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Production origins and matrix constituents of spiculate pottery in Florida, USA: Defining ubiquitous St Johns ware by LA-ICP-MS and XRD

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ABSTRACT

Fine-grained "chalky" pottery containing microscopic sponge spicules is commonly recovered from archaeological sites throughout peninsular Florida, but many questions remain about its composition and origins. It is identified by different names, but most are associated with the St. Johns Type series. While it has been commonly assumed to originate in the St. Johns River drainage for which it is named, the prevalence of pottery with these characteristics in other locations has presented the likelihood of independent production in multiple places. In this study, we conducted LA-ICP-MS and XRD analysis of spiculate pottery from three Woodland period (ca. 1000 BCE to 1000 CE) sites, along with comparative clay samples, in order to characterize the raw materials and determine the geographic scope of production. Our results support the theory that this ware was independently produced across peninsular Florida. We further evaluate the hypothesis that this pottery was made with common wetland muck, through consideration of the material properties of muck constituents. This project emphasizes the importance of an ecosystem framework for understanding the long history of spiculate pottery production and its geographic spread within Florida.

1. Introduction

Prior to European colonization, nearly 60% (20.3 million acres) of Florida was covered by wetland environments. As of 1996 it was 28%, still a larger percentage of wetlands than any of the other lower 48 states (Dahl, 2005). Suffice it to say, the Florida landscape is abundantly and pervasively wet. This is due in large part to the flat topography and sedimentary geologic formations that promote the development of rivers, lakes, sinkholes, and particularly, wide shallow wetlands.

Within this landscape the past people of Florida hunted, fished, trapped, and gathered a wide variety of resources. Marginal today, these marshy places were critical to the subsistence of native groups from the first occupation in the region. Evidence may be found in the zooarchaeological record, documenting the use of both year-round (e.g., Emydidae, *Lepisosteus* sp.) and seasonal (e.g., *Branta canadensis*) wetland animal species (e.g., Cumbaa and Fairbanks, 1972; Wing and McKean, 1987).

It is within this ecological context that we must consider the development of spiculate pottery, which contains the body parts of freshwater sponges, filtering animals that grow on river beds and other hard parts of fresh water bodies. Sensitive to turbidity, freshwater sponges thrive in slow shallow wetlands (Schwandes and Collins, 1994). Spicules, strong, acicular shaped elements composed predominantly of amorphous silica, form the sponge endoskeleton. In Florida, spicules found in archaeological pottery range up to 250 μm in length and 30 μm in diameter (Cordell, 2007). Pottery containing abundant spicules is found across peninsular Florida from the Archaic period onwards. The paste of these wares makes them readily identifiable visually and by touch. Though the spicules are only visible under magnification, the body is generally soft and lightweight, with dark firing cores and a "chalky" feel.

1.1. Research problem

While broadly identified as St. Johns ware after the St. Johns River of northeast Florida, the distribution of chalky-paste, spiculate pottery is far wider than either the geographic boundaries of the St. Johns River, or the St. Johns culture area. Vessels produced with the same paste characteristics were made by a range of peoples, from those of the late Archaic Orange culture to contact era Timucuans (Deagan and Thomas, 2009; Hays and Weinstein, 2004; Sassaman, 2003; Wallis et al., 2014). Despite the apparent homogeneity of the raw materials used to produce it, the geographic and temporal extent of this pottery,

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coupled with stylistic variability, belies a single origin. We investigate the theory that spiculate pottery shares significant material attributes, not because of production within a narrow geographic region, but because of the shared exploitation of a widely available resource. We demonstrate through elemental and mineralogical analysis that variation in paste composition indicates multiple geographic origins. We argue that the constituents of muck, a raw material shared across wetland environments in peninsular Florida, together produce pottery with these characteristics. While first proposed in 1935 (Stirling, 1935; see also Cordell, 1992; Espenshade, 1983; Lollis et al., 2015) the use of muck as the raw material for this ware has not been conclusively demonstrated. Instead, the presence of spicules has been given prime consideration, divorced from the ecological context in which sponge endoskeletons naturally occur. While spicules formed a critical constituent of the ceramic body, the organic and mineral constituents of muck were equally necessary for successful production of this pottery.

2. Background

2.1. History

The Florida pottery that we now know to be spiculate was first described by Wyman (1875), later called Chalky ware by W. H. Holmes (1894) and others. Matthew Stirling reported on the presence of “muck ware” in Florida (Stirling, 1935:382, 1936:352), but the name never gained wide usage. These wares were presumed to be free of inclusions until the mid-20th century, when the sponge spicules were first identified (Goggin, 1952:101).

The earliest pottery in Florida to contain spicules dates to the late Archaic period as early as ca. 4300 cal BP and is associated with the Orange culture along the northeast coast, within the St. Johns River drainage. This pottery was intentionally tempered with fiber, generally Spanish moss (*Tillandsia usneoides*) (Gilmore, 2015; Simpkins and Allard, 1986). Orange pottery is found with, but more commonly without, sponge spicules (Cordell, 2004). The ceramic sequence in northeast Florida shows a shift from fiber-tempered vessels to macroscopically temperless spiculate wares, occurring around 3600 BP, identified as the transition of the Archaic Orange culture into the St. Johns culture (Gilmore, 2016; Russo and Heide, 2002).

In 1945, James Griffin, describing the chalky, non-fiber-tempered ware along the St. Johns River, called it “St. John's Ware” (Griffin, 1945:220). Since then, the name St. Johns has become the dominant type name for this broad class of wares found in peninsular Florida (Bullen, 1968). Due to the eponymous association with the St. Johns River, these chalky-pasted wares recovered elsewhere are sometimes identified as trade goods from the St. Johns region (e.g., Crusoe, 1971; DePratter, 2009:35).

