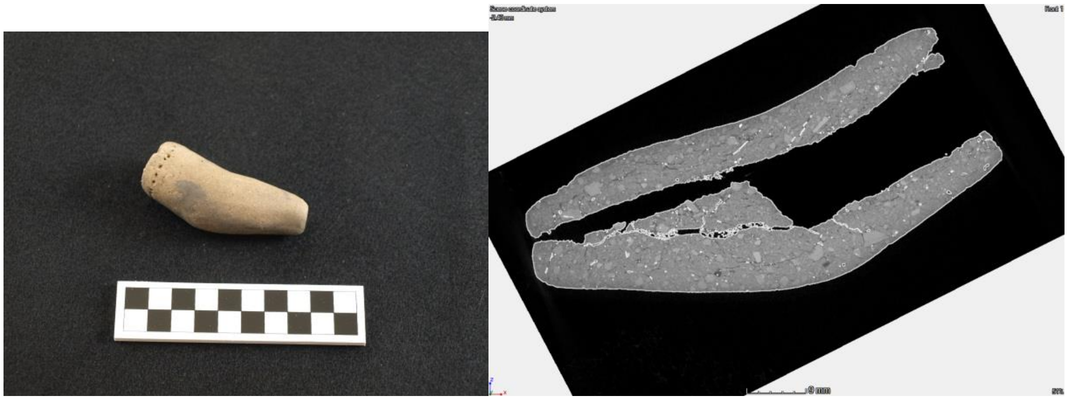
StJohnCT013 AgHk-54



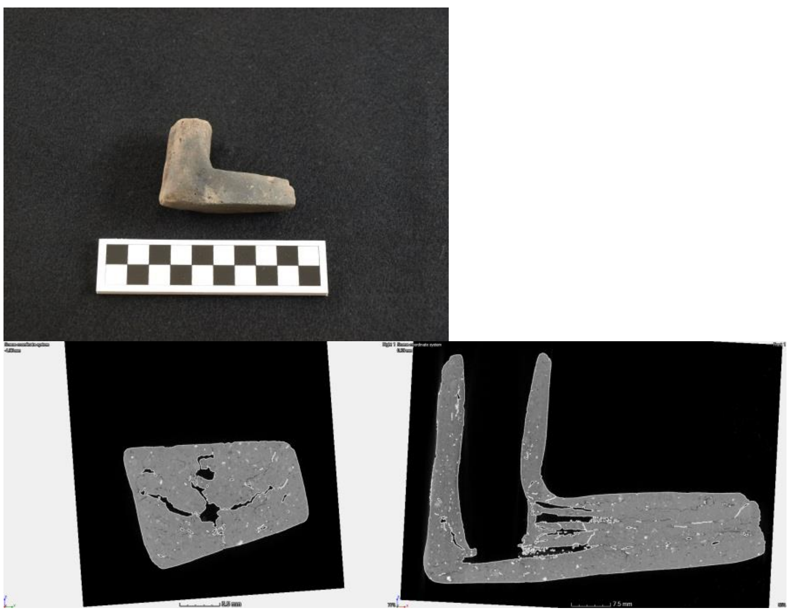


StJohnCT014 AgHk-54

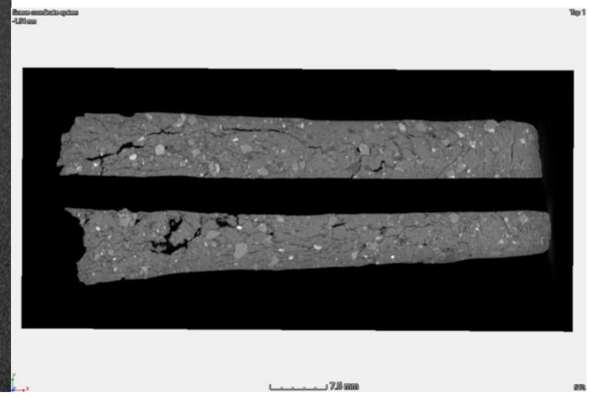
Arkona Clay pipes



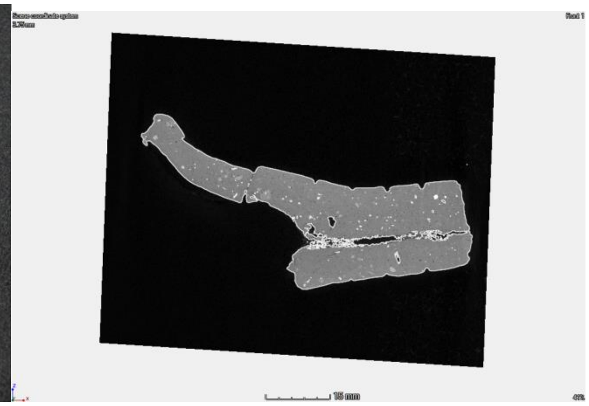
StJohnCT086 AgHk-42



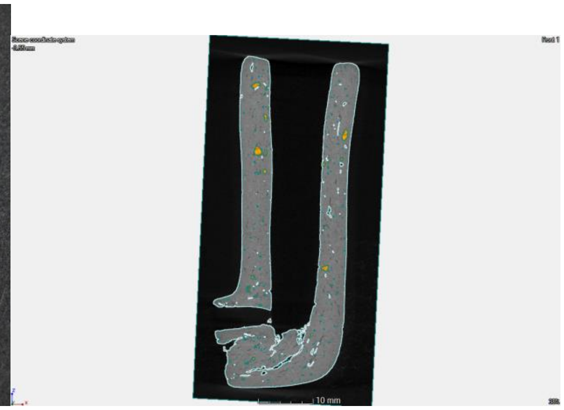
StJohnCT087 AgHk-42

StJohnCT088 AgHk-42

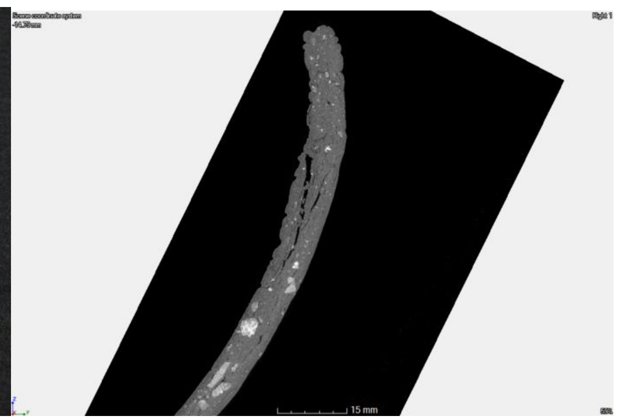
StJohnCT089 AgHk-52

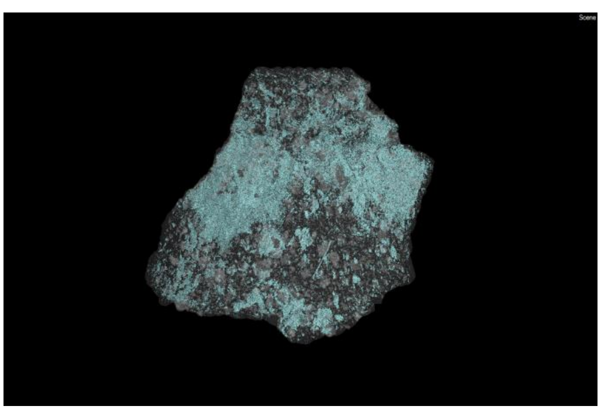



StJohnCT103 AgHk-42

Late Woodland Ceramic Vessels from southern Ontario

StJohnCT120 Bruner-Colasanti AaHq-8

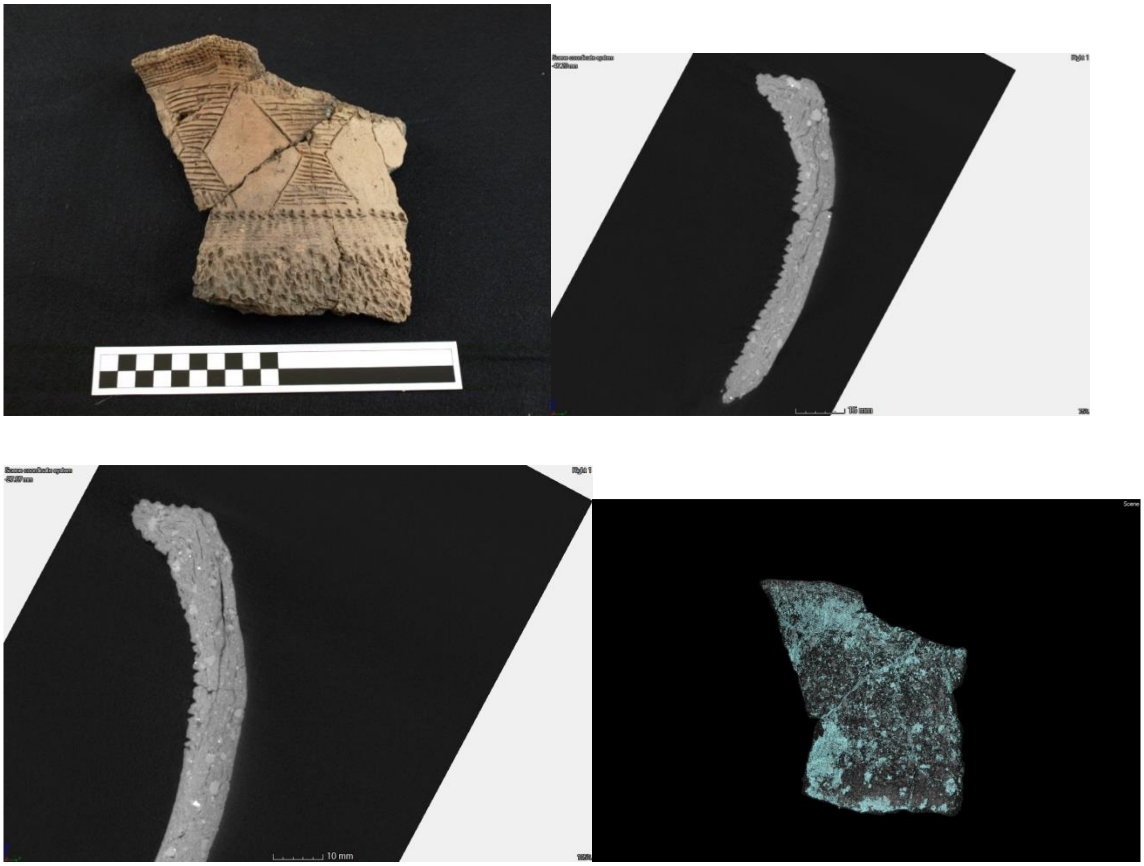




StJohnCT121 Dymock AeHj-2

StJohnCT125 Bruner-Colasanti AaHq-8

StJohnCT128 Dymock AeHj-2



StJohnCT129 Dymock AeHj-2

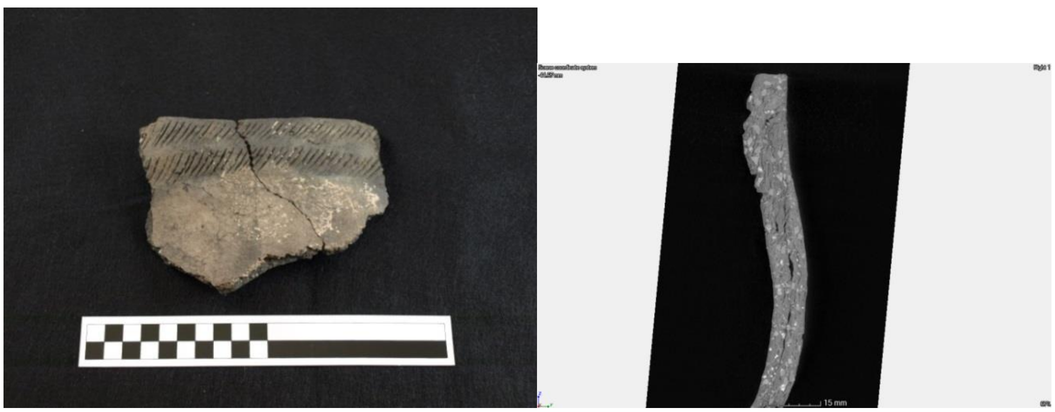
StJohnCT131 Cherry Lane AaHp-21

StJohnCT130 Robson Road AaHp-20

StJohnCT080 Lawson AgHh-1

StJohnCT081 Lawson AgHh-1

StJohnCT082 Praying Mantis AfHi-178



StJohnCT083 Praying Mantis AfHi-178

StJohnCT084 Praying Mantis AfHi-178

Iroquoian Vessel McKeown Site BeFv-1

Appendix B: Recording of specimen information and scanning parameters for all scans.

Sample ID	Use for analysis ?	Site Name	Borden # (where available)	Context within site (Feature, unit)	Vessel #, Catalogue # (if available)
StJohnCT001	no	Inland West Pit Loc. 3	AgHk-54	F.7	V. 11, Cat. 187
StJohnCT002	no	Inland West Pit Loc. 3	AgHk-54	F.38	JVE. 6, Cat. 522
StJohnCT003	no	Inland West Pit Loc. 3	AgHk-54	F85	V. 33, Cat. 382
Incomplete1	no	Inland West Pit Loc. 3	AgHk-54	F. 24	V. 1 Cat. 248
Incomplete2	no	Inland West Pit Loc. 3	AgHk-54	F. 42	V. 23
Incomplete 3	no	Inland West Pit Loc. 3	AgHk-54	F.42	V.23
StJohnCT004	yes	VanBree	AgHk-32	F. 27	V. 14, Cat. 208
StJohnCT005	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 117	V. 228, Cat. 3172
StJohnCT006	yes	Van Bree	AgHk-32	F.24 F.25	V. 49
StJohnCT007	no	Van Bree	AgHk-32	F. 58	V. 30
StJohnCT008	yes	Van Bree	AgHk-32	F. 71&73	V. 37, Cat. 323
StJohnCT009	yes	Inland West Pit Loc. 3	AgHk-54	F. 24	V.1Cat. 248
StJohnCT010	yes	Inland West Pit Loc. 3	AgHk-54	F. 25	V. 13 Cat. 592
StJohnCT011	yes	Inland West Pit Loc. 3	AgHk-54	F. 24	V. 3 Cat. 246
StJohnCT012	yes	Inland West Pit Loc. 3	AgHk-54	F. 38	JVE. 6, Cat. 522
StJohnCT013	yes	Inland West Pit Loc. 3	AgHk-54	F. 31	JVE. 15, Cat. 513
StJohnCT014	yes	Inland West Pit Loc. 3	AgHk-54	F. 26	JVE. 10, cat. 578
StJohnCT015	no	Inland West Pit Loc. 3	AgHk-54	F. 42	V. 23
StJohnCT016	yes	Inland West Pit Loc. 3	AgHk-54	F. 42	V. 23
StJohnCT017	no	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT018	no	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT019-1	no	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT019-2	no	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT019-3	no	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT020	yes	Figura	AgHk-52	F. 24	V. 223 /V. 80, Cat. 1841
StJohnCT021	yes	Figura	AgHk-52	F. 24	V. 229, Cat. 1838
StJohnCT022	yes	Figura	AgHk-52	F. 25	V. 84/230, Cat. 770
StJohnCT023	yes	Figura	Aghk-52	F. 6	V. 73/74, Cat. 1091
StJohnCT024	yes	Figura	AgHk-52	F. 117	V. 10, Cat. 938
StJohnCT025	yes	Figura	AgHk-52	F. 92	V. 164, Cat. 1220
StJohnCT026	yes	Figura	AgHk-52	F. 12	V. 4/V. 161/V. 9, Cat. 14
StJohnCT027	yes	Figura	AgHk-52	F. 5	V. 134/ V. 13, Cat. 1052
StJohnCT028	yes	Figura	AgHK-52	F. 89	V. 49/V. 93, Cat. 256
StJohnCT029	yes	Figura	AgHk-52	F. 94	V. 92, Cat. 649
StJohnCT030	no	Bingo Pit Village Loc. 10	AgHk-42	F. 461	Cat. 8571
StJohnCT031	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 99	V. 71, Cat. 8122
StJohnCT032	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT033	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT034	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT035	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721

