Journal of Archaeological Science: Reports 9 (2016) 586–598

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Investigating pottery vessel manufacturing techniques using radiographic imaging and computed tomography: Studies from the Late Archaic American Southeast

Matthew C. Sanger

Department of Anthropology, PO Box 6000, Binghamton University, Binghamton, NY 13902, United States

ARTICLE INFO

Article history:
Received 30 May 2016
Received in revised form 10 August 2016
Accepted 11 August 2016
Available online 2 September 2016

Keywords:
Pottery
Radiography
Social boundaries
CT-scanning
Experimental archaeology

ABSTRACT

Advances in image acquisition and processing, including the increasing availability of computed tomography (CT), have expanded the research potential for radiography. This paper employs recent radiographic advancements to investigate how hand-formed pottery was manufactured, with a focus on defining "micro-techniques" that may be isomorphic with past social groups. By creating and imaging experimental vessels, unique structural "fingerprints" are defined for a number of micro-techniques, which are then used to categorize assemblages from two contemporaneous and neighboring archaeological sites. Results suggest that the two sites were occupied by distinct potting communities and that radiographic imaging can be a powerful tool for determining the presence of past social groups.

1.1. Introduction

Although still uncommon, archaeologists are beginning to use radiography and computed tomography (CT) at increased rates, particularly to study the internal structures of objects. Recent radiographic studies have identified the advent and spread of novel technologies and investigated complex patterns of production and consumption in past societies (e.g. Abraham et al., 2014; Bettuzzi et al., 2015; Bugani et al., 2009; Lang and Middleton, 2005). The availability and applicability of radiography is steadily increasing as technological improvements reduce the price of analysis and increase the speed and accuracy of imaging. These improvements, coupled with the growing application of computer vision, photogrammetry, and image processing within archaeology have created a fertile field of study that threatens to revolutionize the study of past objects (e.g. Berg, 2008; Lang et al., 2005; O'Connor and Maher, 2001; O'Connor et al., 2002).

This paper incorporates advances in imaging and processing to reinvigorate one of the original topics for archaeologists using radiographic imaging – the study of ceramic vessel manufacture. In earlier radiographic studies, determining vessel manufacturing methods has proven useful in tracing the emergence and distribution of new technologies, such as the potter's wheel, and the development of particular practices, including standardized vessel manufacture (e.g. Carr, 1990; Rye, 1977). The present study expands beyond traditional radiographic studies by exploring how vessel manufacture data can assist in determining the presence of past potting communities. Ethnographic studies demonstrate that "primary formation" techniques (i.e. coiling, wheel-throwing) often pattern along societal lines and are relatively resistant to change over time, making them good indicators of past social groups (Gosselain, 1998; Leroi-Gourhan, 1993; Minar, 2001; Plog, 1980). Typically, primary formation techniques are some of the first skills learned by novice potters who mimic the actions of their instructors. As such, a shared pattern of primary formation techniques can be found among contemporary potters with a similar "teaching lineage" as well as across generational lines of novices and instructors. Primary formation techniques are particularly useful in studying the presence of past social groups when they are difficult to discern in the completed vessel. To the extent that smoothing, buffing, and other finishing techniques obfuscate the manner by which the vessel was formed, it is increasingly unlikely that techniques will be adopted by potters who encounter finished vessels yet reside outside of the community.

Recent research has refined the scale by which archaeologists can investigate the presence of past social groups by revealing a wealth of "micro-techniques" that often cluster among particular potting groups (e.g. Lindahl and Pikirayi, 2010; Thér, 2015). Although there are technological and functional factors that influence how potters fashion vessels, there are also practices, such as the manner by which coils are smoothed together, which are far more dependent on habitual actions. These

E-mail address: msanger@binghamton.edu.

http://dx.doi.org/10.1016/j.jasrep.2016.08.005

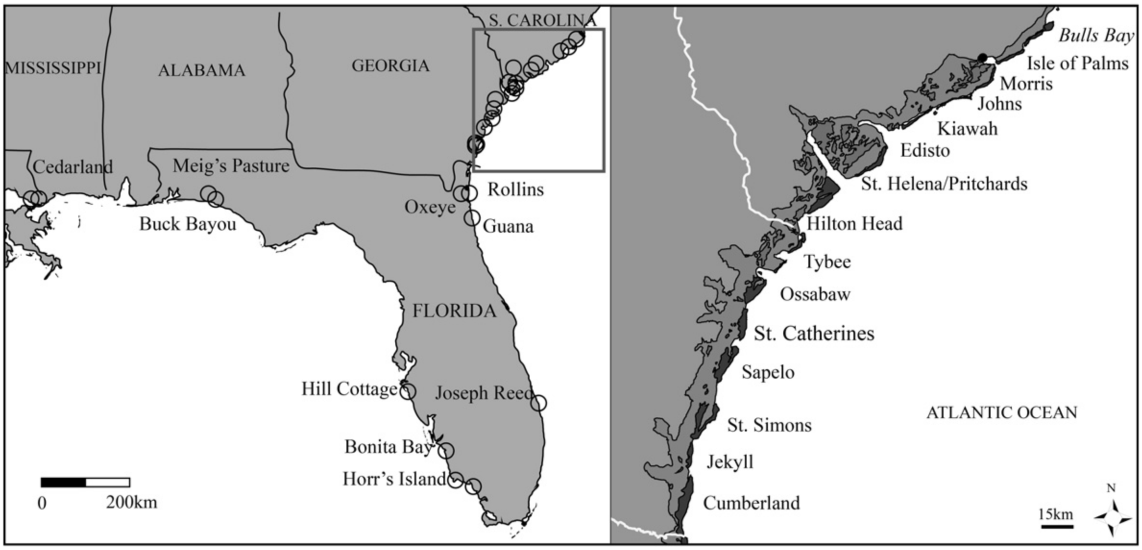

Fig. 1. Location of selected shell rings and close-up of the Georgia and South Carolina Sea Islands.

habitual practices often become rote, resulting in little change over time even as more reflexive actions, such as decorating or embellishing vessels, can change dramatically during the life of the potter (Gosselain, 1998; Minar, 2001).

Currently, the study of micro-techniques has depended on destructive analyses as they require thin-sectioning or polishing fresh breaks in vessels, and can even require the addition of polymers to enhance visibility. Radiographic studies obviously have the benefit of being non-destructive, yet have rarely engaged in the study of micro-techniques, partially because the structural features that define these techniques are difficult to discern using traditional radiographic methods.

Within this paper, I demonstrate how advances in radiographic technologies and imaging software have expanded analytical thresholds, making the study of micro-techniques increasingly possible. Specifically, with the advent and increasing availability of real-time imaging and CT-scanning, new methods of ceramic analyses are becoming possible (e.g. Sanger et al., 2013). These advances allow researchers to engage directly with samples by rotating, magnifying, and otherwise manipulating objects to allow visual inspection of internal structures otherwise difficult to see in static imagery (e.g. Kahl and Ramminger, 2012). Imaging data can now be investigated in increasingly robust manners as software allows the application of algorithmic analyses, pattern recognition, and enhancement parameters.

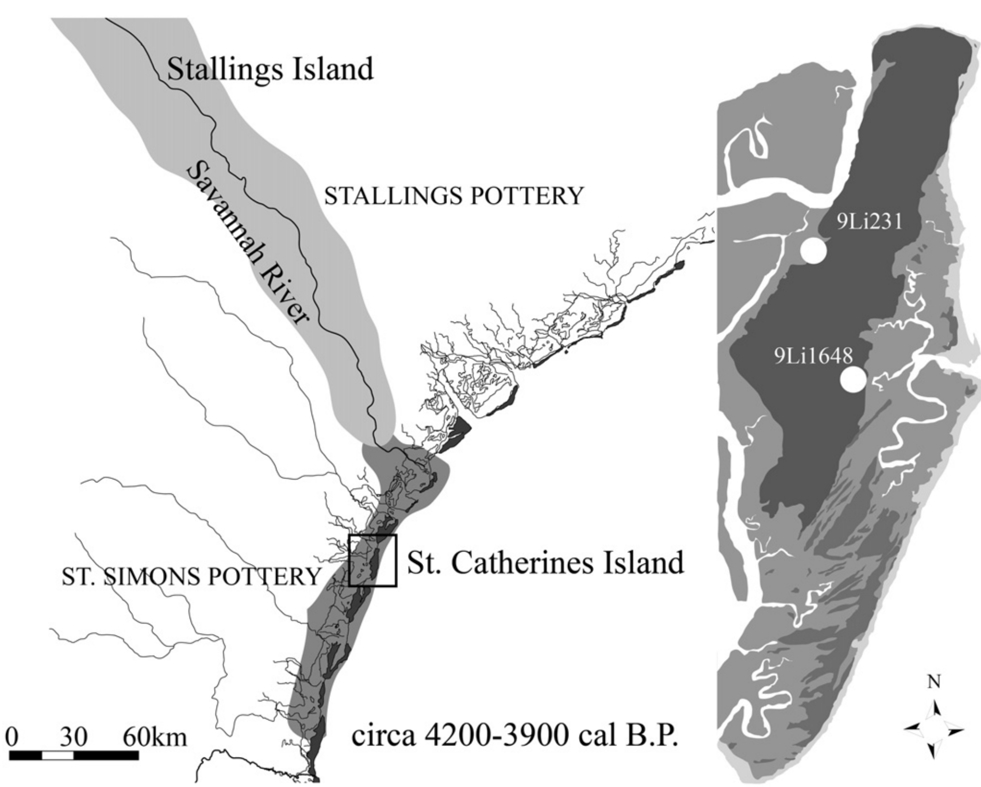

Fig. 2. Distribution of pottery types ca. 4200–3900 cal B.P. and close-up of St. Catherines Island with shell ring locations marked.

Table 1
Tempering and decoration rates.