Table 1 presents a list of all named spiculate wares in Florida. The vessel forms, decorations, and surface treatments on spiculate pottery such as check-stamping and zoned incising are not unique to the material, appearing contemporaneously on vessels with other paste compositions. In South Florida, the Belle Glade Series also consists of spiculate wares. These differ from St. Johns in several respects, the most notable being that spicule size tends to be smaller (Cordell, 2007), suggesting perhaps different sponge species or growth in the southern climate.

2.2. Paste description

The texture and appearance of spiculate wares are distinctive from other pottery types recovered in Florida (Fig. 1). Quartz sand is naturally present in the majority of Florida clays, resulting in pottery with abundant sand inclusions. With the exception of Sandy St. Johns and Belle Glade, sand-sized particles are rare in spiculate pastes. Aplastics in clay bodies, such as sand or spicules, serve as “opening material” or temper, components that help a pot maintain shape and reduce shrinkage during drying and firing. They create a matrix to which clay minerals can bond. Fine and acicular-shaped aplastics are particularly good for this purpose (Rice, 2015:87). The siliceous composition and shape of sponge spicules makes them ideal for strengthening vessels at all stages (Natalio et al., 2015).

Table 1
Spiculate ware types in Florida.

Series	Type and surface treatment	Primary distribution
Orange[a]	Orange (Fiber Tempered)	East Florida
	Plain	
	Incised	
	Tick Island	East Florida
	Incised	
St. Johns	St. Johns	Peninsular Florida
	Plain	
	Check Stamped	
	Incised	
	Red-on-Buff	
	Simple Stamped	
	Dunns Creek Red	Peninsular Florida
	Oklawaha	East Florida
	Plain	
	Incised	
	Tomoka	East Florida
Papys Bayou	Papys Bayou	Central Gulf Coast
	Plain	
	Incised	
	Punctated	
	Red	
Little Manatee	Little Manatee	Central Gulf Coast
	Shell Stamped	
Safety Harbor	Sarasota	Central Gulf Coast
	Incised	
Belle Glade	Belle Glade	South Florida
	Incised	
	Red	

[a] Spiculate paste is sometimes present, but does not define this series.

Spicule concentration in this ware can be very high, comprising upwards of 50% of the body (Cordell, 2007). Spicules and spicule fragments tend to be oriented lengthwise, parallel to the vessel surface as a result of coil formation (Natalio et al., 2015). Previous scholars attributed the chalky texture of these wares to the sloughing of sponge spicules (Borremans and Shaak, 1986:128). However, the entire body of the fired sherd is poorly consolidated. With light rubbing or scraping, the paste particles separate from the body into a fine powder. In their replication experiments, Lollis et al. (2015:105) found that presence of spicules was not tied to chalky texture.

The sloughing is better described as weathering. In the firing process, chemically bound water is burned off and clay minerals bond and reform. The temperature at which this irreversible bonding (sintering) occurs varies according to the molecular structure of the clay. Certain clay minerals require high temperature to fully sinter (Gertjejansen et al., 1983). If that temperature is not reached, over time the clay minerals will undergo rehydroxylation, incorporating water back into the molecular structure (Hamilton and Hall, 2012). This form of chemical weathering causes separation of the paste constituents, which produces the characteristic texture over time.

The clarification of the chalky texture origin is critical because it highlights that whereas spicules have been treated as the defining feature of this pottery, the properties of other constituents are just as diagnostic. The entire “recipe” of this pottery—clay, aplastics, and organics—must be given equal attention. From this perspective, one can more readily appreciate similarities between Florida spiculate wares and other “chalky” wares such as Tchefuncte pottery from Louisiana (Gertjejansen et al., 1983).

Most spiculate pottery also retains a dark firing core, indicating a high organic content (Cordell, 2007; Cordell and Koski, 2003; Mitchem, 1986:70; Stirling, 1935:382). The retention of carbon within a fired