Sample ID	Specimen Object (rim, body, base, pipe)	Observable Specimen characteristics (temper, decoration, residue, thickness, friable, coil breaks)	Date of scan DD/MM/YY YY	Duration of scan (open chamber to aqusition computer)
StJohnCT001	Rim sherd	medium amount of coarse temper, exterior bosse	10/07/2014	1 hr 46 min
StJohnCT002	Rim sherd	juv. Vessel. little visable temper, minimal decora	11/07/2014	2 hrs 2 mins
StJohnCT003	Rim, neck, shoulder sherd	Decorated exterior, lots of fine mica inclusions a	11/07/2014	1 hour 30 mins
Incomplete1	Complete profile: approx le	Small vessel, burnt residue at interior, exterior is	14/07/2014	1hr 20mins
Incomplete2	rim, neck sherd	deep puntates on exterior and other decoration,	14/07/2014	40 mins
Incomplete 3	rim, neck sherd	deep puntates on exterior and other decoration,	14/07/2014	1hr
StJohnCT004	rim sherd	visible temper (quartz), incised decoration on ri	02/12/2014	1hr:53 min scan
StJohnCT005	Neck sherd	visible temper, inscrition on exterior is faint	02/12/2014	53min scan
StJohnCT006	Rim, neck, body sherd	friable fabric, glued in several places, large temp	05/12/2014	15mins set up 51 min scan
StJohnCT007	Rim, neck, body sherd	large sherd, visible inclusions, puctates and exte	05/12/2014	15mins set up 53 min scan
StJohnCT008	Rim, collar, neck	Large sherd with castellation, and high collar (ch	08/12/2014	10mins set up 1:40 scan
StJohnCT009	Complete profile: approx le	Small vessel, burnt residue at interior, exterior is	11/12/2014	15mins set up, 53 min scan
StJohnCT010	Rim, neck, shoulder sherd	visible temper, exterior punctates, incised cross	12/12/2014	20mins set up, 53 min scan
StJohnCT011	Rim, neck, shoulder sherd	visible temper, deep rectangular interior punctat	18/12/2014	15 mins set up, 53 min scan
StJohnCT012	Rim, neck	juv. Vessel. little visable temper, minimal decora	18/12/2014	10mins set up 53 min scan
StJohnCT013	Rim	juv. Vessel white, coarse granitic temper, roughly	16/01/2015	2 hours 10 mins 54 seconds
StJohnCT014	Rim sherd, juv. Smooth fab	juv. Vessel	20/01/2015	2 hours 10 mins 54 seconds
StJohnCT015	rim, neck sherd	deep puntates on exterior and other decoration,	09/09/2015	15mins set up 53 min scan
StJohnCT016	rim, neck sherd	deep puntates on exterior and other decoration,	09/09/2015	5mins set up 2 hour 10 min
StJohnCT017	Rim sherd	Deep vertical punctates, with cord wrapped stick	23/11/2015	10 mins set up, 2 hour 10 m
StJohnCT018	Rim sherd	Deep vertical punctates, with cord wrapped stick	23/11/2015	failed scan
StJohnCT019-1	Rim sherd	Deep vertical punctates, with cord wrapped stick	26/11/2015	failed scan
StJohnCT019-2	rim sherd	Deep vertical punctates, with cord wrapped stick	26/11/2015	failed scan
StJohnCT019-3	rim sherd	Deep vertical punctates, with cord wrapped stick	26/11/2015	53 mins
StJohnCT020	rim sherd	Deep vertical punctates, with cord wrapped stick	18/12/2015	2 hours 8 mins
StJohnCT021	rim sherd	cord wrapped stick, visible mica, rolled over rim	05/01/2016	2 hours 10mins 54 seconds
StJohnCT022	rim, neck sherd	western basin tradition triangle pattern	05/01/2016	2 hours 10mins 54 seconds
StJohnCT023	rim, neck sherd	visible mica, upright rim, chevron incise or cws	06/01/2016	2 hours 10mins 54 seconds
StJohnCT024	rim sherd	incised deoration in chevron and straight line pa	08/01/2016	1hour 44mins 43 seconds
StJohnCT025	rim, neck sherd	veritical profile, cord wrapped stick some incise	08/01/2016	1hour 44mins 43 seconds
StJohnCT026	rim sherd	deep punchtates, denate? Stampes at rim	12/01/2016	2 hours 10mins 54 seconds
StJohnCT027	rim, neck sherd	exterior bosses, castelleation, more upright prof	13/01/2016	1hour 44mins 43 seconds
StJohnCT028	rim, neck sherd	western basin tradition triangle pattern, castella	13/01/2016	1hour 44mins 43 seconds
StJohnCT029	rim, neck sherd	punctates, very flared/everted rim profile	13/01/2016	1hour 44mins 43 seconds
StJohnCT030	rim, neck sherd	Deep exterior punctates, cws at rim	15/01/2016	1hour 44mins 43 seconds
StJohnCT031	rim	folded rim? Incised lines	15/01/2016	1hour 44mins 43 seconds
StJohnCT032	rim	exeterior bosses, incised lines	19/01/2016	53 mins
StJohnCT033	rim	exterior bosses, incised lines	19/01/2016	2 hours 10 mins 54 seconds
StJohnCT034	rim	exterior bosses, incised lines	19/01/2016	2 hours 10 mins 54 seconds
StJohnCT035	rim	exterior bosses, incised lines	20/01/2016	1hour 44mins 43 seconds

Sample ID	Duration of reconstruction (in Ct Pro)	Mounting Method (loose, mounted, in box, foam, styrofoam etc.)	filter (type/mm)	Gain	target (reflective, rotating, etc)
StJohnCT001-Da	20 mins	foam	0.5 Cu	n/a	refl.
StJohnCT002-Da	20mins	foam	0.5Cu	n/a	refl.
StJohnCT003-Da	19mins	light grey foam	0.5Cu	n/a	refl.
Incomplete1	20 mins	inside white styrofaom box	0.25Cu	n/a	refl.
Incomplete2	20 mins	foam	0.25Cu	n/a	refl.
Incomplete 3	20 mins	foam	0.25Cu	n/a	refl.
StJohnCT004	10mins	foam	1Cu	30dB	refl.
StJohnCT005	15mins	foam	1Cu	30dB	refl.
StJohnCT006	15mins	foam	1Cu	30dB	refl.
StJohnCT007	10mins	inside white styrofaom box	1Cu	30dB	refl.
StJohnCT008	14mins	inside white styrofaom box	0.5Cu	30dB	refl.
StJohnCT009	12mins	inside white styrofaom box	0.5Cu	30dB	refl.
StJohnCT010	15mins	mounted in foam	0.5Cu	30dB	refl.
StJohnCT011	15mins	inside white styrofaom box	0.5Cu	30dB	refl.
StJohnCT012	15mins	foam pool noodle	0.5Cu	30dB	refl.
StJohnCT013	15mins	foam	.5Cu	30dB	refl.
StJohnCT014	14mins	foam	none	24dB	refl.
StJohnCT015- fa	13mins	large cell white foam	0.25Cu	24db	refl.
StJohnCT016	15 mins	large cell white foam	0.25Cu	24db	refl.
StJohnCT017	n/a	large cell white foam	none	24dB	refl.
StJohnCT018	n/a	large cell white foam	none	24dB	refl.
StJohnCT019-1	n/a	large cell white foam	none	24dB	refl.
StJohnCT019-2	n/a	large cell white foam	none	24dB	refl.
StJohnCT019-3	n/a	large cell white foam	none	24dB	refl.
StJohnCT020	15 mins	large cell white foam	none	24db	refl.
StJohnCT021	20mins	large cell white foam	none	24dB	refl.
StJohnCT022	15 mins	large cell white foam	none	24dB	refl.
StJohnCT023 sa	13 mins	large cell white foam	none	24dB	refl.
StJohnCT024	15mins	large cell white foam	none	24dB	refl.
StJohnCT025	13mins	large cell white foam	none	24dB	refl.
StJohnCT026	12 mins	large cell white foam		24db	refl.
StJohnCT027	15 mins	large cell white foam	none	24db	refl
StJohnCT028	15 mins	large cell white foam	.25Cu	24dB	refl.
StJohnCT029	20 mins	large cell white foam	.25Cu	24dB	refl.
StJohnCT030	15 mins	large cell white foam	none	24bB	refl.
StJohnCT031	20 mins	large cell white foam	none	24db	refl.
StJohnCT032	20 mins	large cell white foam	none	24dB	refl.
StJohnCT033	22 mins	large cell white foam	none	24dB	refl.
StJohnCT034	15 mins	large cell white foam	0.1mm Cu	24dB	refl.
StJohnCT035	15 mins	large cell white foam	0.1mm Cu	24dB	refl.

Sample ID	Comments	Scan Successful
StJohnCT001	First scan: lots of time doing shading corrections, how to set variables, playing wit	Yes! On the second reconstruction it is clear… s
StJohnCT002	cannot figure out shading corrections! Almost an hour spent on playing with shadir	Maybe:the interior of the ceramic is clear and s
StJohnCT003	pratice for mounting/scanning larger sherds	yes data lost
Incomplete1	These settings made it easier to get watts under 8 and a wider spread on the histogr	no! AXIS ROTATION ERRORS TWICE
Incomplete2	Axis Rotation Error	
Incomplete 3	Attempt after system restore	
StJohnCT004	my first scan with new inspectX interface	yes, 0.89 over rotate error
StJohnCT005	0.89 over rotate error	Huge rings not very clear… not as nice a scan lo
StJohnCT006	0.89 over rotate error	still rings. A nice contrast scan though
StJohnCT007	0.89 over rotate error	yes but ring artifact is bad
StJohnCT008	0.77 over rotate error	yes, And this is a way nicer image than the shor
StJohnCT009	30dB gain, 0.89 over rotate error	yes, there is a ring artifact but not that noticabl
StJohnCT010	30db gain, 0.89 over rotate error fingerprints on bosses	yes with rings
StJohnCT011	30dB gain, 0.89 over rotate error ,	yes ring artifact is bad
StJohnCT012	30dB gain, 0.89 over rotate error	yes, really bad rings
StJohnCT013	used minimize rings	yes
StJohnCT014		yes
StJohnCT015	testing not using minimize ring artifacts setting: did not work! Horrible artifact	no huge ring- failed
StJohnCT016	Used ring artifact minimizing. Fingerprints on bosses	yes
StJohnCT017	Rotation error! Not successful. Used ring artifact minimizing	no
StJohnCT018	Not succesful Spinning table at 245 degrees	same scan as above: trying to get it to work
StJohnCT019-1	Not successful Spinning table at a couple mins in: scans with Minimize rings are ma	same scan as above: trying to get it to work
StJohnCT019-2	Not successful spinning table at 40 degrees into scan	same scan as above: trying to get it to work
StJohnCT019-3	scan successful but there is a huge ring artifact	same scan as above: trying to get it to work
StJohnCT020	Yes!!! Fingerprints interior punctate middle and edge	
StJohnCT021	Yes!!!	
StJohnCT022	yes	nice scan
StJohnCT023	yes	same as calibrated 056
StJohnCT024	testing to see is 1 frames/projection will make a difference and allow us to cut dow	yes: need to see if it makes a difference in resolu
StJohnCT025	same as above	
StJohnCT026		yes
StJohnCT027	on the next one try a filter. Did longer shading correction: 200.	not a great image in terms of focus… blurry. Tri
StJohnCT028	Quite a bit of movement between sequential images. Not a great scan, fairly blurry.	Terrible scan! You can see the movement in reco
StJohnCT029	better quality scan than 28… not sure why. The filter doesn't really seem to help with noise in the images.	
StJohnCT030	Dropped 10 images will not reconstruct	
StJohnCT031		
StJohnCT032	testing shading, corrections to see if they can eliminate ring artifacts	Nope… still ring artifacts
StJohnCT033	same scan as above but minimize rings on	No ring artifacts, still pretty bad beam hardenir
StJohnCT034	same scan as above but with filter	yes, possibly one of the best ones yet
StJohnCT035	same scan as above but with 1 frames/time	yes, almost as good as the one above

Sample ID	Use for analysis ?	Site Name	Borden # (where available)	Context within site (Feature, unit)	Vessel #, Catalogue # (if available)
StJohnCT036	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT037	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT038	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 132A	V. 72, Cat. 2987
StJohnCT039	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 178	Cat. 10, 037
Amy-Andrew sherd test	no	Bingo Pit Village Loc. 10	AgHk-42	F. 86	V. 122, Cat. 10721
StJohnCT040	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 56	V. 194, Cat. 3237
StJohnCT041	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 407	V. 120, Cat. 11070
StJohnCT042	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 589	V. 22, Cat. 9151
Nelson Jan 23 test scan	no	Bingo Pit Village Loc. 10	AgHk-42	F. 589	V. 22, Cat. 9151
Nelson Jan 23 test 1	no	Bingo Pit Village Loc. 10	AgHk-42	F. 589	V. 22, Cat. 9151
StJohnCT043	yes	Bingo Pit Village Loc. 10	AgHk-42	Sq. Feature 301: no	V. 93, Cat. 1651
StJohnCT044	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 302 B	V. 41, Cat. 8172
StJohnCT045	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 74	V. 155, Cat. 9276
StJohnCT046	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 590	V. 148, Cat. 5306
StJohnCT047	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 323	Cat. 6749
StJohnCT048	yes	Bingo Pit Loc. 3	AgHk-40	F. 37	V. 7, Cat. 247
StJohnCT049	yes	Bingo Pit Loc. 3	AgHk-40	F. 32	V. 2, Cat. 224
StJohnCT050 -same V as 8	yes	Bingo Pit Loc. 3	AgHk-40	F. 5	V. 12, Cat. 441
StJohnCT051	yes	Bingo Pit Loc. 3	AgHk-40	F. 5	V. 1 Cat. 418
StJohnCT052	yes	Figura	AgHk-52	F. 100	V. 39, Cat. 531
StJohnCT053	yes	Inland West Pit Loc. 6	AgHk-56	F. 3	Cat. 59, V. 2/3?
StJohnCT054	yes	Van Bree	AgHk-32	F. 58	V. 30
StJohnCT055	yes same	Van Bree	AgHk-32	F. 71	V. 37, Cat. 323
StJohnCT056	calibrate	Figura	AgHk-52	F. 6	V. 73/74, Cat. 1091
StJohnCT057	calibrate	Bingo Pit Loc. 3	AgHk-40	F. 37	V. 7, Cat. 247
StJohnCT058	calibrate	Bingo Pit Village Loc. 10	AgHk-42	F. 589	V. 22, Cat. 9151
StJohnCT059	calibrate	Bingo Pit Village Loc. 10	AgHk-42	F. 589	V. 22, Cat. 9151
StJohnCT060	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 301	Cat. 13090
StJohnCT061	yes	Van Bree	AgHk-32	F. 8	V. 6
StJohnCT062	yes	Van Bree	AgHk-32	F. 73, F. 71	V. 35, Cat. 391
StJohnCT063	yes	Bingo Pit Loc. 3	AgHk-40	F. 1, cat 474	V. 4
StJohnCT064	yes	Van Bree	AgHk-32	F. 71	V. 48/3
StJohnCT065	yes	Figura	AgHk-52	F. 24	Cat. 1256
StJohnCT066	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 117	V. 228
StJohnCT067	yes	Bingo Pit Village Loc. 10	AghK-42	F. 283	V. 229, Cat. 7450
StJohnCT068	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 184	V. 64, Cat. 7031
StJohnCT069	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 291	V. 146, Cat. 2552
StJohnCT070 - same V as 020	yes	Figura	AgHk-52	F. 24	V. 80, V. 233, Cat. 1828
StJohnCT071	yes	Figura	AgHk-52	F. 92	V. 164
StJohnCT072	no	Experimental	n/a	n/a	V. 7
StJohnCT073	no	Experimental	no good	n/a	V. 3
StJohnCT074	no	Experimental	n/a	n/a	V. 9
StJohnCT075	no	Experimental	no good	n/a	V. 4
StJohnCT076	no	Experimental	n/a	n/a	V. 2
StJohnCT077	no	Experimental	n/a	n/a	V. 12
StJohnCT078	no	Experimental	n/a	n/a	V. 13
StJohnCT079	yes	Van Bree	AgHk-32	F. 30	V. 26
StJohnCT080	yes	Lawson	AgHh-1	Rim from display c	Cat. L1535