		Temper %			Embellishments %	
	Num. of Sherds	Fiber	Sand	Other	Plain	Decorated
St. Catherines shell ring	11,444	97.2	1.8	1	99.7	0.3
McQueen shell ring	44,127	95.5	2.3	2.2	98.5	1.5

Used in conjunction, this paper applies advances in image capture and analyses to determine the structural "fingerprints" associated with particular micro-formation techniques. Structural fingerprints include the orientation, shape, and size of pores, tempers, and aplastics within the clay fabric as these features are affected by the manipulation of materials when making a vessel. By constructing experimental vessels using a variety of micro-techniques, structural fingerprints are defined for each and are then applied to archaeological assemblages.

The archaeological assemblages used within this study were recovered from two neighboring and contemporaneous Late Archaic sites located on St. Catherines Island, Georgia, in the American Southeast. The collections from St. Catherines Island are particularly well-suited for the current study because; 1) Late Archaic pottery manufacturing techniques in the American Southeast are particularly heterogeneous, and 2) Late Archaic vessels from St. Catherines Island were made using vegetal fibers, leaving behind empty cavities that are highly visible in radiographic imaging.

Rather than evolving through time, results offered in this paper show that different techniques were employed contemporaneously. Distribution is non-random between the two sites and suggests that each may have been occupied by different social groups. Based on these results, it is clear that advances in radiography have archaeological applications that may expand our ability to study the formation and character of past communities.

2.1. Study area

The American Southeast is home to the earliest pottery in the United States (Saunders and Hays, 2004). Some of the earliest pottery in the region comes from sites known as shell rings. Shell rings are found throughout the coastal American Southeast and are named as such because they consist, in part, of circular or C-shaped midden deposits (Fig. 1). Shell ring morphology varies by where they are located, with closed circles often measuring <100 m wide in South Carolina, Georgia, and northern Florida, and open C-shaped rings measuring up to 300 m elsewhere in Florida. Almost all of the rings date to the Late Archaic and their use and function are much debated with some contending that they are empty ceremonial centers (Russo and Heide, 2003; Saunders, 2002, 2004a, 2004b), others viewing them as early village sites (Calmes, 1967; Colaninno, 2010, 2012a, 2012b; Trinkley, 1980), and others still suggesting their use changed through time (Thompson, 2006, 2007; Thompson and Andrus, 2011).

However they are interpreted, shell rings play a pivotal role during the Late Archaic as they are evidence of increased population levels along the coast as well as a reduction in mobility during this period (Russo, 1998; Thompson and Andrus, 2011). Coincident with reduced mobility and rising population levels during the Late Archaic is the emergence of larger, more spatially constrained, and increasingly formalized social groups on the South Atlantic coast and neighboring river valleys (e.g. Anderson, 1996; Anderson et al., 2007; Anderson and Sassaman, 2012; Sassaman, 2010). Societal boundaries between Late Archaic social groups were mediated through exchange and trade networks that could, at times, span vast portions of the Eastern Woodlands and tied together diverse populations into extended social networks (Gilmore, 2016; Sassaman and Randall, 2007; Sassaman et al., 1988; Waggoner, 2009).

For these reasons, defining social groups and the interactions between them has become increasingly important when studying the Late Archaic American Southeast. Traditionally, studies have focused on variations within material culture, particularly pottery, to determine cultural affinity, trade, and collaboration (e.g. Saunders and Hays, 2004). Because southeastern pottery typologies rely, in part, on the presence of decorative patterns for distinguishing between different types, they are difficult to apply to most Late Archaic assemblages where the vast majority of vessels are plain, undecorated pots. Many researchers suggest that tempering agents can also be used to differentiate between pottery types, although these divisions operate on a relatively macro-scale (e.g. pottery found in Florida compared to pottery found in Georgia) and do not always follow expectations (Saunders and Hays, 2004).

The challenges associated with employing traditional typologies are demonstrated when looking at the present study sample. More than 55,000 pottery fragments were recovered from excavations conducted on two Late Archaic shell rings located on St. Catherines Island, Georgia (Fig. 2). The shell rings on St. Catherines Island occupy an important point in time as they were both created ca. 4200–3900 cal. B.P. (Kennett and Culleton, 2012; Sanger and Thomas, 2010: 67), a period when increasingly regionalized pottery types were emerging in the American Southeast, presumably marking the rise of more differentiated or well-defined social groups in the area (Sassaman, 2004).

Specifically, during this portion of the Late Archaic, Stallings pottery is found along the Savannah River and centered on Stallings Island, located roughly 225 km to the northwest of St. Catherines Island (Fig. 2). Stallings pottery may relate to a specific group of people or peoples who originated along the Georgia and South Carolina coasts before moving up river and displacing or co-residing among interior peoples who did not produce pottery at the time (Sassaman et al., 2006). Along the coast of Georgia, a new pottery type and perhaps people, known as St. Simons, emerged at the same time that Stallings wares are found in interior river valleys. It is possible that St. Simons and Stallings "peoples" were in competition or conflict with one another and that the movement of Stallings off of the coast and into the interior river valleys reflects a retreat from their original homelands. The factors promoting the emergence of St. Simons pottery on the coast and the movement of Stallings wares into interior river valleys are poorly understood, but the temporal and spatial inflection points surrounding these changes falls on St. Catherines Island and occurred when the shell rings on the island were being formed.

Radiometric results from the St. Catherines Island shell rings have been presented in detail elsewhere (Sanger and Thomas, 2010) along with a Bayesian analysis (Kennett and Culleton, 2012). These studies show that one of the rings – the St. Catherines Shell Ring – may have begun accumulating slightly earlier (likely <100 years), yet because of the inaccuracies inherent in radiometric dating, it is possible that both

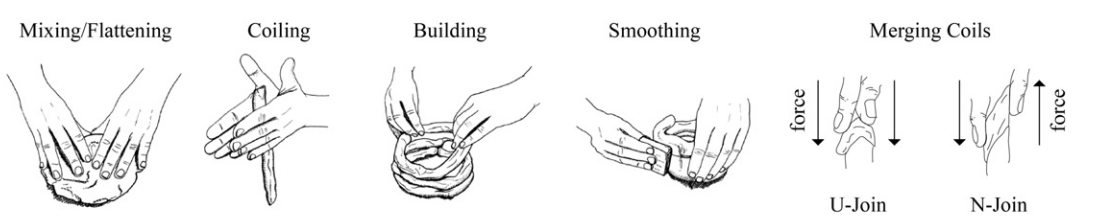

Fig. 3. Steps in coil-building.

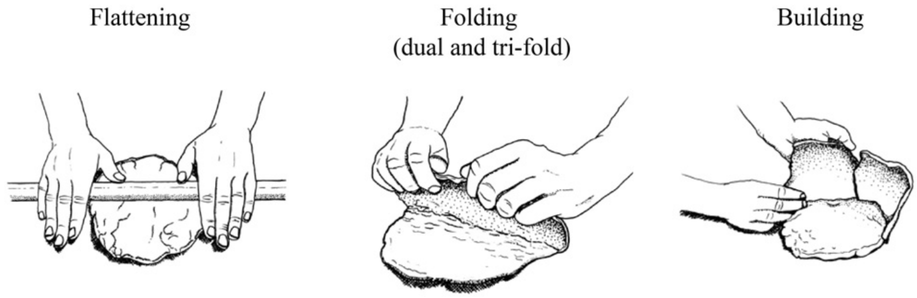

Fig. 4. Steps in slab-building.

rings began at near the same time. Whether accumulation begun at the same moment at each ring, or if there was a delay between the two, both were occupied at the same time over several centuries before accumulation ceased simultaneously at both. As such, I describe the two as contemporaneous even while acknowledging that they may not overlap entirely.

Perhaps unsurprisingly, considering the social changes occurring in the region at the time, prior research suggests that the St. Catherines Island shell rings were occupied by different social groups. Despite the rings being less than an hour's walk from one another, there are significant differences in depositional practices (Sanger, 2015a), stone tool assemblages (Ogden, 2011), faunal remains (Colaninno, 2010), manner of digging pits (Sanger, in press), and cooking traditions (Sanger, 2015b). These divergent practices suggest some level of social or cultural differentiation between the two sites, although differences could also be explained based on functional factors; perhaps with one ring being used for residence and the other as a gathering point (as per Thompson, 2007; Thompson and Andrus, 2011).

Studying pottery from each site would presumably allow greater insights in their relation to one another, but preliminary studies were stymied by the limited applicability of current typological classifications (Sanger and Thomas, 2010). Pottery from the rings are similar as they are almost entirely (>95%) plain wares tempered with vegetal fibers, the most common method in the region (Sanger, in press) (Table 1). Despite superficial similarity, the few decorated wares found at each ring are often embellished in different manners. Decorated sherds from the St. Catherines Shell Ring, located on the western edge of the island, are more often embellished with punctates, typically aligned in single or multiple parallel lines, a characteristic of Stallings pottery. Decorated sherds from McQueen Shell Ring also included sherds with punctates, although they are generally smaller. The McQueen collection also includes a larger proportion of sherds embellished with incisions, grooving, and mixed techniques (Sanger, 2015b, in press), which is similar to how many St. Simons vessels were decorated. Because of the very small number of decorated wares at each ring, it is unclear whether they reflect the presence of different potting communities, lines of trade, use histories, or are simply a sampling error.

3.1. Methods

To better understand how the St. Catherines Island shell ring pottery assemblages relate to one another, traditional typologies had to be enhanced. The possibility of investigating formation techniques as a method of typological differentiation was supported by a wealth of studies that demonstrated a notable diversity in vessels formation techniques during the Late Archaic (DePratter, 1976, 1979; Griffin, 1943; Sassaman, 1993, 2004; Saunders, 2004a; Trinkley, 1980, 1983; Waring, 1968). Unlike later time periods, when coil-building is the norm (Sassaman, 1993), archaeologists have long noted that Late Archaic pottery sherds break in odd fashions and have internal structures inconsistent with coil-building, including sherds formed through thin successive layers of clay, resulting in a laminate or layered cross-section running perpendicular to the rim (Simpkins and Allard, 1986). Small-scale studies by other archaeologists demonstrated the viability of using radiography to investigate the diversity of Late Archaic potting techniques, yet none attempted a systematic approach (Beck et al., 2002; Endonino, 2013; Sanger et al., 2013; Trinkley, 1986).