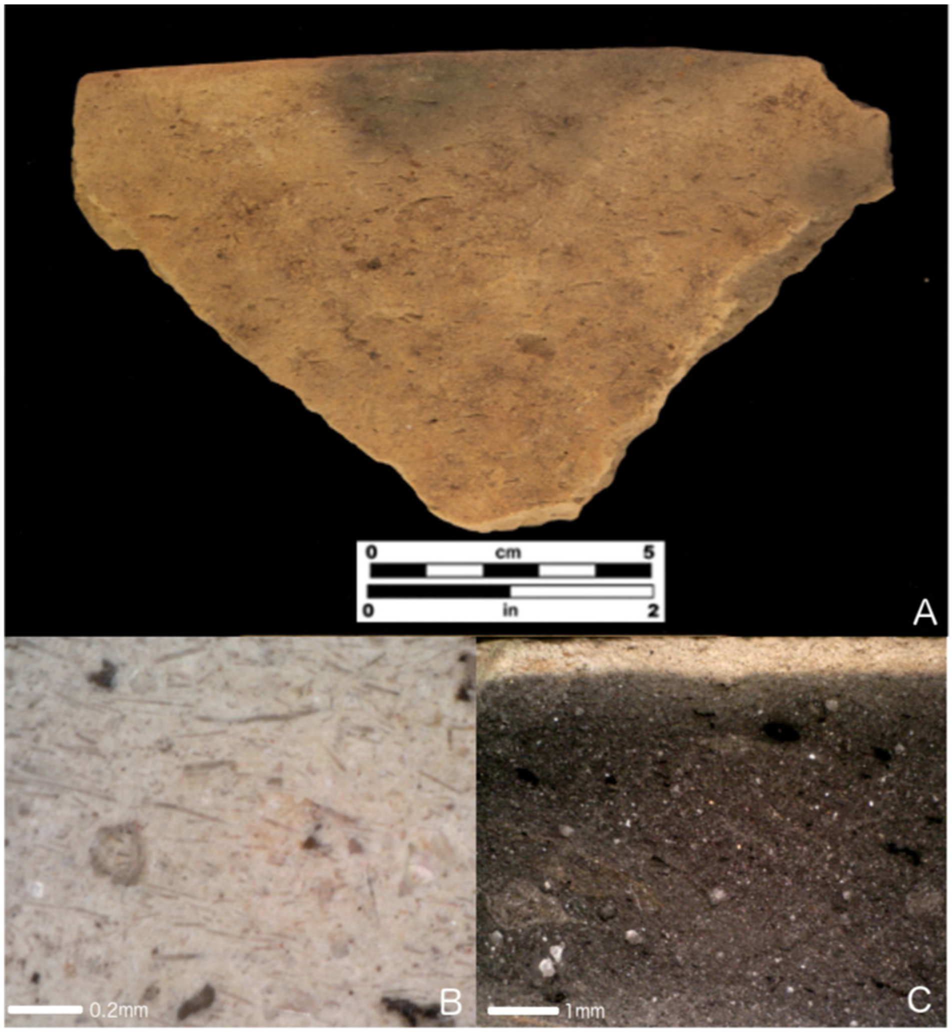

Fig. 1. Florida spiculate pottery; a) St. Johns Plain sherd; b) sherd surface at 200× magnification, showing spicules in dominant parallel orientation; c) cross-section at 50× magnification showing dark firing core and fine-grained texture.

vessel is related to a number of factors: presence of organic material, firing temperature, and the clay minerals present, since certain clays such as smectite bond more strongly to carbon (Rice, 2015:104). The organics in Florida spiculate wares are very fine, lacking characteristic voids expected from larger particles of plant material. Potters have long recognized that organic materials can serve as binders for clay bodies, improving the plasticity of wet clay and increasing the green strength of unfired pots (Rice, 2015:84). The development of carbon-rich colloidal gels through microbial activity in clay is desirable for plasticity, even in modern pottery manufacture (Rye, 1981:31).

2.3. Previous research

The questions surrounding the origins and spread of spiculate pottery have been investigated by a variety of researchers in Florida over the past century. For many years the Ceramic Technology Laboratory (CTL) at the Florida Museum of Natural History (FLMNH) has collected raw clay specimens from across Florida, with the goal of surveying the clayey resources that may have been available to past pottery makers (Cordell et al., 2017; Rice, 2015:253–255). Samples have been characterized by physical properties and analyzed via petrography, neutron activation analysis, and other methods, permitting the comparison between clay resources and archaeological pottery (e.g., Cordell, 1984; Gilmore, 2016; Wallis, 2011). To date, none of these nearly 300 samples has had the same mechanical and physical attributes of St. Johns or other spiculate pottery (Cordell and Koski, 2003; Lollis et al., 2015; Wallis et al., 2015). Some clay samples are high in spicules, but exhibit high shrinkage and become friable when fired. Most lack spicules, and nearly all clay samples found are much higher in larger aplastics than St. Johns.

Crusoe (1971) tested chalky-paste pottery recovered from Florida and Georgia as well as clay samples. Performing petrographic analysis, he found no matches between clays and archaeological materials; however, he mistakenly identified sponge spicules as diatoms, and on that basis proposed diatomaceous deposits as the origins of this material. A project surveying clayey resources in the lower St. Johns drainage recovered no clays with sponge spicules, leading the authors to suggest that spicules were intentionally added to the clay as tempering agents (Rolland and Bond, 2003). While there is ethnographic and archaeological evidence for prepared sponge temper in the Amazon (Linné, 1965:29; Natalio et al., 2015), there is no such evidence in the southeastern U.S.

Sponge spicules are naturally occurring in muck, which is a soil composed primarily of heavily decomposed organic material, generally developing in waterlogged conditions. The characteristics of mucks as fine-grained, organic, and of watery origins make mucks compelling as potential raw materials for spiculate pottery production. Espenshade (1983) surveyed clayey resources in Brevard County, Florida as possible sources for St. Johns and concluded that muck from the Tomoka formation matched the characteristics of St. Johns ware from the Gauthier site. He further proposed muck as the material for all St. Johns ware in Florida. However, Espenshade presumed spicule presence based on chalky texture. Experiments in the CTL found that one of Tomoka clay samples contained spicules but became friable when fired, while another had few spicules (Cordell and Koski, 2003:116). No further testing was completed on muck resources outside of the neighborhood of the Gauthier site. Lollis et al. conducted replication experiments with different raw materials, evaluating potential mixtures of clay with muck added as temper, but were unable to replicate the fineness and texture of St. Johns paste (Lollis et al., 2015).

Given the commonness of St. Johns and other spiculate wares on archaeological sites, the failure to successfully identify raw materials or recipe indicates that the "effective ceramic environment" (Rice, 1987:314) has not been adequately surveyed. The current study is an attempt to more comprehensively characterize the elemental and mineralogical attributes of this pottery in order to better understand the source.

2.4. Geology

Florida's surficial geology is composed of sedimentary formations. Much of the peninsula is overlain by relatively recent Pleistocene and Holocene deposits of sandy sediments (Fig. 2). On the western side of the peninsula are outcrops of older deposits: carbonate rocks from the Eocene and mixed siliciclastic-carbonate Miocene-age formations with an Appalachian provenance for the silicate minerals. This region, broadly identified as the Hawthorn Group, has outcrops of limestone and a variety of mixed clayey and sandy lithologies of marine origin. The weathering of limestone bedrock within Florida's karst environment creates lakes, sinkholes, and depressions that form wetlands (Haag and Lee, 2010:38).