Sample ID	Specimen Object (rim, body, base, pipe)	Observable Specimen characteristics (temper, decoration, residue, thickness, friable, coil breaks)	Date of scan DD/MM/YY YY	Duration of scan (open chamber to aqusition computer)
StJohnCT036	rim	exterior bosses, incised lines	20/01/2016	1hour 44mins 43 seconds
StJohnCT037	rim	exterior bosses, incised lines	20/01/2016	53 mins
StJohnCT038	rim	exterior bosses, incised decoration, castellation	20/01/2016	2hour 10 mins 54 sec.
StJohnCT039	rim, neck sherd	dentate, cws, pairs of punctates, incipent collar?	22/01/2016	2hour 10 mins 54 sec.
Amy-Andrew sh	rim	above	21/01/2016	53 mins
StJohnCT040	rim, neck sherd	csw, flared rim, deep circular punctates, one of v	22/01/2016	1hour 44mins 43 seconds
StJohnCT041	rim, neck sherd	deep square punctates, incised wb type lines, dia	22/01/2016	1hour 44mins 43 seconds
StJohnCT042	rim sherd	deep oblong punctate, large dentate like stamps	22/01/2016	1hour 44mins 43 seconds
Nelson Jan 23	rim	deep oblong punctate, large dentate like stamps	23/01/2016	53min scan
Nelson Jan 23 1	rim	deep oblong punctate, large dentate like stamps	23/01/2016	53min scan
StJohnCT043	rim	small vessel, oval punctates at interior, bosses a	24/01/2016	53min scan
StJohnCT044	rim and neck	castellation, not clear decoration, bosses, oval i	24/01/2016	53 min scan
StJohnCT045	rim	very light coloured fabric, incised pattern and ro	24/01/2016	2 hour 10 min
StJohnCT046	rim and neck	large sherd, cws and crescent shaped punctates	26/01/2016	53min scan
StJohnCT047	rim and neck	large sherd, incised cross hatch at rim, large poi	26/01/2016	53 min scan
StJohnCT048	rim	incised or stamped veritcal lines at rim, deep po	26/01/2016	53 min
StJohnCT049	rim and neck	large sherd with castellation, 4 diagonal rows of	26/01/2016	53 min
StJohnCT050	rim	castellation, cws on diagonal, oval punctates	26/01/2016	53 min
StJohnCT051	rim and neck	heavy vessel with incised? Diagonal lines at rim	27/01/2016	53 mins
StJohnCT052	Rim sherd	cws at rim, Glen meyer type neck short, with inci	08/03/2016	53 mins
StJohnCT053	Neck sherd	Western Basin type, elongated neck with triangle	09/03/2016	53 mins
StJohnCT054	rim and neck	Western Basin type, elongated neck with elabora	09/03/2016	53 mins
StJohnCT055	rim and neck	Western Basin but not totally typical Cunningha	09/03/2016	53 mins
StJohnCT056	see above	see above	12/05/2016	53 mins
StJohnCT057	see above	see above	12/05/2016	53 mins
StJohnCT058	see above	see above	12/05/2016	53 mins
StJohnCT059	see above	see above	12/05/2016	53 mins
StJohnCT060	complete pot		20/05/2016	4 hours, 21 mins
StJohnCT061	rim and neck	Wbish	26/05/2016	53 mins
StJohnCT062	rim and neck	Wbish	26/05/2016	53 mins
StJohnCT063	rim and neck		26/05/2016	53 mins
StJohnCT064	rim sherd		26/05/2016	53 mins
StJohnCT065	Rim, neck shoulder	Glyph vessel: anthropomorphic decoration very	30/05/2016	53 mins
StJohnCT066	Neck and shoulder, approc	glyph vessel, typical Wb elongated nexk	30/05/2016	53 mins
StJohnCT067	Neck and shoulder, approc	Wbish	30/05/2016	53 mins
StJohnCT068	Rim, neck shoulder	Small vessel, some incised patterns	30/05/2016	53 mins
StJohnCT069	Rim, neck, shoulder sherd	Not WB, Glen Meyer	30/05/2016	53 mins
StJohnCT070	Rim, neck sherd	Similar to 051, Castellation, deep punctates	30/05/2016	53min scan
StJohnCT071	Neck, shoulder, approching	triangles on neck	30/05/2016	53 min scan
StJohnCT072	Rim, neck	n/a	11/08/2016	53 min scan
StJohnCT073	Rim, nexk	n/a	12/08/2016	53 min scan
StJohnCT074	Rim, neck	n/a	12/08/2016	53 min scan
StJohnCT075	rim, neck	n/a	12/08/2016	53 min scan
StJohnCT076	rim	n/a	15/08/2016	53 min scan
StJohnCT077	rim	n/a	15/08/2016	53 mins
StJohnCT078	rim, neck	n/a	15/08/2016	53 mins
StJohnCT079	rim, neck	n/a	15/08/2016	53 mins
StJohnCT080	Rim	Neutral Iroquoian- high collared. Inclised rim de	16/08/2016	53 mins

Sample ID	Duration of reconstruction (in Ct Pro)	Mounting Method (loose, mounted, in box, foam, styrofoam etc.)	filter (type/mm)	Gain	target (reflective, rotating, etc)
StJohnCT036	14 mins	clamp	0.5mm Cu	24dB	refl.
StJohnCT037	15 mins	clamp	none	24dB	refl.
StJohnCT038	15 mins	foam	0.25Cu	24dB	refl.
StJohnCT039	16 mins	clamp and foam	0.1Cu	24dB	refl.
Amy-Andrew sh	14 mins	clamp	0.1Cu	24dB	refl.
StJohnCT040	15 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT041	15 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT042	15 mins	clamp and small cell foam	0.1Cu	24dB	refl.
Nelson Jan 23	15 mins	clamp	0.1Cu	24dB	refl.
Nelson Jan 23 1	15 mins	clamp	0.1Cu	24dB	refl.
StJohnCT043	15 mins	clamp and small cell foam	0.1Cu	24dB	refl
StJohnCT044	15 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT045	15 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT046	14 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT047	15 mins	foam	0.1Cu	24dB	refl.
StJohnCT048	16 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT049	13 mins	foam	0.1Cu	24dB	refl.
StJohnCT050	13 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT051	13 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT052	13 mins	clamp and small cell foam	0.1Cu	24dB	refl.
StJohnCT053	13 mins	foam	0.1Cu	24dB	refl
StJohnCT054	13 mins	foam	0.1Cu	24dB	refl.
StJohnCT055	14 mins	small cell foam and clamp	0.1Cu	24dB	refl.
StJohnCT056	14 mins	large cell foam with black cla	none	24dB	refl.
StJohnCT057	14 mins	large cell foam with black cla	none	24dB	refl.
StJohnCT058	13 mins	large cell foam with black cla	none	24dB	refl
StJohnCT059	14 mins	large call foam with black cla	none	24dB	refl.
StJohnCT060	14 mins	pool noodle and museum wax	1mm Cu	24dB	refl.
StJohnCT061	13 mins	foam and clamp	1mm Cu	24dB	refl.
StJohnCT062	14 mins	foam and clamp	1mm Cu	24dB	refl.
StJohnCT063	13 mins	foam and clamp	0.5mm Cu	24db	refl.
StJohnCT064	15 mins	foam and black plastic clamp	1mm Cu	24db	refl.
StJohnCT065	17 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT066	17 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT067	15 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT068	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT069	15 mins	foam and green packing pean	0.5mm Cu	24dB	refl.
StJohnCT070	14 mins	foam and clamp	0.5mm Cu	24db	refl.
StJohnCT071	14 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT072	14 mins	foam and clamp	0.5mm Cu	24	refl.
StJohnCT073	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT074	13 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT075	13 mins	foam and clamp	0.5mm Cu	24db	refl.
StJohnCT076	13 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT077	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT078	13 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT079	13 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT080	13 mins	foam and clamp	0.5mm Cu	24dB	refl.

Sample ID	KV	micro amps	Exposure (msecs)	# projections	Frames/time	effective pixel size in micro meters	Operator	minimize rings?	Shading corrections
StJohnCT036	205	75	500	3142	1	49.83	AS	yes	3 images, 128 frames t
StJohnCT037	170	40	500	3142	2	49.83	AS	no	5 images, 300 frames t
StJohnCT038	185	60	500	3142	2	47.90	AS	yes	3 images, 128 frames t
StJohnCT039	195	45	500	3142	2	68.43	AS	yes	3 images, 128 frames t
Amy-Andrew sh	195	45	500	3142	2	47.96	AN	no	5 images, 350 frames t
StJohnCT040	195	45	500	3142	1	73.63	AS	yes	3 images, 128 frames t
StJohnCT041	195	45	500	3142	1	57.10	AS	yes	3 images, 128 frames t
StJohnCT042	195	45	500	3142	1	44.30	AS	yes	3 images, 128 frames t
Nelson Jan 23	195	45	500	3142	2	43.98	AN	no	3 images, 500 frames t
Nelson Jan 23 1	195	45	500	3142	2	42.35	AN	no	3 images, 400 frames t
StJohnCT043	195	45	500	3142	2	35.51	AS	no	3 images, 500 frames t
StJohnCT044	195	45	500	3142	2	54.72	AS	no	3 images, 600 to avg.
StJohnCT045	195	40	500	3142	2	35.85	AS	yes	3 images, 300 to avg.
StJohnCT046	195	45	500	3142	2	81.70	AS	no	3 images, 600 to avg.
StJohnCT047	200	45	500	3142	2	95.20	AS	no	3 images, 600 to avg.
StJohnCT048	195	45	500	3142	2	56.12	AS	no	3 images, 600 to avg.
StJohnCT049	195	45	500	3142	2	87.08	AS	no	3 imgaes, 600 to avg.
StJohnCT050	195	45	500	3142	2	64.22	AS	no	tried using shading co
StJohnCT051	200	47	500	3142	2	64.89	AS	no	3 images, 600 to avg.
StJohnCT052	154	35	1	3142	1	66.49	AS	no	3 images, 128 frames t
StJohnCT053	145	40	1	3142	1	114.71	AS	no	3 images, 128 frames t
StJohnCT054	145	35	1	3142	1	97.59	AS	no	3 images, 128 frames t
StJohnCT055	145	35	1	3142	1	71.12	AS	no	3 images, 128 frames t
StJohnCT056	100	55	1	3142	1	n/a	AS	no	3 images, 128 frames t
StJohnCT057	100	55	1	3142	1	61.02	AS	no	3 images, 128 frames t
StJohnCT058	100	55	1	3142	1	n/a	AS	no	3 images, 128 frames t
StJohnCT059	120	35	1	3141	1	54.13	AS	no	3 images, 128 frames t
StJohnCT060	165	92	1	3141		80.75	AS	yes	3 images, 150 frames t
StJohnCT061	170	95	1	3141	1	72.57	AS	no	3 images, 150 frames t
StJohnCT062	170	80	1	3141	1	69.20	AS	no	3 images, 150 frames t
StJohnCT063	175	42	1	3141	1	56.96	AS	no	3 images, 150 frames t
StJohnCT064	170	80	1	3141	1	37.20	AS	no	3 images, 150 frames t
StJohnCT065	160	60	1	3142	1	112.98	AS	no	3 images, 150 frames t
StJohnCT066	160	60	1	3141	1	112.98	AS	no	3 images, 150 frames t
StJohnCT067	160	55	1	3141	1	107.39	AS	no	3 images, 150 frames t
StJohnCT068	155	55	1	3141	1	68.93	AS	no	3 images, 150 frames t
StJohnCT069	160	55	1	3141	1	108.95	AS	no	3 images, 150 frames t
StJohnCT070	155	58	1	3141	1	74.83	AS	no	3 images, 150 frames t
StJohnCT071	160	55	1	3141	1	119.73	AS	no	3 images, 150 frames t
StJohnCT072	150	65	1	3142	1	54.81	AS	no	3 images, 150 frames t
StJohnCT073	150	65	1	3142	1	n/a	AS	no	3 images, 150 frames t
StJohnCT074	150	65	1	3142	1	56.05	AS	no	3 images, 150 frames t
StJohnCT075	150	65	1	3141	1	81.24	AS	no	3 images, 150 frames t
StJohnCT076	150	65	1	3141	1	35.99	AS	no	3 images, 150 frames t
StJohnCT077	150	65	1	3141	1	43.13	AS	no	3 images, 150 frames t
StJohnCT078	150	65	1	3141	1	55.94	AS	no	3 images, 150 frames t
StJohnCT079	165	60	1	3141	1	50.23	AS	no	3 images, 150 frames t
StJohnCT080	165	60	1	3141	1	81.32	AS	no	3 images, 150 frames t

Sample ID	Comments	Scan Successful
StJohnCT036	same scan as above but with .5mm Cu filter...had to use much higher kV and amps	A bit less noise than the 0.1mm Cu filter, still sc
StJohnCT037	Same as scan 32, to see if even longer shading corrections eliminate rings.	Still rings. Maybe less than before?
StJohnCT038	Fingerprints exterior punctate left	
StJohnCT039	long scan, normal shading. Testing clamping the foam into the clamp.	pretty nice scan
Amy-Andrew sh	longer shading corrections. Was a fast scan and seemed to improve rings but not eliminate them	
StJohnCT040	trying foam in clamp mounting. Took cell photo	The scans with 2 frames/time are better in term
StJohnCT041		not really a great scan.
StJohnCT042		same as calibrated 058 and 059
Nelson Jan 23	Andrew running tests with shading corrections to get rid of rings	seemed to get rid of rings. Longer shading corre
Nelson Jan 23 1	same as above, this shading correction takes 10 mins	maybe a hint of the ring core but not visible in t
StJohnCT043	this shading correction takes 13 mins. We shall see if there are rings.	maybe a hint of the ring core but not visible in t
StJohnCT044	this shading correctiont takes 15 mins. Fingerprints exterior Bosses at the left	
StJohnCT045	going back to long scan... just because I am going to leave and go to the barn.	
StJohnCT046	had some trouble mounting this sherd... hopefully won't get too much movement.	
StJohnCT047	mounted in foam thing	
StJohnCT048	Fingerprints on inside bosses! May want to run a higher resolution scan of this one	same as calibrated 57
StJohnCT049	mounted in foam thing	
StJohnCT050	See if this turns out okay and if so may not need to do shading correction every time.	
StJohnCT051	similar vessels in terms of decoration at Figura	
StJohnCT052	First scan since engineer. Autoconditioning still a problem, seems to be taking less kv and micro amps to get penetration on histogr	
StJohnCT053	neck to get typical WB type.	
StJohnCT054	In these last two, recommended to just do one frame to reduce noise, because you are not averaging out 2 frames but only correctin	
StJohnCT055	last one of first sample set. I don't really see an improvement in noise so switch back to 500 and 2frames for the next batch?	
StJohnCT056	Calibrated scan: scanned with water phantom	really nice quailty scan. Maybe lower kv is bett
StJohnCT057	Calibrated scan: scanned with water phantom	
StJohnCT058	Calibrated scan: water phantom: tried glitter tube phantom with distilled water to see if it is more accurate.	
StJohnCT059	Calibrated scan: scanned with glitter tube water phantom and with glitter tube full of quartz from Linda Howie	
StJohnCT060	2 frames per projection on aquision screen, trying for a nicer scan	Museum wax is too close to ceramic. Do not us
StJohnCT061	1 frames to average.	
StJohnCT062		
StJohnCT063		fingerprints on exterior bosses
StJohnCT064		
StJohnCT065		
StJohnCT066		
StJohnCT067		
StJohnCT068		
StJohnCT069		
StJohnCT070		fingerprints see if it matches 51 in manufacture
StJohnCT071	too large a sample: might screw up shading corrections.	Cropped out bottom with bad shading correctio
StJohnCT072		
StJohnCT073		Lost this scan, rescanned as 095
StJohnCT074		
StJohnCT075		
StJohnCT076		
StJohnCT077		
StJohnCT078		
StJohnCT079		really nice scan
StJohnCT080		this is not the greatest sample as there are lots