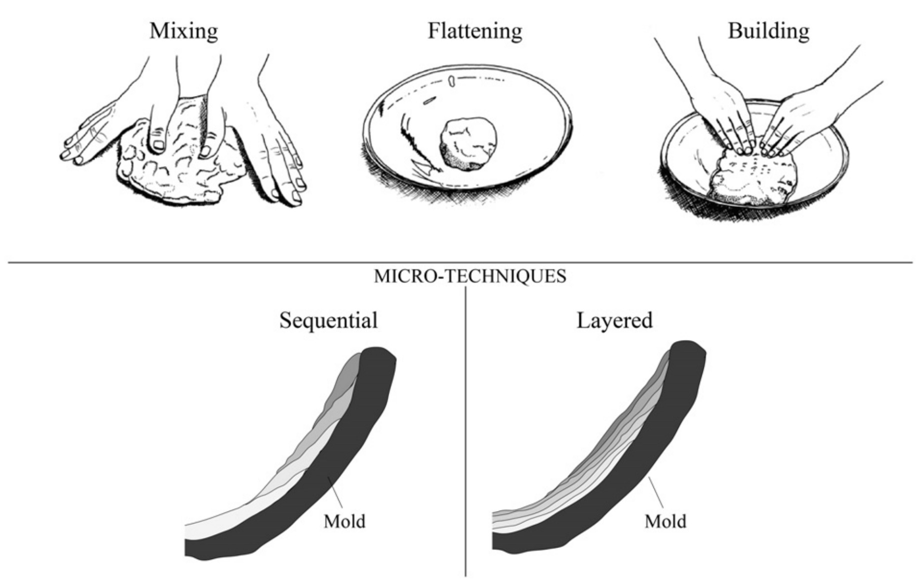

Fig. 5. Steps in mold-building.

Table 2
Numbers of experimental vessels.

		Vessels	Tiles
Coil	U-technique	4	1
	N-technique	2	0
Slab	Homogenous	2	3
	Dual-fold	2	3
	Tri-fold	2	3
Mold	Sequential/convex	2	1
	Sequential/concave	2	1
	Layered/convex	2	2
	Layered/concave	2	2
	Alternating/convex	2	1
	Alternating/concave	2	1
	Lattice/convex	1	0
	Lattice/concave	1	0
	Total	26	18

To make the link between past methods of vessel formation and specific potting techniques, the present study engaged in a systematic program of experimental vessel formation, the results of which were then imaged radiographically. The imaging of experimental vessels created using known techniques allowed the definition of particular structural fingerprints unique to each technique that could then be applied to archaeological assemblages.

3.2. Experimental vessel formation

Experimental studies were critical for the current project as using vegetal fibers for tempering resulted in a medium that responded differently than most clay fabrics. Spanish moss (*Tillandsia usneoides*) is the most likely material used to temper Late Archaic vessels from Georgia (Cordell, 2004; Simpkins and Allard, 1986) and was used in this study. Because of its structure, when Spanish moss is mixed with clay the result is a fabric with significant tensile strength, yet difficult to work as it can clump together and become entangled. It is therefore likely that potters using vegetal fibers would form vessels in ways unlike those who use other tempering agents and is perhaps one of the reasons why there is such diversity in Late Archaic vessel formation techniques in the American Southeast.

The present study attempted to replicate this diversity by forming vessels and test tiles (generally 20×20 cm squares) through coiling, mold-building, and slab-building techniques (Rice, 1987; Rye, 1981). Variations in each of these broader methods are also offered and form a number of "micro-techniques," the details of which are offered below.

Coil-Building - Coiling is the best documented formation technique in the ethnographic and radiographic literature (e.g. Berg, 2008; Carr, 1990; Gosselain, 1992; Kahl and Ramminger, 2012; Rye, 1977, 1981). Coil-building consists of melding together clay and temper into a solid roll that is then placed around the circumference of the vessel until the appropriate height is reached (Fig. 3). The method of merging coils together varies as potters can either push one coil over the coil below it (U-join) or provide bi-directional pressure to merge together coils (N-join) (Lindahl and Pikirayi, 2010; also see Gibson and Woods, 1990). Both techniques were used when building experimental vessels. After an appropriate height was reached, the vessel walls were smoothed by pulling either an empty hand or small device (often a small, smooth stone) across its interior and exterior faces.

Slab-building – Slab-building is a method by which pots are constructed out of prefabricated sheets of clay and temper (Carr, 1990; Vandiver, 1987). To form sheets, clay and temper are typically mixed into a ball and rolled out until flattened (Fig. 4). During the creation of the experimental vessels, it became apparent that excessive folding and rolling resulted in the fiber tempering becoming entangled to the extent that the sheet was virtually unusable. To accommodate their use, it was necessary to not fold the sheets more than a few times after the addition of fibers to the clay. In total, three different successful slab-building micro-techniques were developed (other techniques were developed but failed to produce usable vessels). These three micro-techniques are homogenous, dual-fold, and tri-fold slab-building. Homogenous slab-building is a method by which sheets were formed by mixing together clay and fibers into balls that were then flattened by applying pressure emanating from the center of the ball until a uniform thickness (10–15 mm) was achieved.

Dual-fold slab-built sheets were formed in a similar manner, but were flattened until reaching a thickness of 6–10 mm, after which they were folded in half and flattened a second time, at which point they measured 10–15 mm thick. Tri-fold slab-built sheets were folded at their thirds after being flattened to 4–6 mm thick. Attempting to fold and merge sheets more than three times resulted in entangled fibers and unstable slabs that were difficult to form into vessels and rarely survived firing. The sheets formed through all of the micro-techniques were allowed to dry for 0.5–0.2 h before being merged together to form a vessel. Using an empty hand, or occasionally a stone, the merge lines between sheets were smoothed.

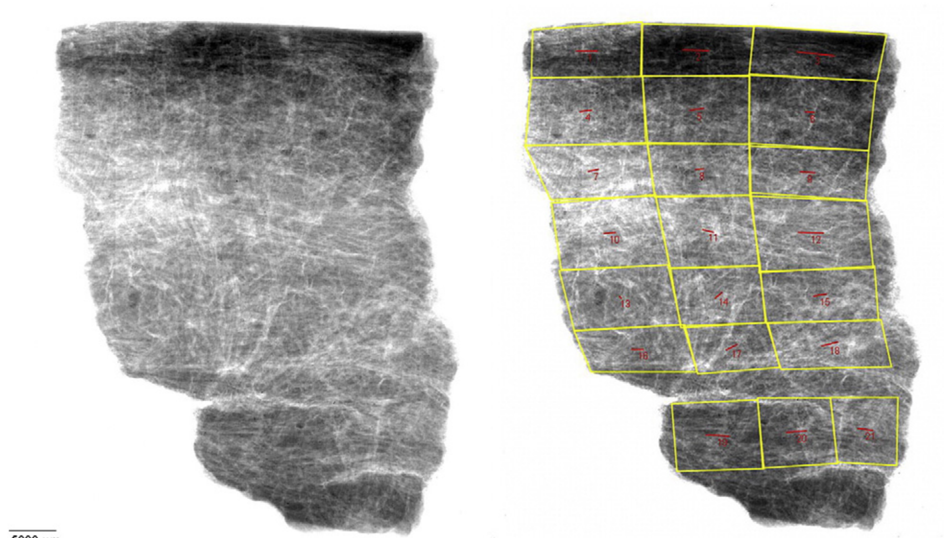

Fig. 6. Visual output from FibrilTool.

Mold-Building - A third method of vessel formation found in the ethnographic literature is molding (Gosselain, 2000, 2011; Rice, 1987, 1999). Mold-building typically consists of applying clay and temper to an already existing form, such as a ceramic vessel or an excavated pit (Rye, 1981: 81) (Fig. 5). Alternatively, potters can use their hands as a support, in which case this technique is quite similar to pinch-potting (Lindahl and Pikirayi, 2010). Two mold-built micro-techniques were developed, sequential and layered.

In sequential mold-building, vessels were formed by placing a ball of clay and fiber at the bottom of already existing vessel (Fig. 5). The ball was then flattened and pulled along the sides and up toward the lip of the vessel. When the walls reached the appropriate thickness (10–15 mm) additional clay and fiber were added to the leading edge of the partially formed vessel, pressed into the mold, and spread until the desired height was reached.

Layered mold-built vessels were formed in much the same manner as sequential mold-built, except the clay and fibers were pulled much further up the wall of the mold, resulting in a very thin layer of clay and fiber (roughly 2–4 mm) (Fig. 5). Additional materials were then added to the bottom of the mold and again pulled toward the lip. This process was repeated until an appropriate wall thickness (roughly 10–15 mm) and height was reached. Several variations in layered mold-building were conducted, including creating distinct layers of fibers and clay, yet the results of these techniques are not applicable to the current study and are not included as separate categories within this paper, but are rather subsumed into the larger layered mold-built category (see Sanger, in press for details).

A total of 44 vessels and test tiles were formed using the techniques defined above (Table 2). Whole vessels were fired in open pits, while tiles were fired in commercial kilns.[1]

3.3. Selection of archaeological sherds

316 sherds from the two shell rings were selected for radiographic analysis (109 St. Catherines Shell Ring, 207 McQueen Shell Ring). Based on an aggressive refitting project, as well as morphometric measurements and color attribution, each sherd could be confidently classified as representing a single vessel with no cross-over between samples.

3.4. Radiographic imaging

The archaeological and experimental samples used in the present paper were imaged with a GE Phoenix v|tome|x CT scanner using a micro-focus, 240 kV X-ray tube with a tungsten target. The GE Phoenix v|tome|x CT scanner is capable of producing both three and two-dimensional imaging, both of which depend on the same general principles of radiography in which samples are bombarded with X-ray photons. The density and composition of materials effect the level to which photons are allowed to pass through the sample to a detector on the other side. Data from the detector is translated into an image where areas of higher and lower absorption are marked by darker and lighter grey tones. The opposite is true in reconstructed three-dimensional models where higher absorption is marked by lighter and lower absorption is marked by darker tones.