The well-weathered and sedimentary nature of clay resources in Florida provides a challenge to provenance studies, as Florida soils are naturally depleted in many trace elements that would serve as chemical fingerprints. As well, abundant mixing of deposits further attenuates meaningful variation. Nevertheless, previous elemental analysis of clay samples from across Florida found measurable differences in clay composition from different parts of the state (Wallis et al., 2015), and similar patterns have been traced through archaeological pottery (Ashley et al., 2015; Gilmore, 2016; Wallis et al., 2010, 2016).

3. Methods

We applied laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) and X-ray diffraction (XRD) to analyze the chemical and mineral composition of St. Johns series pottery. These methods provided fundamental characterization related to the geological and pedological origins of the raw materials used to produce this pottery. This was the first study of spiculate wares to focus on the composition of the clay fraction. Prior sourcing studies of spiculate pottery have been based on surveys of clayey resources, with similarities to archaeological specimens assessed via mechanical testing, replication experiments, and petrography. These studies have also been limited in scope, focused primarily on matching local clay resources

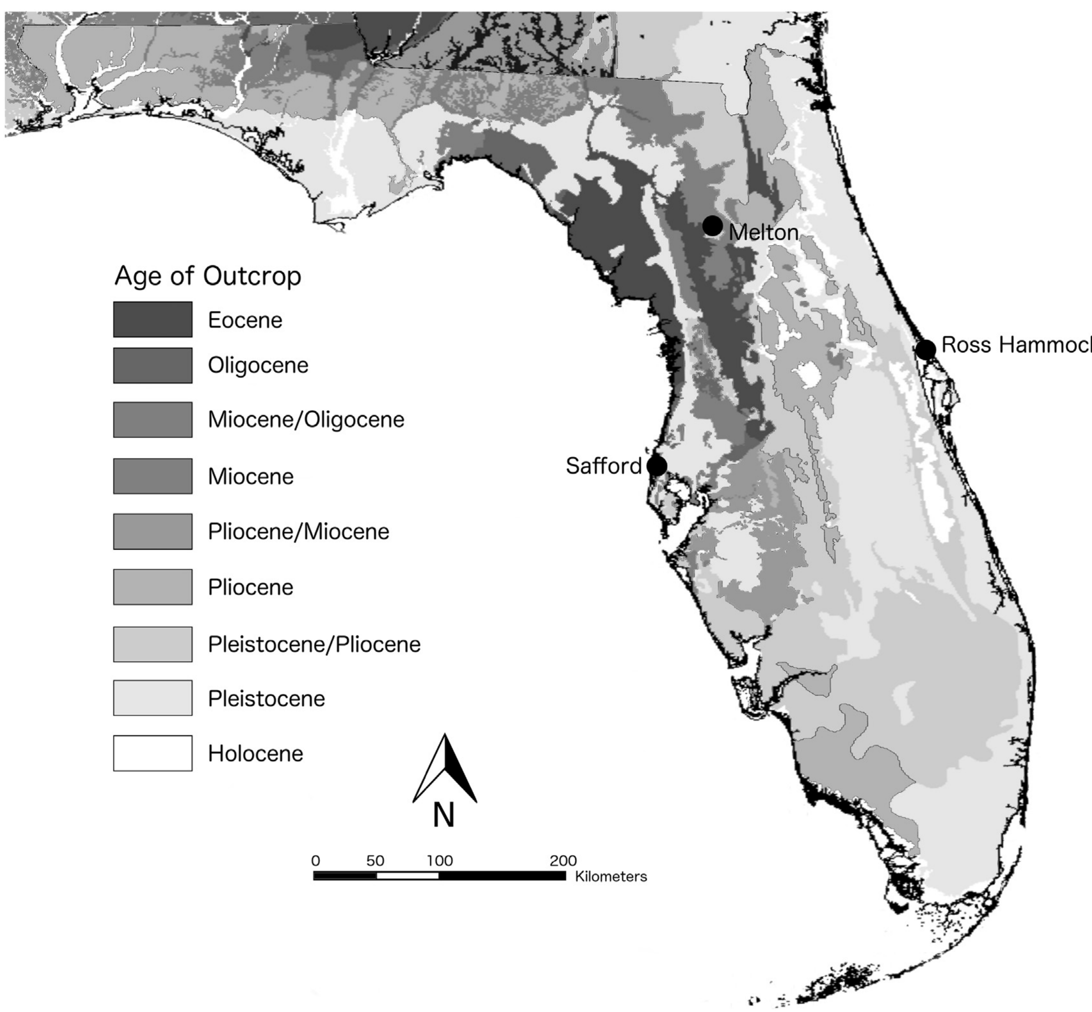

Fig. 2. Map of Florida showing geological regions by age of deposit. Archaeological sites sampled in this study are indicated.

with pottery from specific archaeological sites (e.g., Cordell, 1984; Espenshade, 1983), or regions (e.g., Crusoe, 1971; Rolland and Bond, 2003).

3.1. Sample selection

We selected three sites from peninsular Florida, within the geographic range of the St. Johns type series (Fig. 2). The site of Ross Hammock, along the Atlantic Coast in Volusia County consisted of two burial mounds and a large midden (Bullen et al., 1967). Pottery samples for this analysis were taken from mound and midden contexts. Given the pottery assemblage, site occupation is assessed at approximately cal 500 BCE to cal 200 CE. This site is within the St. Johns culture area, to the east side of the St. Johns River. Geologically, Ross Hammock is located within the late Quaternary deposits on the Atlantic coast.