Sample ID	Use for analysis ?	Site Name	Borden # (where available)	Context within site (Feature, unit)	Vessel #, Catalogue # (if available)
StJohnCT081	yes	Lawson	AgHh-1	From display case	Cat. 27269, cat. 28004
StJohnCT082	yes	Praying Mantis	AfHi-178	MOA box 2047	Cat. 157 c and b
StJohnCT083	yes	Praying Mantis	AfHi-178	MOA box 2052	Cat. 1404 and 1405
StJohnCT084	yes	Praying Mantis	AfHi-178	MOA box 2049 F. 2	Cat. 430-625 #625
StJohnCT085	yes	Van Bree	AgHk-32	F. 291	V. 23
StJohnCT086	yes	Bingo Pit Village Loc. 10	AgHk-42	sq 433	Cat. 1103
Incomplete 4	no	Bingo Pit Village Loc. 10	AgHk-42	F. 364	Cat. 9748
StJohnCT087	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 364	Cat. 9748
StJohnCT088	yes	Bingo Pit Village Loc. 10	AgHk-42	Square 241	Cat. 1682
StJohnCT089	yes	Figura	AgHk-52	F. 116	Cat. 1257
Incomplete 5	no	Routledge	AlGu-18?	Midden	crockery
StJohnCT090 -same V as 028	yes	Figura	AgHk-52	F. 94	V. 93, Cat. 285
StJohnCT091	yes	Figura	AgHk-52	F. 91	V. 57, Cat. 410
StJohnCT092	yes	Routledge	AlGu-18?	Midden	crockery
StJohnCT093-rescan of 030	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 461	Cat. 8571
StJohnCT094- rescan of 028	no	Figura	AgHK-52	F. 89	V. 49/V. 93, Cat. 256
StJohnCT095-rescan of 073	yes	Experimental	n/a	n/a	V. 3
StJohnCT096- rescan of 028	yes	Figura	AgHK-52	F. 89	V. 49/V. 93, Cat. 256
StJohnCT097- same V. as 050	yes	Bingo Pit Loc. 3	AgHk-40	F. 5	V. 12, Cat. 466
StJohnCT098- same V. as 064	yes	Van Bree	AgHk-32	F. 71	V. 3, Cat. 498
StJohnCT099	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 99	V. 135, Cat. 11411
StJohnCT100 - same V. as 051	yes	Bingo Pit Loc. 3	AgHk-40	F. 5	V. 1, Cat. 435
StJohnCT101 -same V. as 044	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 302 B	V. 41, Cat. 9791
StJohnCT102 - same V. as 049	yes	Bingo Pit Loc. 3	AgHk-40	F. 32	V. 2, Cat. 225
StJohnCT103	yes	Bingo Pit Village Loc. 10	AgHk-42	F. 140 L. 3	Cat. 13129
StJohnCT104 rescan of 075	yes	Experimental	n/a	n/a	V. 4
StJohnCT105	yes	Inland West Pit Loc. 9	AgHk-58	F. 103	V. 42 -1
StJohnCT106	yes	Inland West Pit Loc. 9	AgHk-58	F. 103	V. 42 -2 can't tell catal
StJohnCT107	yes	Inland West Pit Loc. 9	AgHk-58	F. 21	V. 80, Cat. 2348
StJohnCT108	no	Inland West Pit Loc. 9	AgHk-58	F. 56	V. 33, Cat. 367
StJohnCT109-rescan of 108	yes	Inland West Pit Loc. 9	AgHk-58	F. 56	V. 33, Cat. 367
StJohnCT110	yes	Inland West Pit Loc. 9	AgHk-58	F. 364	V. 15
StJohnCT111	yes	Inland West Pit Loc. 9	AgHk-58	F. 16	V. 8, Cat. 2074
StJohnCT112	yes	Inland West Pit Loc. 9	AgHk-58	F. 38	V. 19
StJohnCT113	yes	Inland West Pit Loc. 9	AgHk-58	F. 41	V. 88, Cat. 780
StJohnCT114	yes	Inland West Pit Loc. 3	AgHk-54	F. 22	V. 14, Cat. 404
StJohnCT115	yes	Inland West Pit Loc. 3	AgHk-54	F. 24	V. 2, Cat. 247
StJohnCT116	yes	Inland West Pit Loc. 3	AgHk-54	F. 38	V. 29, Cat. 543
StJohnCT117	yes	Inland West Pit Loc. 3	AgHk-54	F. 85	V. 33, Cat. 382
StJohnCT118 same V as 119	yes	Inland West Pit Loc. 3	AgHk-54	F. 19	V. 25, Cat. 468
StJohnCT119 same V. as 118	yes	Inland West Pit Loc. 3	AgHk-54	F. 19	V. 25, Cat. 464
StJohnCT120	yes	Bruner-Colasanti	AaHq-8	F. 189	unknown
StJohnCT121	yes	Dymock	AeHj-2	unknown	unknown
StJohnCT122	no	Bruner-Colasanti	AaHq-8	F. 142	unknown
StJohnCT123	no	Dymock	AeHj-2	38? Maybe	unknown
StJohnCT124	yes but r	Dymock	AeHj-2	38? Maybe	unknown
StJohnCT125	yes	Bruner-Colasanti	AaHq-8	F. 142	unknown

Sample ID	Specimen Object (rim, body, base, pipe)	Observable Specimen characteristics (temper, decoration, residue, thickness, friable, coil breaks)	Date of scan DD/MM/YY YY	Duration of scan (open chamber to aqusition computer)
StJohnCT081	Rim, neck, shoulder sherd	Neutral Iroquoian- Lawson incised. One line of i	16/08/2016	53 mins
StJohnCT082	Rim, neck	GM two rows cws diagonals, neck roughly vertic	16/08/2016	53 mins
StJohnCT083	Rim, neck	GM two rows diagonal incised at exterior of rim,	17/08/2016	53 mins
StJohnCT084	Rim, neck, body sherd	GM 4 rows incised diagonals at exterior and int	17/08/2016	53 mins
StJohnCT085	Rim sherd	GM cross hatch at rim, one incised diagonals be	18/08/2016	53 mins
StJohnCT086	pipe bowl	one row of dots around rim	18/08/2016	53 mins
Incomplete 4	pipe bowl	undecorated, sits flat at base	18/08/2016	53 mins
StJohnCT087	pipe bowl	undecorated, sits flat at base	25/08/2016	53 mins
StJohnCT088	pipe stem and mouthpiece	undecorated, sits flat at base	25/08/2016	53 mins
StJohnCT089	flared pipe bowl	incised concentric lines	25/08/2016	53 mins
Incomplete 5	Rim of dish, milk pan?	dirty, brown glaze	26/08/2106	53 mins
StJohnCT090	Rim and neck	Wbish	31/08/2016	53 mins
StJohnCT091	rim and neck	Wbish	31/08/2016	53 mins
StJohnCT092	Rim of dish, milk pan?	dirty, brown glaze	31/08/2016	53 mins
StJohnCT093	rim, neck sherd	Deep exterior punctates, cws at rim	05/12/2016	53 mins
StJohnCT094	rim, neck sherd	western basin tradition triangle pattern, castell	05/12/2016	53 mins
StJohnCT095	Rim, neck		05/12/2016	53 min scan
StJohnCT096	rim, neck sherd	western basin tradition triangle pattern, castell	05/12/2016	53 mins
StJohnCT097	rim	cws on diagonal, oval punctates	05/12/2016	53 min
StJohnCT098	Rim, neck, shoulder sherd	punctates, obliques, see cunningham	07/12/2016	53 mins
StJohnCT099	Rim, neck shoulder	cws, castellation	07/12/2016	53 mins
StJohnCT100	Rim, neck shoulder	same as 051 but with castellation	07/12/2016	53 mins
StJohnCT101	Rim, neck, shoulder sherd	same as V. 44	08/12/2016	53 mins
StJohnCT102	Rim, neck	same as V. 49 but no casteallation	08/12/2016	53 mins
StJohnCT103	pipe bowl	undecorated, smooth bowl	03/01/2017	53 mins
StJohnCT104	rim, neck		12/01/2017	53 min scan
StJohnCT105	Rim, neck	two castellations, large rim sherd	12/01/2017	53 mins
StJohnCT106	Rim, neck, shoulder sherd	castellated, punctates	12/01/2017	53 mins
StJohnCT107	Rim sherd	Applied? Decoration, bumps out	12/01/2017	53 mins
StJohnCT108	Rim sherd	triangles on neck/rim	12/01/2017	53 mins
StJohnCT109	Rim sherd	triangles on neck/rim	13/01/2017	53 mins
StJohnCT110	Rim sherd	trianlges incised on separate neck sherd, maybe	13/01/2017	53 mins
StJohnCT111	Rim, neck sherd	stamped obliques	13/01/2017	53 mins
StJohnCT112	Rim sherd	csw, castellation	13/01/2017	53 mins
StJohnCT113	Rim, neck sherd	csw, castellation	13/01/2017	53 mins
StJohnCT114	Rim, neck sherd	cws, appears to be incised triangles on neck	13/01/2017	53 mins
StJohnCT115	Rim, neck, shoulder	castellations	13/01/2017	53 mins
StJohnCT116	Rim, neck, shoulder sherd	Multiple castellations	18/01/2017	53 mins
StJohnCT117	Rim, neck, shoulder		18/01/2017	53 mins
StJohnCT118	Rim, neck, shoulder sherd	castellations, large interior punctates	18/01/2017	53 mins
StJohnCT119	Rim, neck sherd	castellations, large interior punctates	18/01/2017	53 mins
StJohnCT120	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	25/01/2017	53 mins
StJohnCT121	Rim, neck sherd	deep punctates	25/01/2017	53 mins
StJohnCT122	Rim, neck sherd	rolled rim	26/01/2017	53 mins
StJohnCT123	Full profile	small vessel, interior punctates	26/01/2017	53 mins
StJohnCT124	Full profile	small vessel, interior punctates	30/01/2017	53 mins
StJohnCT125	Rim, neck sherd	rolled rim	30/01/2017	53 mins

Sample ID	Duration of reconstruction (in Ct Pro)	Mounting Method (loose, mounted, in box, foam, styrofoam etc.)	filter (type/mm)	Gain	target (reflective, rotating, etc)
StJohnCT081	14 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT082	14 mins	foam and clamp	0.5mm Cu	24dB	relf.
StJohnCT083	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT084	13 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT085	18 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT086	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
Incomplete 4	14 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT087	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT088	14 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT089	17 mins	foam and clamp	0.5mm Cu	24dB	refl.
Incomplete 5	16 mins	foam and clamo	0.5mm Cu	24dB	relf.
StJohnCT090	14 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT091	15 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT092	16 mins	foam and clamp	0.5mm Cu	24db	refl.
StJohnCT093	15 mins	foam and clamp	0.5mm Cu	24bB	refl.
StJohnCT094	15 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT095	16 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT096	14 mins	foam and clamp	0.5mm Cu	24dB	refl.
StJohnCT097	13 mins	clamp and large cell foam	0.5mm Cu	24dB	refl.
StJohnCT098	14 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT099	14 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT100	13 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT101	15 mins	foam box and green packing p	0.5mm Cu	24dB	refl.
StJohnCT102	15 mins	foam slot taped to table	0.5mm Cu	24dB	refl.
StJohnCT103	15 mins	foam and clamp	0.25mm Cu	24dB	refl.
StJohnCT104	15 mins	foam and clamp	0.5mm Cu	24db	refl.
StJohnCT105	15 mins	foam box green peanuts	0.5mm Cu	24dB	refl.
StJohnCT106	14 mins	foam box green peanuts	0.5mm Cu	24dB	refl.
StJohnCT107	14 mins	foam pool noodle on platform	0.5mm Cu	24dB	refl.
StJohnCT108	14 mins	foam on platform	0.5mm Cu	24dB	refl.
StJohnCT109	13 mins	shallow foam box on platforn	0.5mm Cu	24dB	refl.
StJohnCT110	15 mins	in a foam cup with green pear	0.5mm Cu	24dB	refl.
StJohnCT111	15 mins	in a foam cup with green pear	0.5mm Cu	24dB	refl.
StJohnCT112	13 mins	in a foam cup with green pear	0.5mm Cu	24dB	refl.
StJohnCT113	14 mins	in a foam cup with green pear	0.5mm Cu	24dB	refl.
StJohnCT114	14 mins	in a foam cup with green pear	0.5mm Cu	24dB	ref.
StJohnCT115	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT116	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT117	14 mins	low foam box with grey and w	0.5mm Cu	24dB	refl.
StJohnCT118	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT119	14 mins	low foam box with grey and w	0.5mm Cu	24dB	refl.
StJohnCT120	14 mins	low foam box with grey and w	0.5mm Cu	24dB	refl.
StJohnCT121	15 mins	low foam box with pool noodl	0.5mm Cu	24db	refl.
StJohnCT122	13 mins	low foam box with pool noodl	0.5mm Cu	24dB	refl.
StJohnCT123	13 mins	low foam box with pool noodl	0.5mm Cu	24dB	refl.
StJohnCT124	14 mins	low foam box with white foan	0.5mm Cu	24dB	refl.
StJohnCT125	14 mins	low foam box with pool noodl	0.5mm Cu	24dB	refl.

Sample ID	KV	micro amps	Exposure (msecs)	# projections	Frames/time	effective pixel size in micro meters	Operator	minimize rings?	Shading corrections
StJohnCT081	160	60	1	3141	1	89.45	AS	no	3 images, 150 frames t
StJohnCT082	165	60	1	3141	1	67.41	AS	no	3 images, 150 frames t
StJohnCT083	160	65	1	3141	1	92.87	AS	no	3 images, 150 frames t
StJohnCT084	160	65	1	3142	1	119.73	AS	no	3 images, 150 frames t
StJohnCT085	165	60	1	3142	1	55.71	AS	no	3 images, 150 frames t
StJohnCT086	165	65	1	3142	1	42.99	AS	no	3 images, 150 frames t
Incomplete 4	160	65	1	3142	1	n/a	AS	no	3 images, 150 frames t
StJohnCT087	150	60	1	3142	1	39.39	AS	no	3 images, 150 frames t
StJohnCT088	145	60	1	3142	1	39.39	AS	no	3 images, 150 frames t
StJohnCT089	150	60	1	3142	1	52.28	AS	no	3 images, 150 frames t
Incomplete 5	160	60	1	3142	1	n/a	AS	no	3 images, 150 frames t
StJohnCT090	160	60	1	3142	1	53.85	AS	no	3 images, 150 frames t
StJohnCT091	160	60	1	3142	1	92.56	AS	no	3 images, 150 frames t
StJohnCT092	160	60	1	3142	1	63.18	AS	no	3 images, 150 frames t
StJohnCT093	160	60	1	3141	1	63.60	AS	no	3 images, 150 frames t
StJohnCT094	160	55	1	3141	1	n/a	AS	no	3 images, 150 frames t
StJohnCT095	150	65	1	3141	1	43.10	AS	no	3 images, 150 frames t
StJohnCT096	160	55	1	3141	1	69.62	AS	no	3 images, 150 frames t
StJohnCT097	160	60	1	3141	1	54.79	AS	no	3 images, 150 frames t
StJohnCT098	160	60	1	3141	1	119.73	AS	no	3 images, 150 frames t
StJohnCT099	160	55	1	3141	1	95.78	AS	no	3 images, 150 frames t
StJohnCT100	160	55	1	3141	1	105.35	AS	no	3 images, 150 frames t
StJohnCT101	160	60	1	3141	1	87.67	AS	no	3 images, 150 frames t
StJohnCT102	160	58	1	3141	1	52.11	AS	no	3 images, 150 frames t
StJohnCT103	175	70	1	3141	1	36.19	AS	no	3 images, 150 frames t
StJohnCT104	160	60	1	3141	1	66.87	AS	no	3 images, 150 frames t
StJohnCT105	160	63	1	3141	1	119.73	AS	no	3 images, 150 frames t
StJohnCT106	165	60	1	3141	1	82.41	AS	no	3 images, 150 frames t
StJohnCT107	165	60	1	3141	1	32.91	AS	no	3 images, 150 frames t
StJohnCT108	170	55	1	3141	1	63.72	AS	no	3 images, 150 frames t
StJohnCT109	172	55	1	3141	1	65.31	AS	no	3 images, 150 frames t
StJohnCT110	170	53	1	3141	1	35.58	AS	no	3 images, 150 frames t
StJohnCT111	170	55	1	3141	1	39.46	AS	no	3 images, 150 frames t
StJohnCT112	170	55	1	3141	1	40.68	AS	no	3 images, 150 frames t
StJohnCT113	170	54	1	3141	1	40.68	AS	no	3 images, 150 frames t
StJohnCT114	170	55	1	3141	1	55.10	AS	no	3 images, 150 frames t
StJohnCT115	170	55	1	3141	1	112.63	AS	no	3 images, 150 frames t
StJohnCT116	170	55	1	3141	1	119.73	AS	no	3 images, 150 frames t
StJohnCT117	168	55	1	3141	1	75.79	AS	no	3 images, 150 frames t
StJohnCT118	170	55	1	3141	1	109.72	AS	no	3 images, 150 frames t
StJohnCT119	168	55	1	3141	1	83.29	AS	no	3 images, 150 frames t
StJohnCT120	170	55	1	3141	1	81.23	AS	no	3 images, 150 frames t
StJohnCT121	170	55	1	3141	1	73.05	AS	no	3 images, 150 frames t
StJohnCT122	170	57	1	3141	1	78.66	AS	no	3 images, 150 frames t
StJohnCT123	170	58	1	3141	1	75.07	AS	no	3 images, 150 frames t
StJohnCT124	175	55	1	3141	1	69.48	AS	no	3 images, 150 frames t
StJohnCT125	170	60	1	3141	1	78.43	AS	no	3 images, 150 frames t