Tube voltage ranged from 90 to 170 kV, and current, detector timing, and gain multiplication were further adjusted based on the needs of the researcher and the particularities of the sample. In order to counter the effects of beam hardening caused by low-energy X-rays, a 0.1 mm copper filter was also used for all scans. A pixel resolution of 40 μm or less was maintained for each sample. Three-dimensional data was collected by putting the sample on a rotating stage and taking two-dimensional images at defined intervals that numbered between six and twelve and included all 360°. Unlike traditional radiographic equipment, which captures two-dimensional images either on film or as static electronic images, the GE phoenix v|tome|x provides real-time imaging of radiographic data.

When required, three-dimensional computed tomography (CT) models were created using GE phoenix datos|× 2.0 software (Herman, 2009). Through this same software, it was possible to segment data into regions of interest (ROI), perform measurements, and otherwise interact with the model. Because it was time-consuming, only 55 three-dimensional models were created, although all of the samples were viewed in three-dimensions in real time while two-dimensional images were being captured.

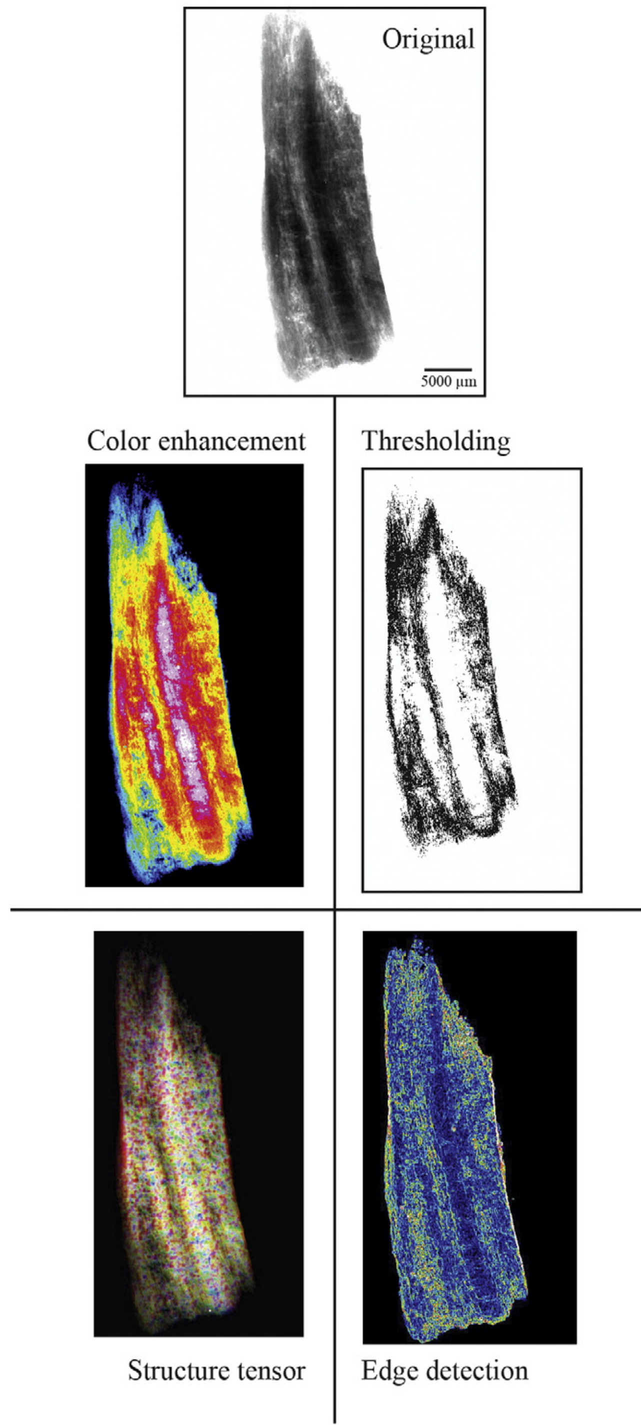

Fig. 7. Tools used for visual enhancement.

[1] Thanks to Galen Boone, Hannah Cain, Emma Gilheany, Emilio Santiago, and Elizabeth Halderson for assisting in the creation of vessels.

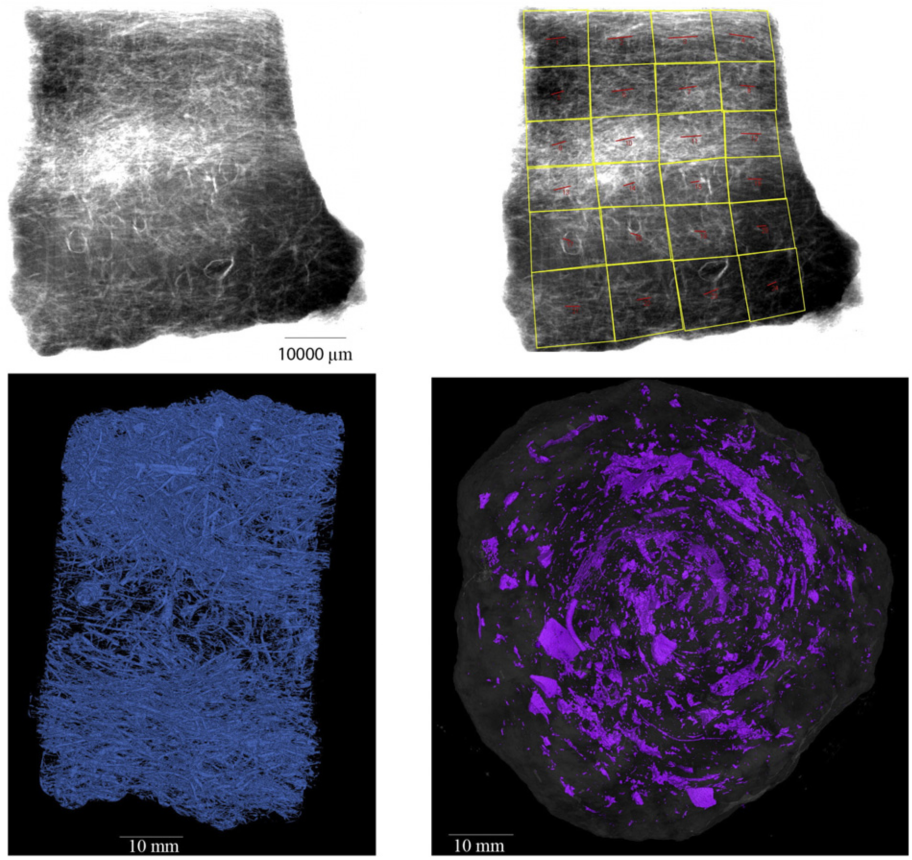

Fig. 8. A) Radiographic image of coil-built body fragment (upper left), B) Orientation and anisotropic values (upper right), C) Three-dimensional model of coil-built body fragment, D) Three-dimensional model of coil-built basal fragment.

Multiple two-dimensional radiographic images were captured for all of the samples. Two-dimensional images were analyzed using ImageJ, an open access image processing software driven by Java. ImageJ has a variety of built in features, including measurements, image enhancements, and plug-ins that allow pattern recognition, complex spatial and visual algorithms, and automated feature transformations.

Used together, two and three-dimensional radiographic imagery provided a number of potential research avenues. The most pertinent to the current study are 1) determining directionality of voids and aplastics within the samples; and 2) characterizing disjunctures and layering on vertical and horizontal axes.

3.5. Determining directionality of aplastics and measuring disjuncture

Prior research shows that directionality, regularity, shape, and boundedness of voids, aplastics, and temper are heavily influenced by potting techniques and structural "fingerprints" can be defined and linked to particular formation methods (Berg, 2008; Braun, 1982;

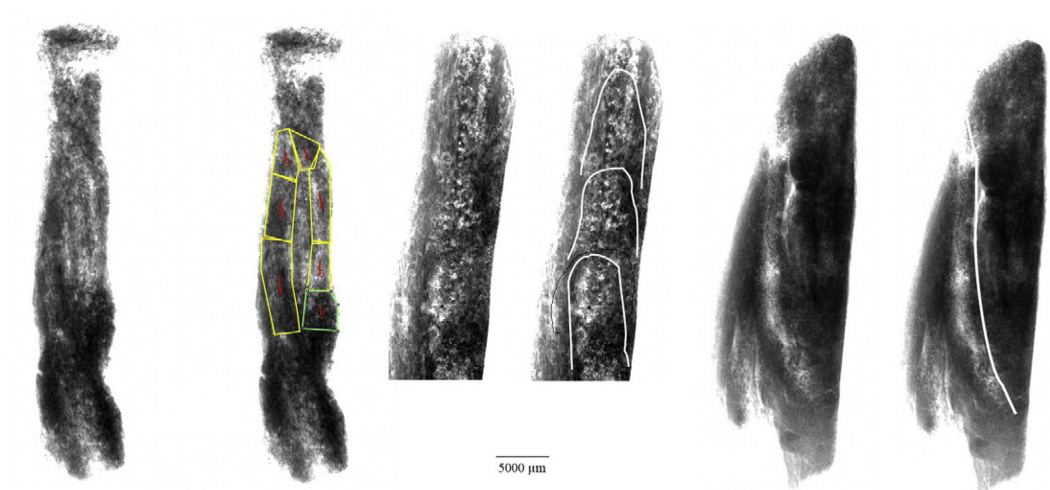

Fig. 9. A) Edge-on image of coil-built body fragment showing circular remnants of coil (left), B) Image of U-shaped coil melding (middle), C) Image of N-technique coil melding (right).

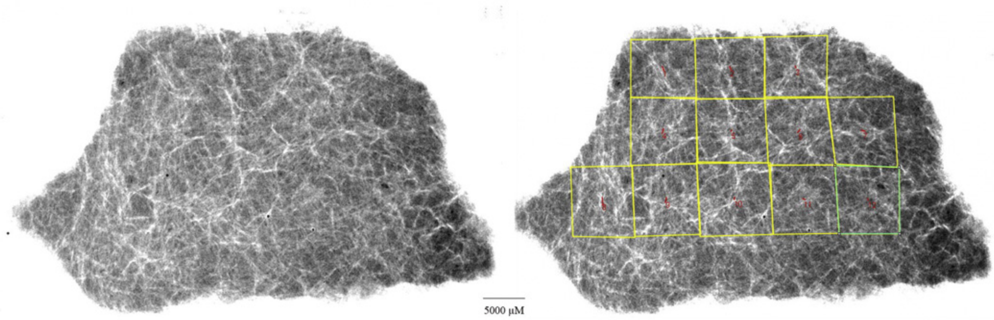

Fig. 10. Face-on radiographic image of slab-built vessel with FibrilTool data.