Melton Mound 3 in Alachua County was excavated in the 1950s (Sears, 1956). ^{14}C dates place mound construction around cal 1 CE–200 CE (Hall, 2015). It is located in north central Florida, on the western boundary of the St. Johns culture area. Safford Mound, in Pinellas County on the Gulf coast, was excavated in 1894 by Frank Hamilton Cushing (Bullen, 1970). It contained a wide array of ceramic wares, many associated with the Weeden Island culture. It dates to approximately 100–1100 CE, making it later than both Ross Hammock and Melton. In contrast to the two early assemblages, which were dominated by St. Johns Plain and Dunns Creek Red wares, Safford had a significant quantity of St. Johns Check Stamped, along with Papys Bayou and Oklawaha chalky-pasted wares. Both Safford and Melton are within the Hawthorn Group region. It was expected that there would be a difference in the clay signatures between the region covered by these earlier deposits, and the late deposits on the St. Johns and Atlantic side to the east.

Six reference clay samples were also sampled from the CTL collection (Table 2). These reference clays were chosen by proximity to one of the archaeological sites, presence of sponge spicules, and/or location within the St. Johns watershed. We hypothesized that one or more of these clay samples would be elementally similar to some of the spiculate sherds, even if the physical properties were not identical, in terms of fineness of paste, percentage of sponge spicules, etc. Clay samples were made into briquettes and fired to 600 °C. Small fragments were removed from each briquette and analyzed in the same manner as archaeological materials.

3.2. LA-ICP-MS instrumentation

The LA-ICP-MS technique allowed us to focus on the clay body, avoiding spicules and other aplastics that would attenuate the elemental signature of the body. We conducted laser ablation on 44 total samples from the three archaeological sites (Table 3). Samples were chosen to represent a range of the chalky-pasted wares recovered on each site and were taken from various depths and deposits when possible to potentially account for change in clay source over time or different depositional contexts.

Pottery samples were prepared and analyzed in the Department of Geological Sciences, University of Florida. A small fragment was removed from each sherd and mounted in epoxy resin with a fresh cross-section exposed to avoid potential surface treatment or contamination.

Table 2
Reference clays (n = 6).

Location	Sample
Alachua County	C8AL02
Brevard County	C8BR15a/16
Citrus County	C8CI05
Putnam County	C8PU01
Volusia County	C8VO01, C8VO07

Table 3
Sample sherds (n = 44).

Site	Ware type	Count
Melton (8AL5)		15
	Dunns Creek Red	5
	Ocklawaha Incised	1
	St. Johns Plain	8
	St. Johns Red on Buff	1
Ross Hammock (8VO131)		15
	Dunns Creek Red	3
	St. Johns Check Stamped	1
	St. Johns Plain	11
Safford (8PI3)		14
	Dunns Creek Red	3
	Papys Bayou Plain	2
	Papys Bayou Punctated	2
	Papys Bayou Red	1
	St. Johns Check Stamped	3
	St. Johns Plain	2
	Tomoka Plain	2

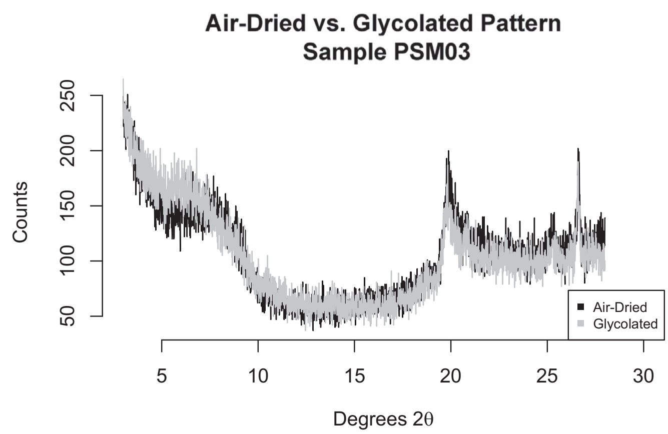

Fig. 3. XRD spectrum under air-dried and glycolated treatments, showing characteristic peak shift for smectite in glycolated sample.

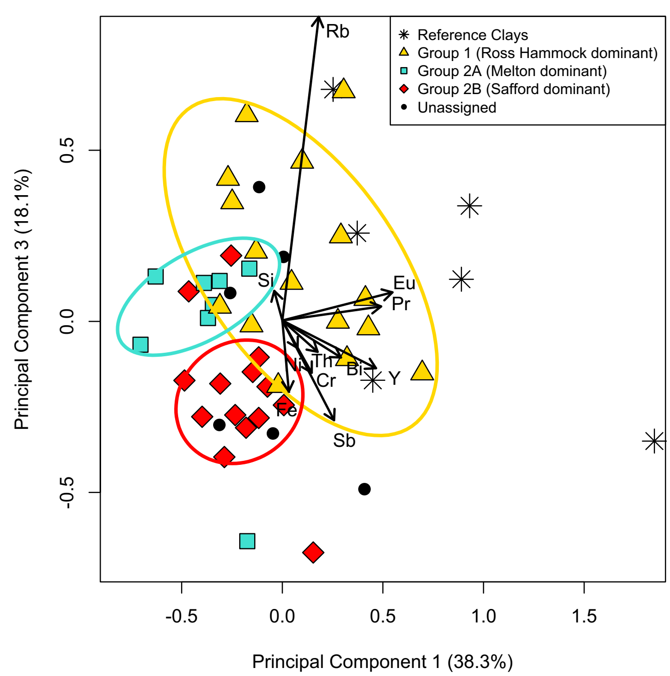

Fig. 4. PCA biplot of components 1 and 3 for elements Si, Cr, Fe, Ni, Rb, Y, Sb, Pr, Eu, Bi, Th. Ellipses represent 90% confidence interval for each group.