Sample ID	Comments	Scan Successful
StJohnCT081		
StJohnCT082		
StJohnCT083		
StJohnCT084		had to cut out the bottom of the pot to fit it in, n
StJohnCT085		seems dark, hard to get the lower end of the his
StJohnCT086		compare pipe construction to pot construction
Incomplete 4		Scan Failed: Blown Filiment!
StJohnCT087		not great, there is some sort of noise at the top
StJohnCT088		
StJohnCT089		see page 33 of the report
Incomplete 5		see what a wheel thrown vessel looks like
StJohnCT090		Already scanned part of this vessel!
StJohnCT091		pretty good scan
StJohnCT092		see what a wheel thrown vessel looks like
StJohnCT093		This = 030 rescan, okay scan, not great. Still sor
StJohnCT094		rescan of 028- FAILED can't get centre of rotatio
StJohnCT095		rescan of 073-okay
StJohnCT096		rescan of 028
StJohnCT097	Attempt to see if the castellation with fold and added clay in scan 050 construction	okay, the inclusions are close to clay density
StJohnCT098	Trying to mount large samples, this is mounted horizontally with part of the rim and part of the shoulder cut out of the edges of the	
StJohnCT099	Multiple castellations	seems to be less movement in scans when they
StJohnCT100		
StJohnCT101	Compare the castellation construction on this one to the others	fingerprints on bosses
StJohnCT102	Compare this one to 49 and see if castellation vs not casetellation built differntly.	
StJohnCT103	testing for ring artifacts	
StJohnCT104	rescan of 075	
StJohnCT105	Trying to see if the castellations are all built in the same way.	fingerprints
StJohnCT106	Trying to see if the castellations are all built in the same way.	
StJohnCT107	Interested in how the raisded decoration was constructed.	
StJohnCT108	Not good mounting, it rocked from first to last image.	
StJohnCT109	Rescan of above tried shallow box mounting.	This one was also 3D scanned by Nelson-Ask Hi
StJohnCT110		This one was also 3D scanned by Nelson-Ask Hi
StJohnCT111		This one was also 3D scanned by Nelson- Ask H
StJohnCT112	Really nice scan	This one was also 3D scanned by Nelson-Aks Hi
StJohnCT113		
StJohnCT114		
StJohnCT115		
StJohnCT116	Large sherd, cut of one edge of the rim in the scan.	Too big to move for shading correction, had to r
StJohnCT117		
StJohnCT118	Scanning this one and one other sherd of the same vessel to examine castellation construction	
StJohnCT119	Scanning this one and one other sherd of the same vessel to examine castellation c	Fingerprints
StJohnCT120		
StJohnCT121		
StJohnCT122	Lots of mends but should be able to see the rim construction.	under rotate error by 0.25 degrees short of 360
StJohnCT123		under rotate error by 0.25 degrees short of 360
StJohnCT124		
StJohnCT125		

Sample ID	Use for analysis ?	Site Name	Borden # (where available)	Context within site (Feature, unit)	Vessel #, Catalogue # (if available)
StJohnCT126	no	Dymock	AeHj-2	F. 29	V. 2?
StJohnCT127	no	Dymock	AeHj-2	F. 29	V. 2?
StJohnCT128	yes	Dymock	AeHj-2	F. 29	V. 2?
StJohnCT129	yes	Dymock	AeHj-2	F. 29	Different vessel than a
StJohnCT130	yes	Robson Road	AaHp-20	Area B	unknown
StJohnCT131	yes	Cherry Lane	AaHp-21	unknown	unknown
StJohnCT132	yes	Figura	AgHk-52	F. 32	V. 25, Cat. 93
StJohnCT133a	no	Figura	AgHk-52	F. 24	Cat. 1806
StJohnCT133b	no	Inland West Pit Loc. 3	AgHk-54	F. 38	Cat. 521
StJohnCT133c	no	Figura	AgHk-52	F. 23	Cat. 826
StJohnCT134a	no	Bingo Pit Village Loc. 10	AgHk-42	F. 290	Cat. 6950
StJohnCT134b	no	Bingo Pit Village Loc. 10	AgHk-42	F. B	Cat. 9824
StJohnCT134c	no	Bingo Pit Village Loc. 10	AgHk-42	F. 527	Cat. 10945
StJohnCT135	no	Inland West Pit Loc. 3	AgHk-54	F. 38	Cat. 521
StJohnCT136	no	Figura	AgHk-52	F. 24	Cat. 1806
StJohnCT137	no	Figura	AgHk-52	F. 24	Cat. 1806
StJohnCT138	no	Bingo Pit Village Loc. 10	AgHk-42	F. 528	Cat. 2174
StJohnCT139a	no	Bingo Pit Village Loc. 10	AgHk-42	F. 527	Cat. 10945
StJohnCT139b	no	Inland West Loc. 3	AgHk-54	F. 38	Cat. 521
StJohnCT139c	no	Figura	AgHk-52	F. 23	Cat. 826
StJohnCT140	no	Bingo Pit Village Loc. 10	AgHk-42	F. 475	Cat. 6253
StJohnCT141a	no	Bingo Pit Village Loc. 10	AgHk-42	F. 290	Cat. 6950
StJohnCT141b	no	Bingo Pit Village Loc. 10	AgHk-42	F. B	Cat. 9824
Ferris Vessel 36	yes	Van Bree	AgHk-32	unknown	V. 36
iroquioan vessel	yes	McKeown Site	BeFv-1	unknown	unknown

Sample ID	Specimen Object (rim, body, base, pipe)	Observable Specimen characteristics (temper, decoration, residue, thickness, friable, coil breaks)	Date of scan DD/MM/YY YY	Duration of scan (open chamber to aqusition computer)
StJohnCT126	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	31/01/2017	53 mins
StJohnCT127	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	31/01/2017	53 mins
StJohnCT128	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	31/01/2017	53 mins
StJohnCT129	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	31/01/2017	53 mins
StJohnCT130	Rim, neck, shoulder sherd	Earlier than most, Rivere au Vase Phase, cord wr	01/02/2017	53 mins
StJohnCT131	Rim, neck, shoulder sherd	Classic WB with triangular neck motif	01/02/2017	53 mins
StJohnCT132	Rin, neck sherd -2 pieces	obilqies and horizontals, small castellation	15/02/2017	53 mins
StJohnCT133a	Lump of clay	none	06/07/2017	53 mins
StJohnCT133b	Lump of clay	none	06/07/2017	53 mins
StJohnCT133c	Lump of clay	none	06/07/2017	53 mins
StJohnCT134a	Lump of clay	none	06/07/2017	53 mins
StJohnCT134b	Lump of clay	none	06/07/2017	53 mins
StJohnCT134c	Lump of clay	none	06/07/2017	53 mins
StJohnCT135	Lump of clay	none	06/07/2017	53 mins
StJohnCT136	Lump of clay	none	06/07/2017	53 mins
StJohnCT137	Lump of clay	none	10/07/2017	53 mins
StJohnCT138	Lumps of clay	none	10/10/2017	53 mins
StJohnCT139a	Lump of clay	none	11/07/2017	53 mins
StJohnCT139b	Lump of clay	none	11/07/2017	53 mins
StJohnCT139c	Lump of clay	none	11/07/2017	53 mins
StJohnCT140	Lumps of clay	none	11/07/2017	53 mins
StJohnCT141a	Lump of clay	none	11/07/2017	53 mins
StJohnCT141b	Lump of clay	none	11/07/2017	53 mins
Ferris Vessel 36	rim and neck	stamped obliques, deep punctates		unknown
iroquioan vessel	complete pot	SLI		unknown

Sample ID	Duration of reconstruction (in Ct Pro)	Mounting Method (loose, mounted, in box, foam, styrofoam etc.)	filter (type/mm)	Gain	target (reflective, rotating, etc)
StJohnCT126	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT127	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT128	14 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT129	15 mins	Foam box with green peanuts	0.5mm Cu	24dB	refl.
StJohnCT130	15 mins	Foam box with green peanuts	0.5mm Cu	24d**B**	refl.
StJohnCT131	13 mins	foam balanced	0.5mm Cu	24dB	refl.
StJohnCT132	13 mins	foam box with second sherd r	0.5mm Cu	24dB	refl.
StJohnCT133a	15 mins	Foam peanuts and cups stack	none	24dB	refl.
StJohnCT133b	14 mins	Foam peanuts and cups stack	none	24dB	refl.
StJohnCT133c	14 mins	Foam peanuts and cups stack	none	24dB	refl.
StJohnCT134a	14 mins	Foam peanut and cup stacked	none	24dB	refl.
StJohnCT134b	15 mins	Foam peanuts and cups stack	none	24dB	refl.
StJohnCT134c	15 mins	Foam peanut and cup stacked	none	24dB	refl.
StJohnCT135	16 mins	Foam in cup	none	24dB	wrong target
StJohnCT136	14 mins	Foam in cup	none	24dB	wrong target
StJohnCT137	15 mins	Foam in cup	0.5mm Cu	24dB	refl.
StJohnCT138	15 mins	Stack of cooler foam	none	24dB	refl.
StJohnCT139a	14 mins	Stack of cooler foam	none	24dB	refl.
StJohnCT139b	13 mins	Stack of cooler foam	none	24dB	refl.
StJohnCT139c	14 mins	Stack of cooler foam	none	24dB	refl.
StJohnCT140	14 mins	Wedged in side of cooler foar	none	24dB	refl.
StJohnCT141a	13 mins	Foam stack	none	24dB	refl.
StJohnCT141b	14 mins	Foam stack	none	24dB	refl.
Ferris Vessel 36	unknown	unknown	none	unknown	refl.
iroquioan vessel	unknown	unknown	0.25 Cu	unknown	refl.

Sample ID	KV	micro amps	Exposure (msecs)	# projections	Frames/time	effective pixel size in micro meters	Operator	minimize rings?	Shading corrections
StJohnCT126	170	58	1	3141	1	111.63	AS	no	3 images, 150 frames t
StJohnCT127	170	58	1	3141	1	111.63	AS	no	3 images, 150 frames t
StJohnCT128	170	58	1	3141	1	115.78	AS	no	3 images, 150 frames t
StJohnCT129	165	53	1	3141	1	118.50	AS	no	3 images, 150 frames t
StJohnCT130	170	60	1	3141	1	109.79	AS	no	3 images, 150 frames t
StJohnCT131	170	58	1	3141	1	119.73	AS	no	3 images, 150 frames t
StJohnCT132	170	55	1	3141	1	88.94	AS	no	3 images, 150 frames t
StJohnCT133a	175	75	1	3141	1	n/a	AS	no	3 images, 150 frames t
StJohnCT133b	175	75	1	3141	1	n/a	AS	no	4 images, 150 frames t
StJohnCT133c	175	75	1	3141	1	n/a	AS	no	5 images, 150 frames t
StJohnCT134a	180	75	1	3141	1	n/a	AS	no	6 images, 150 frames t
StJohnCT134b	180	75	1	3141	1	n/a	AS	no	7 images, 150 frames t
StJohnCT134c	180	75	1	3141	1	n/a	AS	no	8 images, 150 frames t
StJohnCT135	170	75	1	3141	1	n/a	AS	no	9 images, 150 frames t
StJohnCT136	155	80	1	3141	1	n/a	AS	no	3 images, 150 frames t
StJohnCT137	175	45	1	3141	1	15.20	AS	no	3 images, 150 frames t
StJohnCT138	115	40	1	3141	1	40.54	AS	no	3 images, 150 frames t
StJohnCT139a	100	55	1	3141	1	52.68	AS	no	3 images, 150 frames t
StJohnCT139b	100	55	1	3141	1	52.68	AS	n	3 images, 150 frames t
StJohnCT139c	100	55	1	3141	1	52.68	AS	n	3 images, 150 frames t
StJohnCT140	100	55	1	3141	1	69.82	AS	no	3 images, 150 frames t
StJohnCT141a	102	55	1	3141	1	69.82	AS	no	3 images, 150 frames t
StJohnCT141b	102	55	1	3141	1	69.82	AS	no	3 images, 150 frames t
Ferris Vessel 36	125	40	500	2882	2	47.26	unknown	no	unknown
iroquioan vessel	180	85	250	3142	1	80.52	unknown	no	unknown

Sample ID	Comments	Scan Successful
StJohnCT126		rotate error: short 0.25 degrees of 360
StJohnCT127		rotate error: short 0.25 degrees of 360
StJohnCT128		no errors
StJohnCT129		not an amazing scan, rescan if time
StJohnCT130		
StJohnCT131		Very large vessel, difficult to mount Pieces will
StJohnCT132		Testing best fit module for mending.
StJohnCT133a	Not a good quality scan I think I'm getting movement in the tower of foam cups	Three lumps of clay in one scan. 133a-c bottom
StJohnCT133b	no good	
StJohnCT133c	no good	
StJohnCT134a	failed scan	Three lumps of clay in one scan. 134a-c bottom
StJohnCT134b	failed scan	
StJohnCT134c	failed scan	
StJohnCT135	Okay but not great scan, ring artifact and a bit of movement.	One lump of clay
StJohnCT136	wrong target	One lump of clay
StJohnCT137	wrong target	One lump of clay
StJohnCT138	Reconstructed as one volume but could be reconstructed as 3 separate if needed.	3 lumps of clay all from same sample. (They me
StJohnCT139a		3 lumps of clay 139a-c bottom to top
StJohnCT139b	same scan as above	Fingerprints
StJohnCT139c	same scan as above	
StJohnCT140	Reconstructed all as one voumbe but could go back and recon each separate	6 lumps of clay all from same sample/cat. #
StJohnCT141a		2 lumps of clay 141 a and b from bottom to top
StJohnCT141b	same scan as above	
Ferris Vessel 36		
iroquioan vessel		

Appendix C: VGStudio Max 2.2 Workflow

This appendix outlines the steps undertaken in VGStudio Max 2.2 to isolate and record inclusion and void volume percentages in ceramic materials.

Steps in image analysis:

-Complete surface determination: automatic on the volume

-Complete simple registration: try to line the specimen with the rim upwards, to make viewing easier and placement of rectangular prism easier.

-create a new ROI from the surface of the registered volume (left click on Volume, New, ROI from surface)

-erode and dilate this new ROI to try to include all interior voids. Complete a volume analysis and record volume variables, export the csv file.

-Threshold out inclusions to create an ROI of inclusions: do volume analysis, record volume variable and export the csv file. Split inclusion ROI and record number of individual ROIs.

-Threshold out voids to create an ROI of voids (detailed steps below). Record volume variable and export the csv file. Split void ROI and record the number of individual ROIs.

-Record the qualitative variables, take angles of void orientations and other notes.

-Images captured for each specimen: The front, back, side of volume exterior. Inclusions and voids in 3D, inclusions in 3D, voids in 3D. Clipping box with voids if they are noteworthy. Lots of images of 2D slices showing construction techniques.

To isolate voids in VGStudio Max 2.2:

-Use erode/dilate function to make sure all your voids are included in your ROI (none of them have their own surface), and replace ROI. If the edge of your scan is close in density to the voids, use the erode function to cut into the edge of your object a bit and replace ROI. Remember yellow lines are a preview of the ROI you are creating, blue lines are the existing ROI.

(erode/dilate, Invert ROI, Thresholding, and Sutract ROI, Spilt ROI functions can all be found on the left bar in VG 2.2. Many are also found by right clicking on the ROI in the scene tree)

-Invert this first ROI to get an inverted ROI (your background air)

-Threshold voids and background together (grey values of 0-whatever), create an ROI of void and background air.

-Control and select both the background air/inverted ROI and the voids and background air ROI and subtract the background air ROI from the voids and background air ROI.

-The resulting ROI should be just the voids.

Notes:

-You can use the erode/dilate function to add a bit to your void ROI then do a surface determination to get a cleaner image in 3D.

-In volume rendering you can check the “swap inner and outer area” to get a nicer image of the void ROI.