Carmichael, 1986; Carr, 1990; Ellingson et al., 1988; Foster, 1983; Glanzman, 1983; Glanzman and Fleming, 1986; Kahl and Ramminger, 2012; Rye, 1977, 1981; Vandiver, 1987, 1988; Vandiver et al., 1991; Vandiver and Tumosa, 1995). The directionality of voids was especially visible in the study sample as they were created by the carbonization of vegetal tempering. While highly visible, voids caused by the carbonization of vegetal fibers were long and geometrically complex, making them difficult to quantify using traditional measurement techniques. To address this challenge, FibrilTool, a plug-in for ImageJ that measures the orientation and anisotropic values of fibers, was used to characterize temper orientation (Boudaoud et al., 2014). FibrilTool utilizes nematic tensors to quantify the orientation of fibrillar structures and how well they are aligned (Boudaoud et al., 2014). Working within a user-defined ROI, fibril orientation is based on pixel intensity to define unit vectors that are locally tangent to fibrils. Quantitative data is extracted using circular statistics that analyze the tangent direction across the ROI. According to the authors of the tool, "(t)he circular average of the tangent direction defines the average orientation in this region (fibril orientation), and the circular variance of the tangent direction defines the score assessing whether the fibrils are well ordered (fibril array anisotropy)" (Boudaoud et al., 2014: 458). Orientation is provided in degrees from horizontal and anisotropic values range from 1 (perfectly ordered or parallel) to 0 (purely isotopic). The mathematic principles driving FibrilTool and a validation of its applicability to a variety of image types can be found elsewhere (Boudaoud et al., 2014). Results of the FibrilTool are available in tabular and visual form. In the visual representation, the ROI is highlighted, within which the average orientation is represented by a line whose length reflects the anisotropic score (Fig. 6).

Directionality of voids was also determined through the analysis of three-dimensional models using Volume Graphics VGStudio Max 2.2. To analyze the internal voids of the sample, they were first defined and extracted using VG's Region Growing function. Once extracted, acuity was increased through the reassignment of non-fibrous voids, including those created by cracks and air pockets, thereby creating three ROI's: fiber voids, non-fiber voids, and the clay fabric. Voids resulting from fibers were the focus of the study and once defined, their size, shape, orientation, coherency, and deviation from norm were determined using a mixture of tools within VGStudio Max, including tools within the Fiber Composite Material Analysis module. In addition to characterizing individual fibers, local and global fiber orientations, concentrations, and distributions were determined. The applicability of the VGStudio Max tools in determining characteristics of fibers and the underlying mathematical principles can be found elsewhere (e.g. Krause et al., 2010).

Concordant with measuring aplastic directionality, horizontal and vertical planes of separation or disjunctures were identified, measured, and used to define discrete layers within the samples. Recognizing disjunctures was facilitated within two-dimensional imagery by using image enhancement plug-ins. The image enhancements most often used were contrast enhancement and sharpening, Fourier elaboration, structural tensors, and color attribution (Fig. 7); the mathematical models for each can be found on the ImageJ website (http://rsb.info.nih.gov/ij/plugins/index.html). These tools were applied in tandem to increase the visibility of micro-structures, particularly the presence of vertical and horizontal layering. Once recognized, layers were defined, extracted from the rest of the dataset, and measured to determine variability in width and distance between layers.

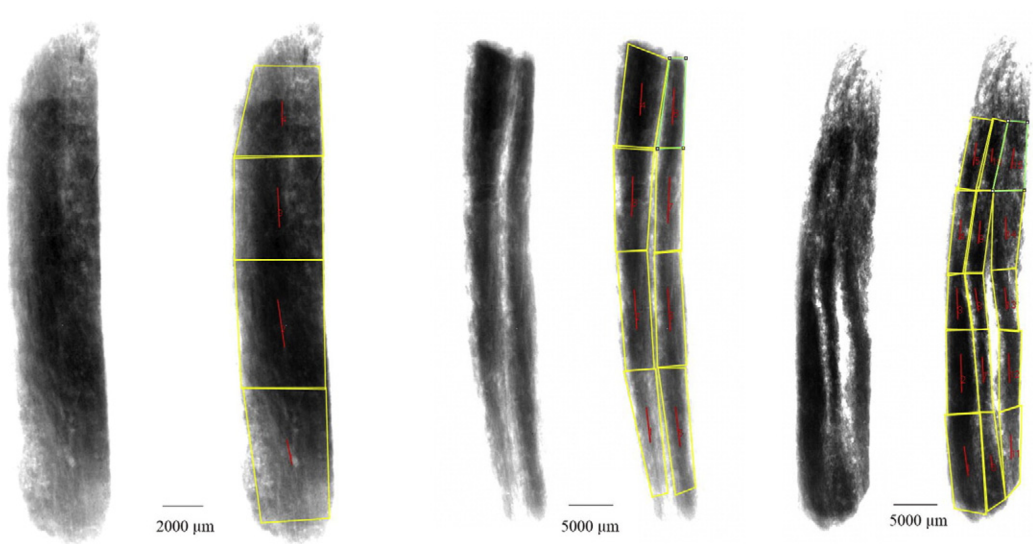

Fig. 11. Edge-on radiographic images of A) homogenous (left); B) dual-fold (middle), C) tri-fold (right) slab-built vessels with FibrilTool data.

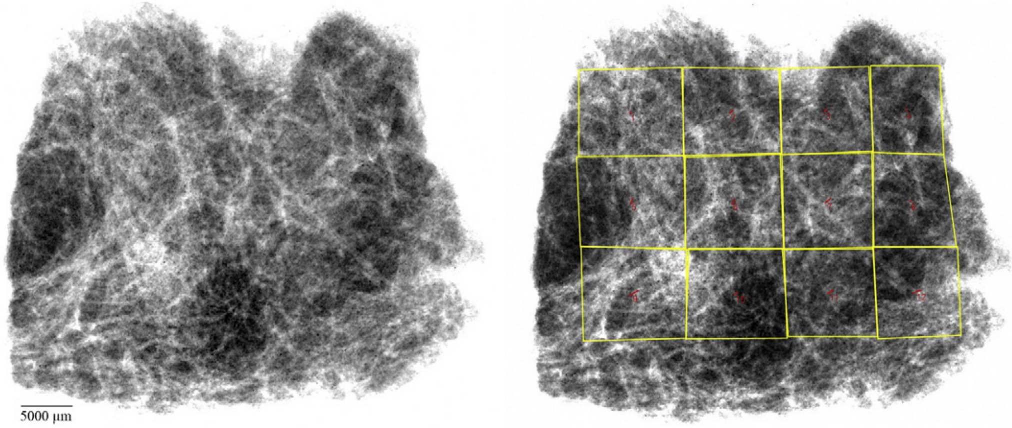

Fig. 12. Face-on radiographic image of mold-built vessel with FibrilTool data.

4.1. Results from experimental vessels

Radiographic data from modern samples were highly patterned based on method of formation. A first attempt at describing and defining the material signatures of particular techniques is offered below.

Coiling – Coil-built vessels displayed clear structural signatures and could be distinguished from non-coil built vessels in a number of ways. First, "face-on" images of rim and body fragments reveal individual coils characterized as regions of numerous voids running parallel to the rim and separated by areas with fewer voids (Fig. 8a–b). Directionality is partially dependent on where measurements are taken. At the core of a coil orientation varies 18° from parallel with a standard deviation of 9.54, while orientation varies more than 30° from parallel with a standard deviation of 14.2 at the coil's edge (Fig. 8b). Not surprisingly, void directionality is more consistent closer to the core of the coil as these areas have anisotropic scores of 0.13–0.26, while edges consistently score below 0.12. Three-dimensional models show that fibers are unevenly distributed within sherds with clumping occurring near the core of the coils and fewer fibers closer to the edges (Fig. 8c).

Coil-built basal fragments were also relatively simple to define when viewing images face-on. Within these images, the directionality of aplastics and voids rotates around a central point, progressively moving outward to the edge of the vessel base (Fig. 8d).

The remnants of coils are also visible in "edge-on" images (Fig. 9a–d). Again, using the FibrilTool, directionality wraps around the core of the coil in an oval that is elongated perpendicular to the rim (Fig. 9a). Merge points between coils are clearly visible and it was often possible to recognize different micro-methods of formation, including U and N coil joining techniques (as per Lindahl and Pikirayi, 2010). N-techniques resulted in join lines running diagonal to the rim (Fig. 9b). U-techniques resulted in less visible internal structures, but generally consisted of arcing join lines (Fig. 9c).

Slab-built: The three methods used to construct slab-built vessels - homogenous, dual-fold, and tri-fold techniques - all resulted in clear radiographic signatures. A common element tying the three slab-built techniques together is a lack of unidirectional orientation in elements when looking at the vessel face-on (Fig. 10). Overall orientation varies widely between perpendicular and parallel to the rim and anisotropic values rarely surpassing 0.05.