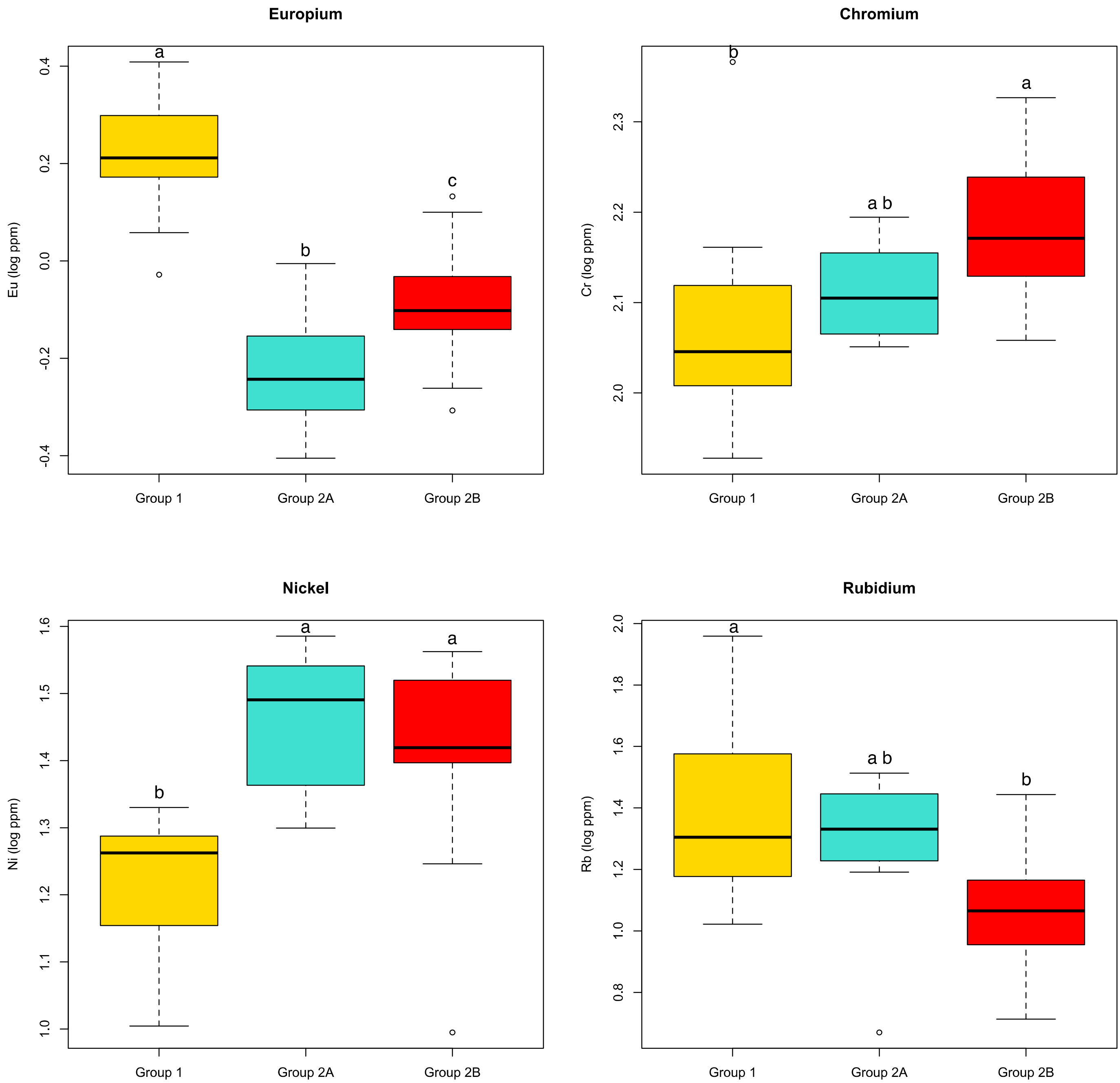

Fig. 5. Boxplots of selected elemental concentrations by compositional group. Groups with different letters are significantly different for each element as shown (Tukey's HSD, $p < 0.05$).

The mount surface was polished with a Buehler Ecomet 6 (Buehler Ltd., Lake Bluff, IL). Glass and clay reference materials were mounted alongside samples, and included USGS volcanic glass BCR-2G, NIST Trace Elements in Glass SRM 610 and SRM 612, and NIST Brick Clay SRM 679.

The pottery and fired clay samples were introduced via a New Wave UP-213 nm Nd:YAG laser ablation system (New Wave Research, Fremont, CA), connected to an Element2 HR-ICP-MS (Thermo Fisher Scientific, Bremen, GER). To obtain an average composition of the pottery matrix, data were collected in three separate ablation lines for each sample, 300 µm long and 60 µm wide, oriented parallel to the spicules. Ablation lines were placed using the integrated camera to avoid sponge spicules and other visible inclusions in the paste. The laser was set to a repetition rate of 10 Hz and scan speed of 5 µm/s, under 60% laser power. Reference materials were analyzed under the same instrument settings as artifacts, and were scanned after every 7–10 samples.