Appendix D: Variables recorded in VGStudio MAX 2.2 image analysis

Legend:

Experimental slabs
Pipes
Learner
Non-Arkona

StJohnCT Sample #	total volume from 2.2 in mm3 eroded and dialated to include voids in micro	total volume in cm3	threshold of inclu	volume of inclu 2.2 mm3	number of inclu from	% volume inclusion
4	34192.88	341.9288	43000-65535	3171.51	306574	9.275352
neck 5	18523.7	185.237	43000-65535	1052.78	45433	5.683422
6	75936.61	759.3661	39000-65535	11329.08	81916	14.91913
8 - sameV. As 55	123777.46	1237.775	39000-65535	12372.53	55651	9.995786
9	100713.17	1007.132	34000-65535	16638.81	88333	16.52099
10 - same V. as 115	47745.71	477.4571	40000-65535	7090.7	75226	14.85097
11	122613.54	1226.135	40000-65535	12308.08	22218	10.03811
12	7876.4	78.764	51000-65535	141.13	2089380	1.791808
13	2278.85	22.7885	40000-65535	49.51	306787	2.172587
14	2920.77	29.2077	50000-65535	89.62	29086	3.068369
16	13830.25	138.3025	53000-65535	1515.36	2175326	10.95685
20	70622.68	706.2268	49000-65535	1352.45	509878	1.915036
21	59535.92	595.3592	38000-65535	11771.73	1068236	19.77248
22	89707.2	897.072	38000-65535	10725.95	47606	11.95662
23	35847.78	358.4778	39000-65535	2862.88	299262	7.986213
24	43358.81	433.5881	37500-65535	2903.91	195201	6.697393
25	99445.71	994.4571	42000-65535	10041.21	254134	10.09718
26	75233.13	752.3313	45500-65535	5995.65	258564	7.969428
27	95270.69	952.7069	41000-65535	5206.7	280588	5.465165
28	82089.51	820.8951	51000-65535	2511.84	166289	3.059879
29	55906.22	559.0622	56000-65535	1080.6	1029654	1.93288
31	21702.32	217.0232	40000-65535	1394.24	552570	6.424382
32/36	37895.9	378.959	41000-65535	4140.02	40213	10.92472
38	42540.94	425.4094	38000-65535	4315.8	93363	10.14505
39	61073.9	610.739	42000-65525	5619.13	59310	9.200542
40	112973.96	1129.74	50000-65535	4225.19	114470	3.739968

StJohnCT Sample #	threshold of voids	volume of voids in mm3	quantity of voids from	% volume voids	Inclusion Distribution:	inclusion orientation,	Void Shape: from petrography	void shape: secondary
4	0-26000	430.73	57748	1.259707	uniform	random	planar	lots of vughs a
5	0-27000	480.14	68869	2.592031	uniform	random	planar	vughs around
6	0-19500	1292.48	47208	1.702051	uniform	random	planar	vughs around
8 - sameV. As 55	0-23000	3040.27	52969	2.456239	uniform	random	planar	vughs around
9	0-19000	4060.12	836852	4.031369	uniform	random	planar	vughs around
10 - same V. as 115	0-24000	1162.19	88705	2.434124	uniform	random	planar	vughs
11	0-25000	1936.68	41208	1.579499	uniform	random	planar	vughs around
12	0-30000	302.19	240188	3.836651	uniform	random	planar	none
13	0-23000	52.57	85524	2.306865	uniform	random	vesticles	planar
14	0-35000	98.48	11911	3.371714	unifom	random	planar	vughs around
16	0-25000	223.41	130563	1.615372	uniform	random	planar	some large vu
20	0-29000	1161.51	93526	1.64467	uniform	random	planar	small vesticle
21	0-24000	2453.94	275256	4.121781	uniform	random	vughs	small planar v
22	0-23000	2296.77	69323	2.560296	uniform	random	planar	vesicles arour
23	0-23000	1057.92	104200	2.951145	uniform	random	planar	vughs around
24	0-22000	893.47	96046	2.060642	uniform	random	vughs	planar
25	0-24000	961.62	37210	0.96698	uniform	random	planar	vughs around
26	0-28500	2025	323438	2.691633	uniform	random	planar	vughs and son
27	0-22000	1592.7	254592	1.671763	uniform	random	planar	vughs around
28	0-34000	757.73	35706	0.923053	uniform	random	planar	vughs around
29	0-29000	402.94	118563	0.720743	uniform	random	planar	vughs around
31	0-23000	352.95	132555	1.626324	uniform	random	planar	large vughs ar
32/36	0-24000	1261.45	63318	3.328724	uniform	random	planar	vughs
38	0-22000	878.78	63143	2.065728	uniform	random	planar	vughs around
39	0-25000	2218.7	67465	3.632812	unifom	random	planar	vughs
40	0-30000	1680.73	101783	1.487715	uniform	random	planar	some vughs ar

StJohnCT Sample #	Void distributi on	void orientati on,	void secondar y	thickn ess at rim	wall thickness : 5cm	Micro structures at rim? Inferred construction technique?
4	non-unifo	parallel	15-20 degı	11.9	10.4	looks like a folded rim, that j
5	non-unifo	parallel	none	no rim	10	difficult to tell without the ri
6	non-unifo	parallel	20-25 degı	8.2	8.6	added section at rim, anothe
8 - sameV. As 55	non-unifo	parallel, 9	at 60mm c	9.2	9.4	really obvious added on piec
9	uniform	parallel	random	6.8	3.8	no really obvious constructio
10 - same V. as 115	non unifo	parallel	void at the	10.1	7.9	large void under castellation
11	non uniform, larger		where the	12.7	5.2	appears to be a small folded
12	non unifo	parallel	horizontal	8.1	4.9 from 3	large voids throughout, I thir
13	uniform, r	parallel	random es	5.2	4.8 from 2	Looks like it might be folded
14	some larg	parallel	30-50 degı	4.3	5.0 from 2	Some pieces might be added
16	fairly unif	parallel	some curv	5.2	6.4	no obvoius folds, pretty ever
20	non unifrc	parallel	some bett	12.1	11.5	not obvious, but it might be f
21	uniform	random	none	9.9	9.9	none visible
22	non-unifo	parallel, 9	at lip non	11.6	7.8	at rim, folds or possible coil a
23	non-unifo	parallel, 9	at lip som	12.3	10.5	at rim, folds or possible coil a
24	non-unifo	vughs ranı	planar, 70	5.5	6.2	about 60mm from lip possibl
25	non-unifo	parallel, 9	at lip non	10.6	11.1	cut or fold at rim, there are v
26	uniform a	parallel bı	vughs arou	10.8	11.5	no obvoius folds or added cla
27	uniform	parallel bı	parallel tc	9.2	10.1	no obvoius folds or added cla
28	non-unifo	parallel	non-parall	7.5	9.9	really noisy scan, maybe a fo
29	non-unifo	parallel, 9	at lip non	9.7	9.1	at rim, folds towards exterioı
31	non-unifo	parallel, 9	at lip non	8.8	8.2	at rim, fold towards exterior
32/36	non-unifo	parallel	fold, non-	12.2	10.3	Appears to be fold at rim, pu
38	non unifo	parallel	between (	13.3	10.8	folded towards exterior, ther
39	non unifo	parallel	parallell	7.7	9.1	might be folded, but I think t
40	non unifo	parallel		9.7	10.9	large voids at punctate level,

StJohnCT Sample #	total volume from 2.2 in mm3 eroded and dialated to include voids in micro	total volume in cm3	threshold of inclu	volume of inclu 2.2 mm3	number of inclu from	% volume inclusion
41	55252.81	552.5281	39000-65535	2402.23	83785	4.347706
42	27380.39	273.8039	39000-65535	2473.83	46404	9.035043
43	10432.56	104.3256	41000-65535	678.28	1019892	6.501568
44	41323.02	413.2302	46000-65535	3292.87	886346	7.968609
45	16134.79	161.3479	41000-65535	1156.78	189906	7.169477
46	128911.09	1289.111	37000-65535	12881.18	114424	9.992298
47	170344.75	1703.448	48000-65535	11387.49	99703	6.684967
48	44570.5	445.705	41000-65535	3074.22	64364	6.897432
49	14370.37	143.7037	41000-65535	9640.3	195933	67.08456
50	69433.45	694.3345	39000-65535	7712.45	66165	11.10769
51	87721.6	877.216	40500-65535	6036.32	135668	6.881224
52	63011.54	630.1154	40000-65535	7153.86	43852	11.35325
53 neck	211770.97	2117.71	51000-65553!	15308.74	79135	7.228913
54	188120.56	1881.206	50000-65535	17466.02	159635	9.284482
55 same V. as 008	44872.3	448.723	40000-65535	5625.49	29785	12.53667
Ferris Vessel 36	18499.97	184.9997	37000-65535	1137.13	397514	6.146659
iroquioan vessel (SL	349266.94	3492.669	41000-65535	4167.25	598415	1.193142
60	284230.09	2842.301	45000-65535	28792.49	177804	10.12999
61	92264.69	922.6469	41000-65535	7494.69	100561	8.123032
62	44776.6	447.766	48000-65535	1402.02	104862	3.131144
63	50301.43	503.0143	41000-65535	3309.81	171448	6.579952
64	19330.17	193.3017	32000-65535	1122.4	281632	5.806467
65	237749.05	2377.491	43000-65535	21603.09	102947	9.086509
66	251406.25	2514.063	43000-65535	12112.13	181947	4.817752
67	204993	2049.93	41500-65535	15671.25	107776	7.644773
68	31847.84	318.4784	44000-65535	2673.12	73590	8.393411
69	200078.64	2000.786	47000-65535	11893.37	667568	5.944348
71	236563	2365.63	44000-65535	14501.88	345047	6.13024
70 same V. as 020	102550.64	1025.506	49000-65535	2060.62	1359635	2.009368
72	20918.54	209.1854	48000-65535	908.13	17916	4.341269
74	21186.66	211.8666	43000-65535	1006.6	45233	4.751103
76	12701.3	127.013	52000-65535	350.75	119381	2.761528
77	8064.98	80.6498	41000-65535	410.48	191000	5.089659
78	34319.72	343.1972	39000-65535	1277.83	23188	3.723311
79	37183.95	371.8395	32000-65535	7394.34	486082	19.88584
80	57977.63	579.7763	43000-65535	5298.39	1299203	9.13868

StJohnCT Sample #	threshold of voids	volume of voids in mm3	quantity of voids from	% volume voids	Inclusion Distribution:	inclusion orientation,	Void Shape: from petrography	void shape: secondary
41	0-21500	1510.61	90721	2.733997	uniform	random	planar	vughs around
42	0-21500	588.54	43162	2.149495	uniform	random	planar	vughs around
43	0-25000	229.7	179809	2.201761	non-unifo	random	planer, wide p	vughs
44	0-29000	905.05	188694	2.190184	uniform	random	planar	vughs around
45	0-24000	758.61	75704	4.701704	uniform	random	planar	vughs around
46	0-19500	3390.51	234390	2.630115	uniform	random	planar	vughs around
47	0-29000	2182.45	35675	1.281196	uniform	random	planar	vughs around
48	0-24000	978.96	82344	2.19643	uniform	random	planar	large vughs at
49	0-26000	2411.85	139086	16.78349	uniform	random	planer	vughs around
50	0-22000	3754.61	246410	5.407495	uniform	random	planar	vughs
51	0-24000	1921.42	65032	2.190361	uniform	random	planar	some vesicles
52	0-22000	1213.84	43127	1.926377	uniform	random	planar	vughs
53 neck	0-28000	2756.74	25646	1.301755	uniform	random	planar	vughs around
54	0-31000	2703.54	39101	1.437132	uniform	random	planar	vughs around
55 same V. as 008	0-23000	1324.83	42564	2.952445	uniform	random	planar	vughs around
Ferris Vessel 36	0-23000	643.65	114735	3.479195	uniform	randon	planar	vughs around
iroquioan vessel (SL	0-23500	7402.95	97119	2.119568	non unifo	random	vesticles	small planar v
60	0-26000	4418.01	174771	1.554378	uniform	random	planar	few vesicles
61	0-23000	1706.29	84042	1.849342	uniform	random	planar	vughs, some r
62	0-29000	793.33	58628	1.771751	uniform	random	planar	vughs, around
63	0-25000	1835.25	176732	3.648505	uniform	random	planar	vughs around
64	0-19000	606.07	132536	3.135358	uniform	random	planar	vughs around
65	0-25000	5409.35	120390	2.275235	uniform	random	planar	vughs around
66	0-22500	4617.79	162345	1.836784	uniform	random	planar	vughs around
67	0-21000	2831.06	159596	1.381052	uniform	random	planar	vughs around
68	0-28000	1529.99	180313	4.804062	uniform	random	planar	vughs around
69	0-29000	2342.17	119750	1.170625	uniform	random	planar	vughs around
71	0-24500	2787.73	143309	1.17843	uniform	random	planar	vughs around
70 same V. as 020	0-26000	1109.34	142295	1.081748	uniform	random	planar	small vughs
72	0-34000	105.4	23700	0.503859	uniform	random	planar	small vesticles
74	0-27500	87.26	37418	0.411863	uniform	random	planar	vesticles arou
76	0-32000	85.87	33732	0.676073	uniform	random	planar	vesticles
77	0-26000	35.71	17638	0.442779	uniform	random	planar	vesticles
78	0-26000	201.59	36622	0.587388	uniform	random	planar	large vesticles
79	0-22000	1157.4	116465	3.112633	uniform	random	planar	vughs around
80	0-25000	482.02	66234	0.83139	uniform	random	planar	small vesticles

StJohnCT Sample #	Void distributi on	void orientati on,	void secondar y	thickn ess at rim	wall thickness : 5cm	Micro structures at rim? Inferred construction technique?
41	non unifrc	parallel, 9	horizontal	11.7	8.4	folded towards exterior to cr
42	fairly unif	parallel	horizontal	12.7	8.8	think this might be added on
43	non unifo	parallel	horizontal	4.1	4.4	I think it is folded about 17m
44	non unifo	parallel	between (	7.2	6.3	seems to be folded in places
45	non unifo	parallel	voids neai	7.2	6.7	Folded, appears to meet the
46	uniform	parallel	some hori	10.7	10.3	Doesn't really appear to have
47	non unifo	parallel	curved arc	11.6	16.2	Not a really obvious rim cons
48	non-unifo	parallel, 9	at 8mm fr	13.1	9.6	at rim, at the right edge, look
49	non-unifo	parallel,	65-70 degi	8.3	10.5	appears to be a folded, large
50	non-unifo	parallel	large void	n/a	n/a	under castellation added clay
51	non-unifo	parallel, 9	at lip som	15.6	10.3	definetly added on clay but i
52	non-unifo	parallel, 9	at about 4	10.1	9.6	At rim it appears there is an a
53 neck	non-unifo	parallel, 9	none	no lip	11.5	no noticeable fold, there are
54	non-unifo	parallel, 9	at lip close	12.4	9.2	Huge micro fold at rim, punc
55 same V. as 008	non unifo	parallel, 9	where it n	8.5	5.7	Added on section at rim: less
Ferris Vessel 36	non unifo	parallel	where it n	7.2	3.8	Really obvious void structure
iroquioan vessel (SL	non unifo	parallel	randomly	4.8	10.6	really dense material on exte
60	uniform	parallel, 9	none	6.6	6	a small piece added at rim, b
61	non-unifo	parallel,	at punctat	8	7.6	really large planar void unde
62	uniform	parallel, 9	some ranc	9.9	5.6	large planar void down the e
63	non unifo	parallel	horizontal	11.1	8.2	not really obvious, the horizc
64	non unifo	parallel	at lip hori	11.9	10.4	appears to be folded to exter
65	non unifo	parallel	at lip som	8.1	11.3	some horizontal voids near li
66	non unifo	parallel	some hori	n/a	13.3 (4mm	Might be a fold and then add
67	non unifo	parallel	some voic	n/a	9	No rim construction evidence
68	non unifo	parallel	some hori	3.7	7	Not entirely sure what is goir
69	uniform	parallel, 9	at rim non	10.1	10.9	void across the rim, looks like
71	non-unifo	parallel, 9	some voic	n/a	12.8 (4mm	Maybe added on rim piece bu
70 same V. as 020	non-unifo	parallel,	horizontal	14.8	10.9	Some of the horizontal voids
72	non-unifo	parallel	horizontal	3.9	8.3	One very clear void where it
74	non-unifo	parallel	horizontal	7.6	8.8 (3mm	Some parallel voids betweer
76	non-unifo	horizontal	none	3.1	10.4	looks like this a coiled vessel
77	non-unifo	parallel	at 22mm,	5.1	4.8	void goes all the way to the l
78	non-unifo	parallel	at about 2	2.7	10.7	no really obvoius constructio
79	uniform	parallel	30-40 fron	7.7	7.4	one large low density inclusi
80	uniform	parallel	none	5.6	7	no real folds or added clay.