To distinguish between the different slab-built micro-techniques, it was necessary to view the samples edge-on as this revealed the presence and character of disjunctures and layers within the samples

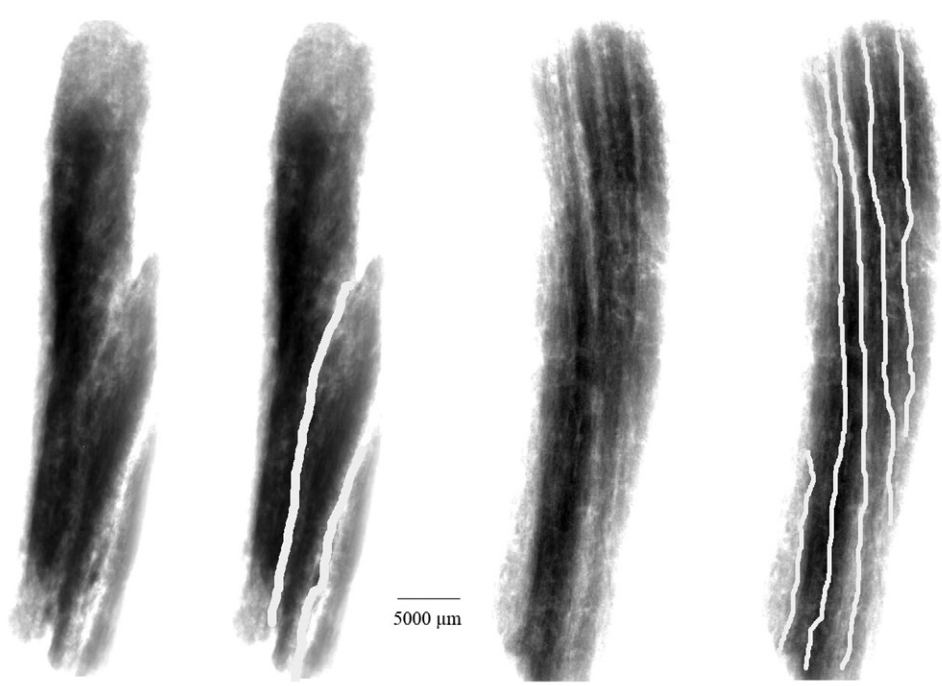

Fig. 13. Edge-on radiographic images of A) sequential (left); B) layered (right) mold-built vessels.

Table 3
Vessel part arranged by formation technique.

			Vessel part				
		N	Rim (%)	Body/rim (%)	Body (%)	Body/base (%)	Base (%)
Coil		36	13.9	67.7	8.3	2.8	8.3
Slab	Homogenous	108	5.5	25	62.9	1.8	4.6
	Dual-fold	90	7.8	23.3	65.5	1.1	2.2
	Tri-fold	17	0	23.5	76.5	0	0
Mold	All	65	7.7	20	61.5	6.1	4.6

(Fig. 11a–c). While homogenous samples lacked layering, dual and tri-fold samples had points at which the clay fabric had not merged when folded over (Fig. 11b–c). The result were clear layers of low attenuation running vertically through the vessel. Dual-fold vessels had one disjuncture separating two layers of clay fabric, while tri-fold had two divisions between the three layers of clay. Within these layers, the orientation of internal features was strongly oriented perpendicular to the vessel rim (<6° from 90) with anisotropic values ranging from 0.29 to 0.5. Often, particularly within three-dimensional models, the orientation of internal features turned 180° when reaching the rim and vertical disjunctures were no longer visible; clear signs of folding the clay slab at the rim edge. Homogenous slab-built vessels had a similar orientational profile as the other slab-built methods in that internal structures were largely perpendicular to the rim with anisotropic values ranging from 0.12 to 0.24 (Fig. 11a).

Mold-built: Mold-built vessels, much like slab-built, had multi-directional structural orientations with very low anisotropic values (<0.05) when viewed face-on (Fig. 12). Discerning mold-built from slab-built vessels required edge-on imaging that reveals the presence of thin vertical layers within mold-built samples (Fig. 13a–b). The numbers of layers varied widely between three and ten, most of which were <1500 μm in thickness. As described previously, slab-building can also result in multiple vertical layers and can therefore be confused with mold-built vessels. The discerning factors between mold and slab-built vessels are that mold-building typically results in more layers (>3) and that these layers often do not continue throughout the length of the sherd. Specifically, within mold-built vessels, vertical layers typically have points of origination and termination within the sample profile while layers generally only terminate at the vessel rim and base in slab-built samples.

Differentiating between micro-techniques of mold-building relied heavily on how vertical layers joined one another at points of termination and origination. Within sequential mold-built samples (vessels formed by adding additional clay fabric to the leading edge of the form), clay layers lie at an angle to one another and typically terminate relatively abruptly (Fig. 13a).

Layered mold-built samples (vessels formed by placing clay and temper at the mold base and pulling it toward the edge multiple times) lacked distinctive join lines and are instead characterized by having numerous thin layers that intermittently terminate and originate throughout the sherd (Fig. 13b). The result is a continuous pinching-out of individual layers, but no point at which an overall disjuncture took place.

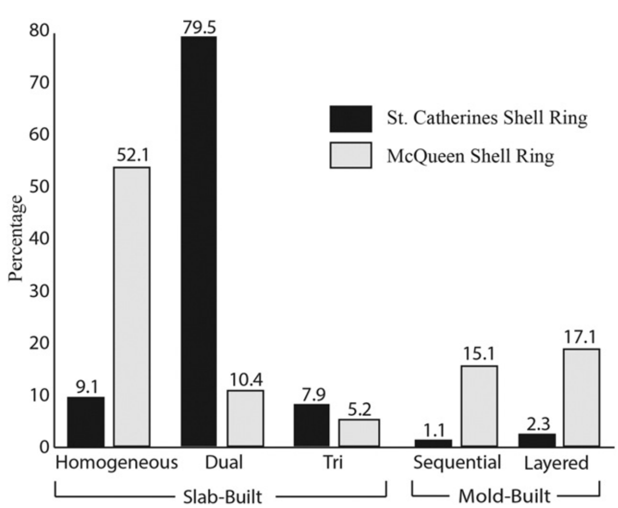

Fig. 14. Distribution of formation techniques.

4.2. Results from archaeological samples

The structural fingerprints unique to each formation technique allowed the classification of archaeological materials and revealed a number of distinct patterns. The first pattern was the relation between vessel part (base, body, rim, or combination) and formation technique as fewer than 10% of coil-built sherds were body fragments (Table 3). This can be contrasted with every other formation technique in which body fragments dominate. Instead, coil-built sherds were largely rim or rim/body fragments (81.6%) as well as relatively large proportion of base and base/body fragments (11.1%). This pattern could be caused by the morphology of coil-built pots as they could be smaller, which would result in an increased number of fragments made up of multiple vessel parts, or they could be open platters rather than deep bowls, which would result in a larger ratio of rim fragments to body fragments. It is also possible that coil-building was not a method of constructing whole vessels, but rather a manner of finishing and, to lesser degree, starting vessel construction. In any regard, coil-building is surprisingly common at both rings considering that Late Archaic pottery is typically thought to include few, if any coil-built vessels. There is no clear patterning of N or U coil-joining as these techniques are found in relatively equal numbers across the various vessel parts.

Ignoring coil-building for the time being, the spatial distribution of the other potting techniques reveals two interesting patterns. First, there is far less diversity in formation techniques at the St. Catherines Shell Ring than at McQueen (Fig. 14). Again, ignoring coil-built fragments, the vast majority (79%) of sherds from the St. Catherines Shell Ring were built using a dual-fold slab-building technique. Other slab-building methods are represented within the St. Catherines Shell Ring assemblage, but they are rare (<10%). Other techniques, including mold-building, are represented by only a few vessels. In contrast, the samples from McQueen Shell Ring reflect a larger array of techniques and a more equitable distribution among techniques. While slightly more than half of the sherds from McQueen Shell Ring were made using a homogenous slab-building technique, other methods, including mold-building, are well represented.

Second, despite being contemporaneous and less than an hour's walk from one another, the techniques used at each ring not only differ in terms of diversity but also pattern in near opposite fashions (Fig. 14). The most common method at the St. Catherines Shell Ring, dual-fold slab-building, is relatively rare at McQueen. Likewise, while homogenous slab-building is quite common at McQueen, it was rarely found at the St. Catherines Shell Ring. Even more striking is the near absence of any mold-building technique at the St. Catherines Shell Ring; a family of techniques that make up more than a third of the vessels at McQueen Shell Ring.

Importantly, the particular constellation of techniques found at each ring remains the same throughout their use-lives. Sherds were sampled from different stratigraphic contexts at each ring, many of which were directly dated and span the use-histories of each site, and the overall proportion of different forming techniques changed little or not at all.

5.1. Discussion

The results of radiographic imaging and associated analyses reveal that formation techniques are distributed in non-random fashions between the rings. Further research is required to determine if formational techniques impact the functionality of vessels as this could explain their spatial patterning. For example, perhaps mold-building results in a vessel with greater resistance to thermal stress and therefore would be used to create cooking (rather than storage or serving) vessels at a higher rate.

In the absence of a functional difference, it is possible that the differences in vessel formation techniques instead reflect the presence of particular potting communities at each ring. The variations in techniques found at each ring might appear quite minor, but prior research has shown that the method of forming vessels is typically one of the first techniques learned by novice potters and is based on mimicking the actions of one's teacher (e.g. Gosselain, 1998). Once mastered, forming vessels often becomes rote and invariant even as potters experiment with vessel form, embellishments, and other characteristics. As such, even minor differences in archaeological assemblages may signal the presence of distinct potting communities, each with its own traditions and practices.

While formation techniques have a strong spatial pattern between the two rings, there are a few "non-local" pots at each. These vessels likely reflect some level of interaction, trade, exchange, or adoption of potting techniques between the two rings and demonstrate that a level of communication spanned the two sites. Perhaps the shared use of coiling as a "finishing" technique is further evidence of cross-ring interaction.

Further research is needed to relate the findings from St. Catherines Island to the larger region, but it appears likely that the divergences between the two rings reflects the presence of St. Simons and Stallings peoples co-residing on the island. Referring back to the few decorated sherds at each ring, the boldly punctated vessels found at the St. Catherines Shell Ring suggests it was occupied by Stallings peoples; the original inhabitants of the Georgia coast who eventually moved from the coast into interior river valleys around 4200–3900 cal B.P. The assemblage from the McQueen Shell Ring, in contrast, included a number of sherds decorated with embellishments (e.g. incising, grooving) more often associated with the newly emergent St. Simons "culture" thought to dislocate Stallings peoples from the coast. Importantly, the distinct decorative pieces linking the assemblages from each ring to the larger St. Simons and Stallings traditions were invariably made using the techniques "local" to that ring. In other words, incised vessels were made using mold-building or homogenous slab-building (the most common methods at McQueen Shell Ring) while broad punctations were most often found on dual-fold slab-built vessels, particularly at the St. Catherines Shell Ring. This may be further evidence that the two rings were occupied by distinct communities and that these communities can, in part, be related to the presence of larger, sub-regional traditions found in the surrounding environs.