For each ablation line, data were collected on 16 scans, for a total of 94 s. The first four scans were collected during laser pause. Of these, scans 2 and 3 were the most stable and were averaged for the calculation of background signal. Only scans with stabilized signals for all elements were included in the final signal average for each ablation line, resulting in the averaging of eight replicates. Data were collected in medium resolution on 55 isotopes (Supplemental Data 1). Particular isotopes for each element were chosen to minimize polyatomic interferences. Quantification of elements from intensities was conducted following the Gratuze method, using silicon as the internal standard (Gratuze, 1999; Speakman and Neff, 2005). The resulting elemental

Table 4
Summary of group assignment.

Group	Excavated from	Count
Group 1		19
	Melton	1
	Ross Hammock	14
	Safford	1
	Clay C8VO01	1
	Clay C8VO07	1
	Clay C8CI05	1
Group 2A		8
	Melton	8
Group 2B		14
	Melton	3
	Safford	11
Unassigned		9
	Melton	3
	Ross Hammock	1
	Safford	2
	Clay C8AL02	1
	Clay C8BR15a/16	1
	Clay C8PU01	1
Total		50

values were log transformed. All data analysis was conducted using the R program for Statistical Computing, version 3.4.2 (R Core Team, 2017) unless otherwise noted.

3.3. XRD methods

The low-fired nature of the Florida spiculate wares made it possible to use XRD for the determination of clay mineralogy for the source deposits of archaeological samples. Two specimens from each source group were selected for XRD analysis, focusing on the clay fraction. A rock saw was used to remove approximately 3 g of sample from sherds, which was then ground in an agate mortar and passed through a #230 sieve, following Poppe et al. (n.d.). To remove organics, powders were suspended in 3% H_2O_2 until bubbling ceased, then dried at 20 °C. The samples were then resuspended in 50 ml of a 2% sodium hexametaphosphate solution, and processed in an ultrasonic bath. The < 2 μm fraction was separated via centrifuge, and oriented aggregate slides were prepared, per Steurer and Underwood (2003).

Mineralogy of the clay-size fraction was analyzed by X-ray diffraction of oriented slides (Moore and Reynolds, 1997). Each sample was analyzed in a Rigaku Ultima IV X-ray Diffraction System with incidence angle between 3 and 23°2θ, at 0.01°2θ step with scan speed of 1 s/step. Ethylene glycol was applied to samples to validate smectite presence (Moore and Reynolds, 1997). Slides were placed in a sealed desiccator with ethylene glycol at 60–65 °C for ~18 h. Each glycolated sample was analyzed once by X-ray diffraction under the same conditions, with the characteristic peak shift of glycolated smectite used to confirm its presence (Fig. 3).

4. Results

4.1. LA-ICP-MS results

Concentrations for all elements measured during the LA-ICP-MS are presented in the on-line supplement. Critically, we found that many of the elements that initially showed the most striking patterns within the data were most likely associated with the diagenetic burial environment of the sherds rather than the raw material source. The migration of mobile elements into the pottery due to diagenesis was anticipated, given prior experience with similar samples (Wallis and Kamenov, 2013) and data from other archaeological contexts (e.g., Freestone et al., 1994; Golitko et al., 2012; Neff et al., 2003). In our case, we found a notable contrast in the calcium concentration of sherds recovered from the shell-rich Ross Hammock midden compared to Ross Hammock mound, with lower shell density. Potential dilution effects of migrating calcium were corrected following Steponaitis et al. (1996). Calcium and strontium were removed from further analysis along with most alkali metals and alkali earth metals, as potential diagenetic contaminants (Golitko et al., 2012). The midden deposit of Ross Hammock was also higher in potassium and magnesium, which are associated with organic wastes such as fish remains (Pastor et al., 2016:50), so these elements were excluded as well.

Principal components analysis of the dataset indicated source specific groupings (Fig. 4). The sherds from Ross Hammock on the Atlantic side of the peninsula, identified as Group 1, separated from the Central and Gulf sherds. Group 1 was characterized by enrichment in rare earth elements (REE). Group 2, encompassing the sites of Melton and Safford, was higher in elements such as iron, nickel, and bismuth. While there was some overlap, Melton sherds (Group 2a) separate from Safford (Group 2b) according to concentrations of several elements.

Elemental differences among groups were tested using One-way Type-III ANOVA. We evaluated model assumptions of normality and homoscedasticity with residual plots. For elements where groups were statistically significant, among group differences were tested with Tukey HSD multiple mean comparisons. An alpha of 0.05 was adopted a priori for all statistical tests. For elements pictured in Fig. 5, elemental compositions were significantly different among groups. Ross Hammock sherds were significantly enriched in europium compared to Safford and Melton, whereas Safford sherds tended to be higher in chromium. The enrichment of elements such as chromium for this Gulf site is consistent with data from the USGS chemical survey for this part of Florida (Smith et al., 2013).

Assignment of the sherds to one of the three compositional groups was verified using Mahalanobis distance probabilities, following methods outlined previously (Bloch, 2016:240; Table 4; Supplementary Data 2). Several sherds were unable to be assigned, or in the case of two sherds from Safford, had shared predictions for both groups 2a and 2b and were treated as unassigned. An analysis of similarity (ANOSIM) was performed as a check on the validity of groups established via Mahalanobis distance probabilities, indicating a rejection of the null hypothesis that similarity within groups was equal to global similarity ($r = 0.358$, $p = 0.001$).

The reference clays were also projected into the model. Three of the samples had no prediction probability for any of the three groups. These samples from Alachua, Putnam, and Brevard counties were not elementally similar to the archaeological material. The two Volusia County clays fell within the Ross Hammock group, a strong indicator that the Ross Hammock sherds were local products. The Citrus county clay sample had a very low prediction to the Atlantic Group 1 as well (1%), despite coming from the Gulf coast. However, it came from the same types of late Quaternary deposits on the Gulf coast as are found on the Atlantic coast, which likely explains the faint similarity. No clay samples could be tied to Melton or Safford vessels.