StJohnCT Sample #	total volume from 2.2 in mm3 eroded and dialated to include voids in micro	total volume in cm3	threshold of inclu	volume of inclu 2.2 mm3	number of inclu from	% volume inclusion
81	102990.98	1029.91	39000-65535	14802.66	236728	14.37277
82	58612.21	586.1221	42500-65535	5387.79	660588	9.192266
83	122731.58	1227.316	41000-65535	11881.79	398688	9.681119
84	482014.73	4820.147	48500-65535	39801.73	1376121	8.257368
85	44626.88	446.2688	43000-65535	1958.15	999494	4.387826
86	28559.54	285.5954	41500-65535	1900.78	861575	6.655499
87	22718.26	227.1826	40000-65535	530.03	338171	2.333057
88	12704.15	127.0415	36000-65535	906.46	271485	7.135149
89	25946.21	259.4621	41000-65535	558.25	561026	2.151567
90 same V. as 28	36706.23	367.0623	41500-65535	2935.51	333213	7.997307
91	141557.922	1415.579	40500-65535	14388.65	376112	10.1645
92	66951.34	669.5134	could not isolate inclusions and vo			0
93 -rescan of 030	66946.749	669.4675	41000-65535	6501.938	46172	9.712104
95	18416.07	184.1607	40000-65535	932.04	21460	5.061015
96 rescan of 28	84153.37	841.5337	48500-65535	2189.41	123522	2.60169
97 same V. as 050	50384.696	503.847	36000-65535	4803.287	94443	9.533226
98- same V. as 064	412110.12	4121.101	45000-65535	17599.33	476591	4.270541
99	159262.075	1592.621	33000-65535	7852.61	85586	4.930621
100 - same V. as 051	277377.98	2773.78	47500-65535	9386.36	74719	3.38396
101 -same V. as 044	84538.312	845.3831	45500-65535	6269.84	216193	7.416566
102 - same V. as 049	64125.45	641.2545	35000-65535	1990.44	819610	3.103978
103	15875.4	158.754	38000-65535	348.93	140082	2.197929
104	29115.134	291.1513	41000-65535	1559.839	50168	5.357485
105 -same V. as 106	160737.99	1607.38	47500-65535	14164.06	126720	8.811893
106 - same V. as 105	105485.8	1054.858	46500-65535	5865.87	424802	5.560815
107	11649.79	116.4979	32500-65535	776.67	292206	6.666815
109	88848.95	888.4895	39000-65535	5587.84	314828	6.289146
110	19830.21	198.3021	30000-65535	1644.46	68024	8.292701
111	16958.88	169.5888	38000-65535	865.96	358526	5.106233
112	35142.39	351.4239	39000-65535	2886.57	267416	8.213926
113	28893.79	288.9379	38500-65535	2232.48	489911	7.726505
114	59916.74	599.1674	37000-65535	3061.75	216341	5.110008
115 - same V. as 010	156295.701	1562.957	41000-65535	20524.02	97658	13.13153

StJohnCT Sample #	threshold of voids	volume of voids in mm3	quantity of voids from	% volume voids	Inclusion Distribution:	inclusion orientation,	Void Shape: from petrography	void shape: secondary
81	0-24000	3070.27	285733	2.981106	uniform	random	planar	vughs and ves
82	0-26000	1248.46	251415	2.130034	uniform	random	planar	vughs around
83	0-24500	6808.25	218468	5.547268	uniform	random	planar	vughs
84	0-33000	7548.66	194517	1.566064	uniform	random	planar	small vesicles
85	0-25000	1052.43	557605	2.358287	uniform	random	planar	vughs around
86	0-26500	700.7	150678	2.453471	uniform	random	planar	vughs around
87	0-26000	620.25	110808	2.730183	uniform	random	planar	small vughs
88	0-20000	799.35	307452	6.292038	uniform	random	planar	small vughs
89	0-22000	304.43	175836	1.173312	uniform	random	small vesticles	
90 same V. as 28	0-26000	494.47	67152	1.347101	uniform	random	planar	vughs around
91	0-22000	576.721	499227	0.40741	uniform	random	planar	vughs around
92				0	uniform	random	vesticles	none
93 -rescan of 030	0-24500	1922.566	101784	2.871784	uniform	random	planar	vughs around
95	0-26000	165.01	23301	0.896011	uniform	random	planar	vughs
96 rescan of 28	0-30000	1068.74	65856	1.269991	uniform	random	planar	small vughs ar
97 same V. as 050	0-20000	1072	108193	2.12763	uniform	random	planar	vughs around
98- same V. as 064	0-25500	7464.12	261352	1.811196	uniform	random	planar	vughs around
99	0-13000	1624.407	268428	1.019958	uniform	random	planar	vughs around
100 - same V. as 051	0-24000	3339	52078	1.203773	uniform	random	planar	some vesticle
101 -same V. as 044	0-25000	873.284	49246	1.033004	uniform	random	planar	vughs around
102 - same V. as 049	0-17000	962.9	515774	1.501588	uniform	random	planar	vughs around
103	0-22000	221.71	31610	1.396563	uniform	random	planar	vughs
104	0-25000	149.245	11646	0.512603	uniform	random	planar	vughs
105 -same V. as 106	0-27000	2880.38	50830	1.791972	uniform	random	planar	vughs arrounc
106 - same V. as 105	0-25000	1671.31	128341	1.584393	uniform	random	planar	vughs
107	0-22000	299.49	74853	2.570776	uniform	random	planar	vughs
109	0-18000	858.95	283425	0.966753	uniform	random	planar	vughs around
110	0-15000	289.37	96558	1.459238	uniform	random	planar	vughs
111	0-22000	354.06	83264	2.087756	uniform	random	planar	some vesticle
112	0-21000	709.54	117838	2.019043	uniform	random	planar	some vughs
113	0-22000	613.63	95774	2.123744	uniform	random	planar	vughs around
114	0-24000	1148.59	82539	1.916977	uniform	random	planar	small vughs ar
115 - same V. as 010	0-25000	4490.381	233336	2.873004	uniform	random	planar	vughs

StJohnCT Sample #	Void distribution	void orientation,	void secondary	thickness at rim	wall thickness: 5cm	Micro structures at rim? Inferred construction technique?
81	some larg	parallel	near the li	4.5	5.6	maybe added on clay at rim,
82	uniform	parallel	between 4	9.3	7.5	seems to be folded towards t
83	non unifo	parallel	between 5	9.4	10	I think this is added on in pla
84	non unifo	parallel	some hori	2.3	12.6	Some horizontal voids near li
85	non-unifo	parallel, 9	at lip, 20 d	9.2	11.8	large planar void especially u
86	non uniform. Large voids wher			n/a	n/a	More ceramic-like clay. I thir
87	non uniform, larger voids wher			n/a	n/a	The bottom appears to be a s
88	non uniform more in the top ha			n/a	n/a	4mm diameter bore. Maybe a
89	uniform			n/a	n/a	Way less voids than the othe
90 same V. as 28	non unifo	parallel	71-75 degr	7.8	8.8	Not really clear, looks like th
91	non unifo	parallel	60 degree	12.7	13.9	Added clay at the interior! Th
92	uniform			13.8	8.1	you can see the glaze on the
93 -rescan of 030	non unifo	parallel	10-20 degr	10	10.1	larger than average temper,r
95	non unifo	parallel	62-64 degr	3.4	6.3	looks like the rim is added or
96 rescan of 28	non unifo	parallel	some 41m	6.3	9.4	I think it is folded, and the fo
97 same V. as 050	non unifo	parallel	some hori	9.9	10.8	it looks like this is folded in p
98- same V. as 064	fairly unif	parallel	Some 8mr	10.5	12.1	Horizontal voids near the lip,
99	non unifo	parallel	some hori	11.4	8.2	Hard to tell what is going on
100 - same V. as 051	non unifo	parallel	horizontal	17	15.1	added clay on exterior. Mayb
101 -same V. as 044	non unifo	parallel	some at 35	6.4	6.3	I think it's folded, maybe mo
102 - same V. as 049	non unifo	parallel	some hori	7.2	14	maybe folded, but not very c
103	non uniform, more voids at the			n/a	n/a	hard to tell what is going on l
104	non unifo	non parall	parallel	7.9	5.8	The rim appears to be added
105 -same V. as 106	non unifo	parallel	some betv	13.5	9.4	Appears to be folded, meetir
106 - same V. as 105	non unifo	parallel	Some betv	10.4	7.4	Folded in places for sure, in s
107	fairly unif	parallel	Some betv	7.2	7.2 at 4mn	I think there is a bit of an adc
109	uniform	parallel	some betv	11.2	10.9	not really any obvoius constr
110	non unifo	parallel	between 5	10.1	6.5	horizontal voids near lip, app
111	non unifo	parallel	between (	6.4	4.3	I think there is a fold and the
112	non unifo	parallel	some hori	10.8	10.8	Punctates through large void
113	non unifo	parallel	some betv	12.3	7.6	Might be a good one to anim
114	slightly nc	parallel	some betv	14.9	12.8	I think it's folded, but not a h
115 - same V. as 010	non unifo	parallel	some at 40	11.5	9	Looks like it is folded, but no

StJohnCT Sample #	total volume from 2.2 in mm3 eroded and dialated to include voids in micro	total volume in cm3	threshold of inclu	volume of inclu 2.2 mm3	number of inclu from	% volume inclusion
116	343186.5	3431.865	33000-65535	22603.16	114148	6.586261
117	91713.19	917.1319	46000-65535	6111.29	117272	6.66348
118 - same V. as 119	120505.85	1205.059	41000-65535	5863.01	201443	4.865332
119 - same V. as 118	93000.75	930.0075	39000-65535	2891.55	292143	3.109168
120	113066.72	1130.667	47000-65535	3597.5	462238	3.18175
121	69577.75	695.7775	39000-65535	3790.65	177498	5.448078
124	94141.19	941.4119	40000-65535	3151.75	992635	3.347897
125	96407.6	964.076	35000-65535	9747.74	605184	10.11097
128	210331.17	2103.312	41000-65535	16275.56	202096	7.738064
129	193793.42	1937.934	46000-65535	9332.54	453115	4.815716
130	112287.62	1122.876	43000-65535	7832.13	184026	6.975061
131	302999.13	3029.991	47000-65535	9906.13	393789	3.269359
132	27468.9	274.689	45000-65535	1185.1	95858	4.314334

StJohnCT Sample #	threshold of voids	volume of voids in mm3	quantity of voids from	% volume voids	Inclusion Distribution:	inclusion orientation,	Void Shape: from petrography	void shape: secondary
116	0-16000	4892.66	156244	1.425656	uniform	random	planar	vughs
117	0-27000	876.98	31992	0.95622	uniform	random	planar	small vughs ar
118 - same V. as 119	0-24000	2693.28	95459	2.234979	uniform	random	planar	small vughs
119 - same V. as 118	0-18000	1066.12	86916	1.146356	uniform	random	planar	some vughs ar
120	0-21000	1418.81	197638	1.254843	uniform	random	planar, thin	vughs around
121	0-18000	1745.21	136904	2.508287	uniform	random	planar, thin w	some vughs ar
124	0-21000	1572.59	282149	1.670459	uniform	random	planar, very th	some vesticle
125	0-16000	1557.04	244048	1.615059	uniform	random	planar, thin	vughs around
128	0-22000	3161.74	115662	1.50322	uniform	random	planar	vughs around
129	0-30000	3970.61	116924	2.048888	uniform	random	planar	vughs around
130	0-26500	3669.4	157594	3.267858	uniform	random	planar	small and not
131	0-22000	1244.33	34939	0.410671	uniform	random	planar	vughs
132	0-29000	740.02	55454	2.694029	uniform	random	planar	small vughs ar

StJohnCT Sample #	Void distribution	void orientation,	void secondary	thickness at rim	wall thickness : 5cm	Micro structures at rim? Inferred construction technique?
116	non unifo	parallel	some hori	11.9	13.9	Looks folded, horizontal voic
117	non unifo	parallel	horizontal	8.8	9.4	Can't really tell what is going
118 - same V. as 119	non unifo	parallel	some betv	10.4	11.2	Seems like a fold lower in so
119 - same V. as 118	non unifo	parallel	some arou	9.7	10.4	larger void in some places, ui
120	non unifo	parallel	some hori	8.1	9	I think there is clay added to
121	non unifo	parallel	some at al	4.8	6.6	Large inclusions overall, It lo
124	Fairly unif	parallel	n/a	4.4	6.4	largest voids are mends not i
125	fairly unif	parllel	some fine	7.3	10	largest voids are mends, Rea
128	non unifo	parallel	some at al	12.7	12.2	Looks like a fold, meeting the
129	non unifo	parallel	some betv	18.2	10.2	Looks like a fold, but there m
130	non unifo	parallel	some betv	7.5	6.6	might be a fold but looks like
131	non unifo	parallel	some betv	8.7	6.7	appears to be a fold at the ri
132	non unifo	parallel	horizontal	5.1	5.7	Folded at rim, meeting the e

Appendix E: Morphological and Finishing Attributes

Rim type code: **A:** Plain **B:** Folded to exterior **C:** Folded with larger fold at castellation **D:** Added clay at exterior **E:** Folded to exterior with added clay **F:** Added clay at exterior and lip **G:** Unidentified **H:** Added clay at interior

StJohn Sample #	Site	Rim Type	Rim type combined	Upper rim profile	Lip shape	Neck shape	Oriface diameter
4	AgHk-32	b	folded	straight	flat	n/a	353.56
5	AgHk-42	g	unidentifie	concave	n/a	n/a	
6	AgHk-32	d	added	straight	flat	short	196.16
8	AgHk-32	d	added	straight	flat	short	231.34
9	AgHk-54	a	no fold or a	concave	furrowed	short	110.3
10	AgHk-54	c	folded	concave	flat	short	225.8
11	AgHk-54	c	folded	concave	flat	short	249.12
16	AgHk-54	a	no fold or a	concave	flat	short	133.44
20	AgHk-52	b	folded	concave	furrowed	short	
21	AgHk-52	a	no fold or a	concave	rounded	short	
22	AgHk-52	b	folded	concave	flat	short	
23	AgHk-52	b	folded	concave	flat	short	
24	AgHk-52	d	added	convex	rounded	short	
25	AgHk-52	b	folded	straight	flat	short	
26	AgHk-52	a	no fold or a	straight	rounded	short	
27	AgHk-52	a	no fold or a	concave	flat	short	
29	AgHk-52	b	folded	concave	rounded	short	
31	AgHk-42	b	folded	concave	flat	short	
38	AgHk-42	e	folded and	straight	flat	n/a	194.04
39	AgHk-42	d	added	concave	furrowed	short	208.56
40	AgHk-42	b	folded	concave	flat	short	289.46
41	AgHk-42	b	folded	concave	flat	short	205.3
42	AgHk-42	f	added	straight	rounded	n/a	356.98
43	AgHk-42	e	folded and	concave	furrowed	short	115.38
44	AgHk-42	b	folded	concave	flat	short	133.34
45	AgHk-42	b	folded	straight	flat	n/a	114.4

StJohn Sample #	Neck main technique (stamped, incised or combo)	neck deco yes/no/unknown	Simplified neck motif	Castellation indeterminate/ present/not present	Number of castellations present	Castellation shape	Int deco yes/no/unknown	lip deco yes/no/unnown
4		u		indeterminate	n/a	n/a	y	y
5	incised	y	triangles	indeterminate	n/a	n/a	u	u
6		n	plain	indeterminate	n/a	n/a	y	y
8	incised	y	triangles	present	1	pointed	y	n
9	combination	y	triangles	not present	n/a	n/a	y	y
10	stamped	y	obliques	present	1	pointed	y	y
11		n	plain	present	1	rounded	y	y
16		u		indeterminate	n/a	n/a	y	y
20	stamped	y	plaits	indeterminate	n/a	n/a	y	y
21		u		present	1	rounded	y	y
22	combination	y	triangles	indeterminate	n/a	n/a	y	y
23		u		indeterminate	n/a	n/a	y	y
24	incised	y	horizontals	indeterminate	n/a	n/a	y	y
25	incised?	y	horizontals	indeterminate	n/a	n/a	y	y
26		n	plain	indeterminate	n/a	n/a	y	y
27	stamped	y	horizontals	present	1	pointed	y	y
29		n	plain	indeterminate	n/a	n/a	y	n
31		u		present	2	pointed	n	y
38		u		present	1	pointed	y	y
39	stamped	y	horizontals	indeterminate	n/a	n/a	y	y
40		u		indeterminate	n/a	n/a	y	y
41	incised	y	obliques	indeterminate	n/a	n/a	y	y
42	incised	y	horizontals	indeterminate	n/a	n/a	y	y
43	combination	y	horizontals	indeterminate	n/a	n/a	y	y
44	stamped	y	obliques	present	1	pointed	y	y
45		u		present	1	pointed	y	y

StJohn Sample #	# of ext. bands present	Ext. bands main tecnique	Ext. bands main motif	Punctate yes/no	Punctate directionality	punctate distance from lip	Possible error correcting?
4	3	stamped	right oblique	n			
5	1	incised	horizontal	y		n/a	
6	3	stamped	right oblique	y	straight int	31.32	
8	5	incised	horizontal	y	left int	34.7	
9	4	stamped	oblique and horizonta	n			
10	4	stamped	alternating obliques	y	straight ext	19.41	
11	3	stamped	left oblique	y	slight right int	30.75	
16	5	stamped	right oblique	y	slight left ext	34.8	
20	3	stamped	left oblique	y	right ext	33.3	
21	4	stamped	right oblique	n			
22	7	stamped	right oblique	y	slight left int	39.92	yes- added to lip
23	3	stamped	alternating obliques	y	slight right int	28.08	
24	5	stamped	alternating obliques	n			
25	4	stamped	right oblique	y	slight right ext	51.54	
26	3	stamped	right oblique	y	left ext	37.96	
27	5	stamped	alternating obliques	y	straight int	29.02	
29	2	stamped	right oblique	y	right ext	25.11	
31	1	incised	right oblique	n			
38	2	stamped	right oblique	y	straight int	41.1	yes- added at castellation
39	5	stamped	right oblique	y	left ext	32.5	yes- added to front/collar
40	3	stamped	right oblique	y	slight right ext	33.05	
41	4	stamped	alternating obliques	y	straight ext	27.79	
42	3	stamped	left oblique	y	straight ext	42.68	yes- added to rim
43	4	stamped	alternating obliques	y	left int	17.95	yes- added to rim
44	5	stamped	left oblique	y	slight left int	29.95	
45	5	stamped	right oblique	n			