Finally, it important to note that the rings were likely not simple villages but may have also been points of gathering in which a broader community of peoples came together on occasion. Perhaps the diversity of potting techniques found at the rings reflects the diversity of peoples gathering at each, with the St. Catherines Shell Ring a place at which more local or more homogenous communities came together while McQueen may have been a locale for more far-flung or heterogeneous populations. Different levels of diversity in potting is not limited to formation techniques, but is also found more broadly in the methods by which St. Simons and Stallings wares are typically decorated. While Stallings wares are largely plain or decorated with simple lines of punctates, St. Simons are decorated with a wide array of incisions, grooves, punctates, and multiple types of embellishments on a single vessel. In this regard, diversity of techniques appears to be a hallmark of St. Simons wares and perhaps peoples. As such, it is possible that the diversity of formation techniques found at McQueen Shell Ring reflects how the St. Simons communities were quite varied, particularly in comparison with the less variable Stallings tradition. Further studies, including sourcing of clays used to make vessels, could address the possibility that the diversity in vessels found at each ring was the product of more or less diverse or spatially distributed communities gathering at each.

Whatever caused the divergences in potting traditions between the two rings, it is notable that this divide was maintained for a hundred years or more. Despite being largely contemporaneous and less than an hour's walk from one another, the potting assemblages from each ring did not become more similar over time.

6.1. Conclusion

Capitalizing on technological advancements in imaging and software, this paper has demonstrated the potential of using radiography to study "micro-techniques" in pottery production. By employing vessels constructed using known methods, unique structural fingerprints for each technique were defined and applied to pottery assemblages drawn from two Late Archaic shell rings located in the American Southeast. The Late Archaic is a period of larger-scale communal formation in the region and the pottery from the St. Catherines Island shell rings may reflect this process. Dissimilar formational techniques were found at the rings, and while the causes of these differences are unknown, they may reflect the presence of different social groups. Whatever the cause(s) of their divergence, this study highlights the feasibility of using radiographic imaging and associated analyses for determining the use of particular potting techniques. Because the study sample included pottery tempered with fibers, which result in radiographically visible voids, the broader application of techniques provided in this paper require testing as most assemblages are made up of pottery tempered with less visible materials.

Despite the need for further testing, this paper demonstrates that advancements made in radiography and imaging software deserve attention from archaeologists as they show promise in providing novel research avenues into how practices, knowledge, and technologies were disseminated in the past. This information can inform archaeological understandings of how past peoples organized themselves into social groups, the level to which these groups had more or less porous boundaries, and how these parameters changed or remained static through time.

Acknowledgements

This research was made possible by the staff of the American Museum of Natural History, particularly David Hurst Thomas and Lorann Pendleton who provided access, guidance, and support. James Thostenson, and Morgan Hill provided technical expertise and Galen Boone, Hannah Cain, Emma Gilheany, Emilio Santiago, and Elizabeth Halderson helped construct the experimental vessels. Analyses were assisted by Rosa Loveszy and facilitated by Anna Semon and Matthew Napolitano. Severin Fowles, Terry D'Altroy, Zoe Crossland, and Victor Thompson provided invaluable critique and helped shape the present paper. Comments by reviewers also provided valuable insights and helped inform the final product. As the author of this paper, I am responsible for its contents, errors, and any unintentional misinterpretations.

References

Abraham, E., Bessou, M., Ziéglé, A., Hervé, M.-C., Szentmiklósi, L., Kasztovszky, Z.S., Kis, Z., Menu, M., 2014. Terahertz, X-ray and neutron computed tomography of an eighteenth dynasty Egyptian sealed pottery. Appl. Phys. Mater. Sci. Process. 117, 963–972.

Anderson, D.G., 1996. Models of Paleoindian and Early Archaic settlement in the lower southeast. In: Anderson, D.G., Sassaman, K.E. (Eds.), The Paleoindian and Early Archaic Southeast. University of Alabama Press, Tuscaloosa, pp. 28–47.

Anderson, D.G., Sassaman, K.E., 2012. Recent Developments in Southeastern Archaeology: From Colonization to Complexity. Society for American Archaeology Press, Washington D.C.

Anderson, D.G., Russo, M., Sassaman, K.E., 2007. Mid-holocene cultural dynamics in southeastern north America. In: Anderson, D.G., Maasch, K.A., Sandweiss, D.H. (Eds.), Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions. Academic Press, London, pp. 457–489.

Beck, M.E., Skibo, J.M., Hally, D.J., Yang, P., 2002. Sample selection for ceramic use-alteration analysis: the effects of abrasion on soot. J. Archaeol. Sci. 29, 1–15.

Berg, I., 2008. Looking through pots: recent advances in ceramics X-radiography. J. Archaeol. Sci. 35, 1177–1188.

Bettuzzi, M., Casali, F., Morigi, M.P., Brancaccio, R., Carson, D., Chiari, G., Maish, J., 2015. Computed tomography of a medium size Roman bronze statue of Cupid. Appl. Phys. A Mater. Sci. Process. 118, 1161–1169.

Boudaoud, A., Burian, A., Borowska-Wykręt, D., Uyttewaal, M., Wrzalik, R., Kwiatkowska, D., Hamant, O., 2014. FibrilTool, an ImageJ plug-in to quantify fibrillar structures in raw microscopy images. Nat. Protoc. 9, 457–463.

Braun, D.P., 1982. Radiographic analysis of temper in ceramic vessels: goals and initial methods. J. F. Archaeol. 9, 183–192.

Bugani, S., Modugno, F., Łucejko, J.J., Giachi, G., Cagno, S., Cloetens, P., Janssens, K., Morselli, L., 2009. Study on the impregnation of archaeological waterlogged wood with consolidation treatments using synchrotron radiation microtomography. Anal. Bioanal. Chem. 395, 1977–1985.

Calmes, A., 1967. Test excavations at two Late Archaic Shell-Ring Mounds on Hilton Head Island, Beaufort County, South Carolina. Pap. Present. 24th Annu. Southeast. Archaeol. Conf. Macon, Georg.

Carmichael, P., 1986. Nasca pottery construction. Nawpa Pacha J. Andean Archaeol. 24, 31–48.

Carr, C., 1990. Advances in ceramic radiography and analysis: applications and potentials. J. Archaeol. Sci. 17, 13.

Colaninno, C., 2010. Zooarchaeological Analysis of Vertebrate Remains from Five Late Archaic Shell Rings on the Georgia Coast, USA Ph.D. dissertation Department of Anthropology, University of Georgia, Athens.

Colaninno, C., 2012a. Evaluating formational models for late archaic shell rings of the southeastern United States using vertebrate fauna from the St. Catherines shell ring, St. Catherines Island, Georgia. J. Isl. Coast. Archaeol. 7, 338–362.

Colaninno, C., 2012b. Evaluating 18O profiles of hardhead catfish and atlantic croaker otoliths as a method of determining seasonal use of fishes. In: Reitz, E.J., Quitmyer, I.R., Thomas, D.H. (Eds.), Seasonality and Human Mobility along the Georgia Bight. American Museum of Natural History Anthropological Papers Number 97, New York, pp. 83–102.

Cordell, A., 2004. Paste variability and possible manufacturing origins of Late Archaic fiber-tempered pottery from selected sites in Peninsular Florida. In: Saunders, R., Hays, C. (Eds.), Early Pottery, Technology, Function, Style, and Interaction in the Lower Southeast. University of Alabama Press, Tuscaloosa, pp. 63–104.

DePratter, C.B., 1976. Shellmound Archaic on the Georgia Coast South Carolina Antiq 11 pp. 1–69.

DePratter, C.B., 1979. Ceramics. In: Thomas, D.H., Larson, C.S. (Eds.), The Anthropology of St. Catherines Island 2: The Refuge–Deptford Mortuary Complex. American Museum of Natural History Anthropological Papers Number 56, New York, pp. 109–132.

Ellingson, W.A., Vandiver, P.B., Robinson, T.K., Lobick, J.J., 1988. Radiographic imaging technologies for archaeological ceramics. In: Sayre, E.V., Vandiver, P., Cruzik, J., Stevenson, C. (Eds.), Materials Issues in Art and ArchaeologyMaterials Research Society Symposium Proceedings 123. Materials Research Society, Pittsburgh, PA, pp. 25–32.

Endonino, J.C., 2013. Examining orange period vessel forming methods through experiment and radiography: implications for chronology, technology, and function. Florida Anthropol. 66, 5–22.

Foster, G. V., 1983. Xeroradiography: non-invasive examination of ceramic artifacts, in: England, P.A., Zelst, L. van (Eds.), Application of Science in Examination of Works of Art. Museum of Fine Arts, Boston, pp. 213–216.

Gibson, A.M., Woods, A.J., 1990. Prehistoric Pottery for the Archaeologist. Leicester University Press, Leicester.

Gilmore, Z., 2016. Gathering at Silver Glen: Community and History in Late Archaic Florida. University Press of Florida, Gainesville.

Glanzman, W.D., 1983. Xeroradiographic Examination of Pottery Manufacturing Techniques: A Test Case from the Baq'ah Valley, Jordan. MASCA (2163–169).

Glanzman, W.D., Fleming, S.J., 1986. Pottery: fabrication methods. In: McCovern, P.E. (Ed.), The Late Bronze and Early Iron Ages of Central Transjordan: The Baq'ah Valley Project, 1977–1981. University Museum, Philadelphia, pp. 164–177.

Gosselain, O.P., 1992. Technology and style: potters and pottery among Bafia of Cameroon. Man 27, 559–586.

Gosselain, O.P., 1998. Social and technical identity in a clay crystal ball. In: Stark, M.T. (Ed.), The Archaeology of Social Boundaries. Smithsonian Institution Press, Washington D.C., pp. 78–106.

Gosselain, O.P., 2000. Materializing identities: an African perspective. J. Archaeol. Method Theory 7, 187–217.

Gosselain, O.P., 2011. Fine if I do, fine if I don't: dynamics of technical knowledge in Sub-Saharan Africa. In: Roberts, B.W., Linden, M.V. (Eds.), Investigating Archaeological Cultures. Springer, New York, pp. 211–227.

Griffin, J.B., 1943. An analysis and interpretation of the ceramic remains from two sites near Beaufort, South Carolina. Bur. Am. Ethnol. Bull. 133, 8.

Herman, G.T., 2009. Fundamentals of Computerized Tomography: Image Reconstruction from Projection. Springer Science & Business Media, New York.

Kahl, W.-A., Ramminger, B., 2012. Non-destructive fabric analysis of prehistoric pottery using high-resolution X-ray microtomography: a pilot study on the late Mesolithic to Neolithic site Hamburg-Boberg. J. Archaeol. Sci. 39, 2206–2219. http://dx.doi.org/10.1016/j.jas.2012.02.029.

Kennett, D.J., Culleton, B.J., 2012. A Bayesian chronological framework for determining site seasonality and contemporaneity. In: Reitz, E.J., Quitmeyer, I.R., Thomas, D.H. (Eds.), Seasonality and Human Mobility along the Georgia Bight. American Museum of Natural History Anthropological Papers, Number 97, New York, pp. 37–50.

Krause, M., Hausherr, J.M., Burgeth, B., Herrmann, C., Krenkel, W., 2010. Determination of the fibre orientation in composites using the structure tensor and local X-ray transform. J. Mater. Sci. 45, 888–896.

Lang, J., Middleton, A., 2005. Radiography of Cultural Material. Butterworth-Heinemann, New York.

Lang, J., Middleton, A., Ambers, J., Higgins, T., 2005. Radiographic images. In: Lang, J., Middleton, A. (Eds.), Radiography of Cultural Material. Elseiver, London.

Leroi-Gourhan, A., 1993. Gesture and Speech. The MIT Press, Cambridge, MA.

Lindahl, A., Pikirayi, I., 2010. Ceramics and change: an overview of pottery production techniques in northern South Africa and eastern Zimbabwe during the first and second millennium AD. Archaeol. Anthropol. Sci. 2, 133–149.

Minar, C.J., 2001. Motor skills and the learning process: the conservation of cordage final twist direction in communities of practice. J. Anthropol. Res. 57, 381–405.

O'Connor, S., Maher, J., 2001. The digitisation of X-radiographs for dissemination, archiving and improved image interpretation. Conservation 25, 3–15.

O'Connor, S., Maher, J., Janaway, R., 2002. Towards a replacement for xeroradiography. Conservation 26, 100–114.

Ogden, Q., 2011. The Late Archaic Lithics of the St. Catherines and McQueen Shell Rings on St. Catherines Island, Georgia MA Thesis Department of Anthropology. City University of New York, Hunter.

Plog, S., 1980. Stylistic Variation in Prehistoric Ceramics: Design Analysis in the American Southwest. Cambridge University Press, Cambridge.

Rice, P.M., 1987. Pottery Analysis: A Sourcebook. University of Chicago, Chicago.

Rice, P.M., 1999. On the origins of pottery. J. Archaeol. Method Theory 6, 1–54.

Russo, M., 1998. Measuring sedentism with fauna: archaic cultures along the southwest Florida coast. In: Rocek, T.R., Bar-Yosef, O. (Eds.), Seasonality and Sedentism: Archaeological Perspectives from Old and New World Sites. Peabody Museum, Cambridge, MA, pp. 143–164.

Russo, M., Heide, G., 2003. Mapping the Sewee shell ring. Report Submitted to the Francis Marion and Sumter National Forests, South Carolina. Copies available from Southeastern Archaeological Center, National Park Service, Tallahassee, Tallahassee.

Rye, O.S., 1977. Pottery manufacturing techniques: X-ray studies. Archaeometry 19, 205–211. http://dx.doi.org/10.1111/j.1475–4754.1977.tb00200.x.

Rye, O.S., 1981. Pottery Technology. Taraxacum, Washington D.C.

Sanger, M.C., 2015a. Life in the Round: Archaeological Investigations of Two Late Archaic Shell Rings on St. Catherines Island, Georgia Ph.D dissertation Department of Anthropology, Columbia University, New York.

Sanger, M.C., 2015b. Determining depositional events within shell deposits using computer vision and photogrammetry. J. Archaeol. Sci. 53, 482–491.

Sanger, M.C., 2016. Coils, slabs and molds: investigating communal affiliation between late archaic shell ring communities on St. Catherines Island, Georgia using radiographic imagery of pottery. Southeast. Archaeol. In press.

Sanger, M.C., Thomas, D.H., 2010. The two rings of St. Catherines Island: some preliminary results from the St. Catherines and McQueen shell rings. In: Thomas, D.H., Sanger, M.C. (Eds.), Trend, Tradition, and Turmoil: What Happened to the Southeastern Archaic? American Museum of Natural History Anthropological Papers Number 93, New York, pp. 45–70.

Sanger, M.C., Thostenson, J., Hill, M., Cain, H., 2013. Fibrous twists and turns: early ceramic technology revealed through computed tomography. Appl. Phys. A Mater. Sci. Process. 111, 829–839.

Sassaman, K.E., 1993. Early Pottery in the Southeast: Tradition and Innovation in Cooking Technology. University of Alabama Press, Tuscaloosa, Alabama.

Sassaman, K.E., 2004. Common origins and divergent histories in the early pottery traditions of the American southeast. In: Saunders, R., Hays, C. (Eds.), Early Pottery, Technology, Function, Style, and Interaction in the Lower Southeast. The University of Alabama Press, Tuscaloosa, pp. 23–39.

Sassaman, K.E., 2010. The Eastern Archaic: Historicized. AltaMira Press, Lanham, Maryland.

Sassaman, K.E., Randall, A.R., 2007. The cultural history of Bannerstones in the Savannah River Valley. Southeast. Archaeol. 26, 196–211.

Sassaman, K.E., Hanson, G.T., Charles, T., 1988. Raw material procurement and the reduction of hunter-gatherer range in the Savannah River Valley. Southeast. Archaeol. 7, 79–94.

Sassaman, K.E., Blessing, M.E., Randall, A.R., 2006. Stallings Island revisited: new evidence for occupational history, community pattern, and subsistence technology. Am. Antiq. 71, 539–565.

Saunders, R., 2002. The Fig Island Ring Complex (38CH42): Coastal Adaptation and the Question of Ring Function in the Late Archaic Submitted to the South Carolina Department of Archives and History, Columbia.

Saunders, R., 2004a. Spatial variation in orange culture pottery: interaction and functions. In: Saunders, R., Hays, C. (Eds.), Early Pottery, Technology, Function, Style, and Interaction in the Lower Southeast. University of Alabama Press, Tuscaloosa, pp. 40–62.

Saunders, R., 2004b. The stratigraphic sequence at Rollins shell ring: implications for ring function. Florida Anthropol. 57, 249–268.

Saunders, R., Hays, C., 2004. Themes in early pottery research. In: Saunders, R., Hays, C. (Eds.), Early Pottery, Technology, Function, Style, and Interaction in the Lower Southeast. University of Alabama Press, Tuscaloosa, pp. 1–22.

Simpkins, D.L., Allard, D.J., 1986. Isolation and identification of Spanish moss fiber from a sample of Stallings and Orange series ceramics. Am. Antiq. 51, 102–117.

Thér, R., 2015. Identification of pottery-forming techniques using quantitative analysis of the orientation of inclusions and voids in thin sections. Archaeometry 58, 222–238.
Thompson, V.D., 2006. Questioning Complexity: The Prehistoric Hunter-Gatherers of Sapelo Island, Georgia PhD. dissertation Department of Anthropology, University of Georgia, Athens.
Thompson, V.D., 2007. Articulating activity areas and formation processes at the Sapelo Island shell ring complex. Southeast. Archaeol. 26, 91–107.
Thompson, V.D., Andrus, F., 2011. Evaluating mobility, monumentality, and feasting at the Sapelo Island shell ring complex. Am. Antiq. 76, 315–344.
Trinkley, M.B., 1980. Investigation of the Woodland Period Along the South Carolina Coast. Unpublished PhD. dissertation, Department of Anthropology, University of North Carolina, Chapel Hill, Chapel Hill.
Trinkley, M.B., 1983. Ceramics of the Central South Carolina Coast South Carolina Antiq. 15 pp. 43–54.
Trinkley, M.B., 1986. Indian and freedmen occupation at the Fish Haul Site (38BU805), Beaufort County, South Carolina. Chicora Foundation Research Series 7, Columbia, South Carolina.
Vandiver, P.B., 1987. Sequential slab construction: a conservative southwest asiatic ceramic tradition, ca. 7000–3000 BCE. Paléorient 13, 9–35.
Vandiver, P.B., 1988. Reconstructing and interpreting the technologies of ancient ceramics. In: Sayre, E.V., Vandiver, P., Cruzik, J., Stevenson, C. (Eds.), Materials Issues in Art and Archaeology. Materials Research Society Symposium Proceedings, 123, Pittsburgh, pp. 89–102.
Vandiver, P.B., Tumosa, C.S., 1995. Xeroradiographic imaging. Am. J. Archaeol. 99, 121–124.
Vandiver, P.B., Ellingson, W.A., Robinson, T., Lobick, J.J., Séguin, F.H., 1991. New applications of X-radiographic imaging technologies for archaeological ceramics. Archeomaterials 5, 185–207.
Waggoner, J.C., 2009. Fiber-tempered pottery, soapstone vessels, and shifting alliances in the interior coastal plain of the late archaic southeast. Southeast. Archaeol. 28, 137–147.
Waring Jr., A.J., 1968. The Bilbo Site: Chatham County, Georgia, the Waring Papers: The Collected Works of Antonio J. Waring Jr. Papers of the Peabody Museum of Archaeology and Ethnology, Cambridge, MA.