StJohn Sample #	Site	Rim Type	Rim type combined	Upper rim profile	Lip shape	Neck shape	Oriface diameter
46	AgHk-42	a	no fold or a	concave	flat	short	432.08
47	AgHk-42	a	no fold or a	concave	flat	elongated	250.64
48	AgHk-40	e	folded and	concave	flat	short	238.38
49	AgHk-40	e	folded and	concave	furrowed	short	187.92
50	AgHk-40	e	folded and	straight	flat	short	336.08
51	AgHk-40	d	added	straight	furrowed	short	404
52	AgHk-52	d	added	straight	flat	short	320.14
53	AgHk-56	g	unidentifie	concave	n/a	elongated	
54	AgHk-32	b	folded	concave	flat	elongated	
60	AgHk-42	d	added	concave	flat	short	
61	AgHk-32	b	folded	concave	flat	elongated	
62	AgHk-32	d	added	convex	furrowed	short	
63	AgHk-40	b	folded	concave	flat	short	
65	AgHk-52	f	added	concave	flat	elongated	
66	AgHk-42	e	folded and	concave	n/a	elongated	
67	AgHk-42	g	unidentifie	concave	n/a	elongated	
68	AgHk-42	b	folded	straight	rounded	elongated	
69	AgHk-42	f	added	concave	flat	short	
71	AgHk-52	g	unidentifie	concave	n/a	elongated	
79	AgHk-32	b	folded	straight	flat	short	
85	AgHk-32	e	folded and	straight	flat	n/a	
91	AgHk-52	h	added	concave	flat	elongated	
98	AgHk-32	e	folded and	straight	flat	elongated	
99	AgHk-42	c	folded	concave	flat	short	
105	AgHk-58	b	folded	concave	flat	short	
107	AgHk-58	f	added	straight	furrowed	n/a	
109	AgHk-58	a	no fold or a	straight	flat	elongated	
110	AgHk-58	b	folded	concave	rounded	n/a	
111	AgHk-58	e	folded and	concave	flat	short	
112	AgHk-58	b	folded	concave	flat	short	
113	AgHk-58	e	folded and	concave	flat	short	
114	AgHk-54	b	folded	concave	flat	short	
115	AgHk-54	b	folded	concave	flat	elongated	
116	AgHk-54	b	folded	concave	flat	short	
117	AgHk-54	e	folded and	concave	flat	short	
119	AgHk-54	e	folded and	concave	rounded	short	
132	AgHk-52	b	folded	concave	flat	short	127.52
36 -recan of 32	AgHk-42	b	folded	straight	flat	short	
93 -rescan of 030	AgHk-42	d	added	concave	flat	short	
96 rescan of 28	AgHk-52	e	folded and	straight	flat	short	
Ferris Vessel 36	AgHk-32	d	added	concave	furrowed	elongated	

StJohn Sample #	Neck main technique (stamped, incised or combo)	neck deco yes/no/un known	Simplified neck motif	Castellation indeterminate/ present/not present	Number of castellations present	Castellation shape	Int deco yes/no/un known	lip deco yes/no/un nown
46	incised?	y	horizontals	indeterminate	n/a	n/a	y	y
47	incised	y	triangles	indeterminate	n/a	n/a	y	y
48		u		present	1	pointed	y	y
49	combination	y	triangles	present	1	pointed	y	y
50		u		present	1	rounded	y	y
51	stamped	y	horizontals	indeterminate	n/a	n/a	y	y
52		u		present	1	pointed	y	y
53	incised	y	triangles	indeterminate	n/a	n/a	y	u
54	incised	y	triangles	present	1	rounded	y	y
60	incised	y	triangles	indeterminate	n/a	n/a	y	y
61	incised	y	triangles	present	1	pointed	y	y
62	stamped	y	triangles	indeterminate	n/a	n/a	y	y
63	incised	y	triangles	indeterminate	n/a	n/a	y	y
65	combination	y	triangles	present	2	pointed	y	n
66	incised	y	triangles	indeterminate	n/a	n/a	y	u
67	incised	y	triangles	indeterminate	n/a	n/a	y	u
68	combination	y	triangles	indeterminate	n/a	n/a	n	y
69	stamped	y	plaits	indeterminate	n/a	n/a	y	y
71	combination	y	triangles	indeterminate	n/a	n/a	y	u
79		u		present	1	pointed	y	y
85		u		present	1	pointed	y	y
91	incised	y	triangles	indeterminate	n/a	n/a	y	y
98	stamped	y	obliques	present	3	pointed	y	y
99		n	plain	present	3	rounded	y	y
105	stamped	y	obliques	present	2	pointed	y	y
107		u		indeterminate	n/a	n/a	y	y
109	incised	y	triangles	present	1	rounded	y	y
110		u		indeterminate	n/a	n/a	y	y
111	stamped	y	plaits	present	1	rounded	y	y
112		u		present	1	rounded	y	y
113		u		present	1	pointed	y	y
114	incised	y	triangles	indeterminate	n/a	n/a	y	y
115	stamped	y	obliques	present	2	pointed	y	y
116	stamped	y	horizontals	present	2	pointed	y	y
117	stamped	y	horizontals	indeterminate	n/a	n/a	y	y
119	stamped	y	obliques	present	1	rounded	y	y
132	stamped	y	horizontals	present	1	pointed	y	y
36 -recan of 32		u		indeterminate	n/a	n/a	y	y
93 -rescan of 030		n	plain	present	1	pointed	y	y
96 rescan of 28	combination	y	triangles	present	1	pointed	y	y
Ferris Vessel 36	incised	y	horizontals	indeterminate	n/a	n/a	y	y

StJohn Sample #	# of ext. bands present	Ext. bands main tecnique	Ext. bands main motif	Punctate yes/no	Punctate directionality	punctate distance from lip	Possible error correcting?
46	2	stamped	right oblique	y	slight left ext	17.74	
47	3	stamped	left oblique	y	left ext	35.24	
48	2	stamped	left oblique	y	straight ext	36.09	yes- added at castellation
49	4	stamped	right oblique	y	right int	34.06	yes - added to rim
50	3	stamped	alternating obliques	y	left ext	19.11	yes - added at castellation
51	5	stamped	left oblique	y	right ext	62.57	
52	3	stamped	right oblique	y	left ext	74.53	
53	5	stamped	alternating obliques	y	right ext	32.32	
54	4	incised	alternating obliques	y	slight left ext	33.31	
60	2	stamped	right oblique	n			
61	3	stamped	right oblique	y	slight right ext	31.75	
62	5	stamped	horizontal	y	slight left int	23.74	
63	6	stamped	oblique and horizonta	y	straight int	31.98	
65	7	stamped	left oblique	y	left ext	21.97	yes- added to lip
66	4	stamped	alternating obliques	y	right ext	approx. 2!	yes- added to rim
67	7	stamped	right oblique	y	straight ext	approx. 14.05	
68	3	stamped	left oblique	n			yes- added to top of rim
69	3	stamped	right oblique	y	slight left ext	25.19	yes- added to rim
71	5	stamped	oblique and horizonta	y	slight right ext	approx. 21.26	
79	7	stamped	oblique and horizonta	y	straight int	80.6	
85	3	stamped	right oblique	n			yes- added at castellation
91	3	stamped	right oblique	n			
98	4	stamped	alternating obliques	y	straight int	47.51	yes- added at castellation
99	1	stamped	right oblique	n			
105	5	stamped	alternating obliques	y	slight left ext	24.53	
107	4	stamped	alternating obliques	y	straight int	34.12	
109	4	stamped	vertical	y	slight left ext	28.21	
110	5	stamped	alternating obliques	y	straight ext	10.6	
111	4	stamped	alternating obliques	n			yes- added at castellation
112	3	stamped	left oblique	y	slight left ext	35.79	
113	4	stamped	alternating obliques	y	right int	25.19	yes- added at castellation
114	4	stamped	left oblique	y	straight int	34.78	
115	5	stamped	alternating obliques	y	straight ext	25.33	
116	5	stamped	alternating obliques	y	slight left int	42.08	
117	4	stamped	alternating obliques	n			yes- added to rim
119	4	stamped	alternating obliques	y	straight int	43.02	yes- added at castellation
132	7	stamped	alternating obliques	n			
36 -recan of 32	3	stamped	right oblique	y	straight int	37.47	
93 -rescan of 030	3	stamped	alternating obliques	y	straight ext	37.99	
96 rescan of 28	4	stamped	alternating obliques	y	left int	47.24	yes- added at rim
Ferris Vessel 36	6	stamped	alternating obliques	y	straight ext	30.12	

duplicates							
StJohn Sample #	**Site**	**Rim Type**	**Rim type combined**	**Upper rim profile**	**Lip shape**	**Neck shape**	**Oriface diameter**
55 same V. as 008	AgHk-32	d	added				
97 same V. as 050	AgHk-40	e	folded and added				
90 same V as 28/96	AgHk-52	e	folded and added				
102 - same V. as 049	AgHk-40	b	folded				
106 same V. as 105	AgHk-58	b	folded				
70 same vessel as 020	AgHk-52	b	folded				
101 -same V. as 044	AgHk-42	b	folded				
100 - same V. as 051	AgHk-40	f	added				
118 - same V. as 119	AgHk-54	b	folded				287.26
64 same V. as 98	AgHk-32	b	folded				

StJohn Sample #	Neck main technique (stamped, incised or combo)	neck deco yes/no/un known	Simplified neck motif	Castellation indeterminate/ present/not present	Number of castellations present	Castellation shape	Int deco yes/no/un known	lip deco yes/no/un nown
55 same V. as 008		y		indeterminate	n/a	n/a	y	n
97 same V. as 050		u		indeterminate	n/a	n/a	y	y
90 same V as 28/96		y		indeterminate	n/a	n/a	y	y
102 - same V. as 049		u		indeterminate	n/a	n/a	y	y
106 same V. as 105		y		present	1	pointed	y	y
70 same vessel as 020		y		present	1	pointed	y	y
101 -same V. as 044		y		present	1	pointed	y	y
100 - same V. as 051		y		present	1	incipient pointe	y	y
118 - same V. as 119		y		present	1	incipient pointe	y	y
64 same V. as 98		u		indeterminate	n/a	n/a	y	y

StJohn Sample #	# of ext. bands present	Ext. bands main tecnique	Ext. bands main motif	Punctate yes/no	Punctate directionality	punctate distance from lip	Possible error correcting?
55 same V. as 008	5	incised	horizontal	y			
97 same V. as 050	3	stamped	alternating obliques	y			yes- added at castellation
90 same V as 28/96	4	stamped	alternating obliques	y			yes- added at rim
102 - same V. as 049	3	stamped	right oblique	y			
106 same V. as 105	6	stamped	alternating obliques	y			
70 same vessel as 020	3	stamped	left oblique	y			
101 -same V. as 044	5	stamped	left oblique	y			
100 - same V. as 051	5	stamped	left oblique	y			
118 - same V. as 119	4	stamped	alternating obliques	y			
64 same V. as 98	4	stamped	alternating obliques	y			

Appendix F: Research Timeline

This micro CT and image analysis timeline attempts to capture the impact of mechanical difficulties, and the steep learning curve involved in scanning and analyzing materials using a micro CT system.

Date	**Research Progress**
September 2013	Completed X-ray safety training requirement for Western
July 2014	Completed first scans on my own. The data for these scans was subsequently lost when the hard drives for the reconstruction computers were switched.
July 2014	Axis rotation errors in attempted scans
Fall 2014	Working on comprehensive exams and research proposal
December 2014	Some scans completed that ended up in analysis, but the machine was plagued by over rotation errors and huge ring artifacts
January 2015	Running scans but with minimize rings function
Winter Spring Summer 2015	Not scanning-Comprehensive exams and Mitacs/ASI internship
September 2015	Running scans but with minimize ring function, still ring artifacts on scans
October 2015	Nikon technicians working on the machine

Fall 2015	Created Experimental Clay Slabs
November 2015	Huge ring artifacts in scans but when minimize rings function was turned on we were getting rotation errors with the stage
Late November 2015	Working with Nikon technicians to try to fix rotation errors and other problems
January 2016	Ran 34 scans this month, mostly run with minimize rings function but also experimenting with longer shading corrections to get rid of ring artifacts with some success. Some ongoing problems with auto-conditioning the machine.
February 2016	Nikon engineer at SA
March 2016	Ran the last scans of the first sample set of 35 specimens
March 2016	Scanner is down for maintenance again. Trikon technicians are in for a few weeks
March-April 2016	Initial analysis of scans in VG 2.2 – lots of time spent trying to figure out ways to segment voids
April 2016	Nikon technicians are in for maintenance on cooler leak
Late April 2016	Experimenting with ORS software to isolate voids
May 2016	Running calibrated scans
May 2016	Running successful scans of second sample of specimens

May-June 2016	Running analysis in 30 day trial version of VG 3.0
May 2016	Nikon technician visit to do some VG training as well as maintenance
June 2016	Analysis in VG 2.2
August 2016	Beginning of August there are a lot of failed scans but by the end I was running mostly successful scans
August 2016	Running analysis on rectangle prism ROIs
August 2016	Ongoing auto-conditioning issues with the scanner
Late August 2016- early September 2016	Some manipulator errors
September 2016	Trikon technician in and out, waiting for a scanner part
September 2016	Running analysis on rectangle prism ROIs
September 2016	Dragonfly by ORS released
October 2016	Running Analysis in VG 2.2 on first sample of specimens
November 2016	Waiting on a scanner part for the machine
November 2016	Running Analysis in VG 2.2 on specimens
December 2016	Successful scanning and running rescans of previously failed scans
December 2016	Running Analysis in VG 2.2 on specimens
January 2017	Good scans at the beginning of the month, later

	January some rotation errors
January 2017	Scanning samples from the Ministry
January 2017	Running Analysis in VG 2.2 on specimens
February 2017	Ran three successful scans, completed the last of the Vessel specimen scans
February-March 2017	Running Analysis in VG 2.2 on specimens and second 30 day trial version of VG 3.0
April 2017	Image analysis in VG 2.2
July 2017	Scanning lumps of clay, some trouble with movement in mounting methods. Finished scans and analysis.
February-March 2018	Rotation errors (not for this project though)
June 2018	Ongoing auto-conditioning errors (not for this project)
Summer 2018 to Summer 2020	Machine running well with few errors

Curriculum Vitae

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Post-secondary Education and Degrees:	Western University London, Ontario, Canada 2013-2020 PhD.
	Memorial University of Newfoundland St. John's, Newfoundland and Labrador, Canada 2007-2011 M.A.
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Publications:

St. John, Amy and Neal Ferris
2019 Unravelling identities on archaeological borderlands: Late Woodland Western Basin and Ontario Iroquoian Traditions in the Lower Great Lakes region. *The Canadian Geographer* 63(1):43-65.

St. John, Amy
2013 Normandy Stoneware at Cap Rouge: A migratory French fishery site on Newfoundland's Petit Nord. In *Exploring Atlantic Transitions: Archaeologies of Permanence and Transience in New Found Lands.* Edited by Peter E. Pope and Shannon Lewis-Simpson, Society for Post-Medieval Archaeology Monograph no. 7: 165-177, Boydell and Brewer,Woodbridge, Suffolk, UK.

Conference Presentations and Posters:

St. John, Amy, Gregory Braun, Joe Petrus, Louis Lesage, Alicia Hawkins
2019 Using Multi-Method Ceramic Analysis to Investigate Huron-Wendat Ties to Ethnicity and Territory. Paper Presented at the joint Annual Meeting of the American Anthropological Association and the Canadian Anthropology Society.

Hawkins, Alicia, Louis Lesage, **Amy St. John**, Gregory Braun, Mélanie Vincent
2019 Examining Huron-Wendat History through Ceramic Communities of Practice. Paper presented at the Annual Meeting of the Canadian Archaeological Association.

St. John, Amy
2018 Fifth Time's a Charm. Give and take between ceramic objects and craft producers in Ontario's Late Woodland, seen through Micro Computed Tomography. Paper presented at the Annual Meeting of the Canadian Archaeological Association.

St. John, Amy
2017 Pre-contact Boundaries of Indigenous Peoples in the Lower Great Lakes. Paper presented at Borders in Globalization 2nd International Conference.

St. John, Amy
2017 Using Micro Computed Tomography to explore Ceramic Rim Formation Practices on a Late Woodlands Borderland. Paper presented at the Annual Meeting of the Canadian Archaeological Association.

St. John, Amy2017 Micro Computed Tomography in Archaeological Ceramic Studies: A Case Study on Ontario Late Woodland Borderlands. Poster Presented at the Society for American Archaeology 82nd Annual Meeting.