Overall, the elemental results strongly pointed to independent local production. At each site there was one dominant source group. There was little evidence for interregional trade of spiculate pottery. A single sherd of St. Johns Plain from Melton, and a sherd of St. Johns Check Stamped from Safford were consistent with the Atlantic-based Group 1, and appeared to represent non-local products. Furthermore, there was no elemental patterning within different ware types. At Safford, clay bodies with the same signature were used to produce multiple types, such as Papys Bayou, St. Johns Plain and Dunns Creek Red wares.

4.2. XRD results

The four XRD samples from Hawthorn compositional groups were broadly similar, composed primarily of smectite clay and crystalline quartz (Fig. 6). In contrast, the samples from the Atlantic group had very little clay material. The high quantity of amorphous silica in all

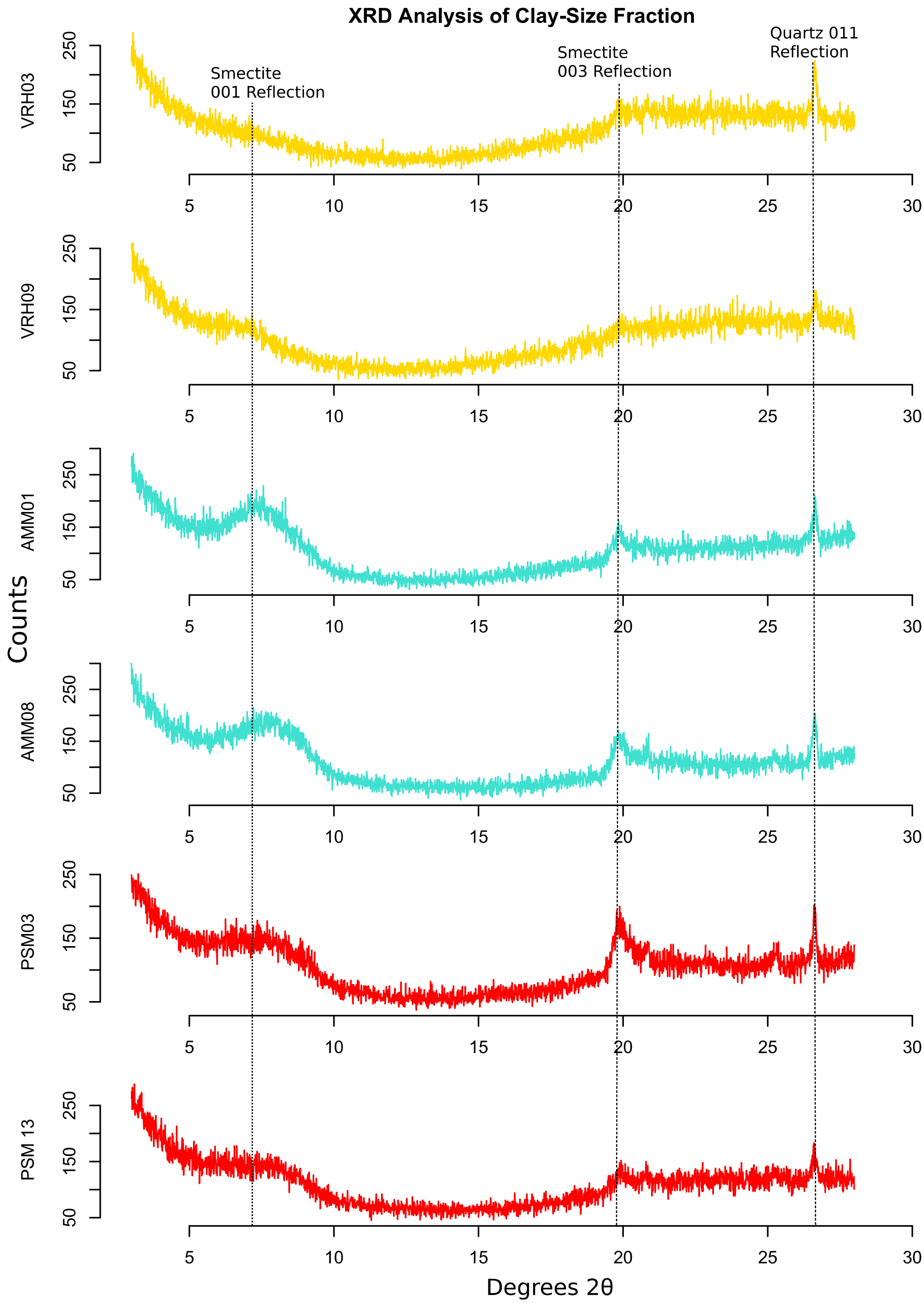

Fig. 6. XRD spectra for six representative sherds showing dominant mineralogy. VRH03 and VRH09 samples from Ross Hammock (Group 1), AMM01 and AMM08 samples from Melton (Group 2a), PSM03 and PSM13 from Safford (Group 2b).

samples is visible as a broad hump between 20 and 30°2θ (Moore and Reynolds, 1989:230). In general, the mineral counts for this clayey material were lower than anticipated. The relative abundance of clay to non-clay constituents may be compared via elemental aluminum concentration, as aluminum is a primary component of smectite (Fig. 7). As expected, Group 1 samples tended to have lower aluminum values, whereas the Group 2a and 2b samples from the Hawthorn formation had higher values, indicating higher clay mineral concentrations.

5. Discussion

The elemental and mineralogical evidence points to a broadly

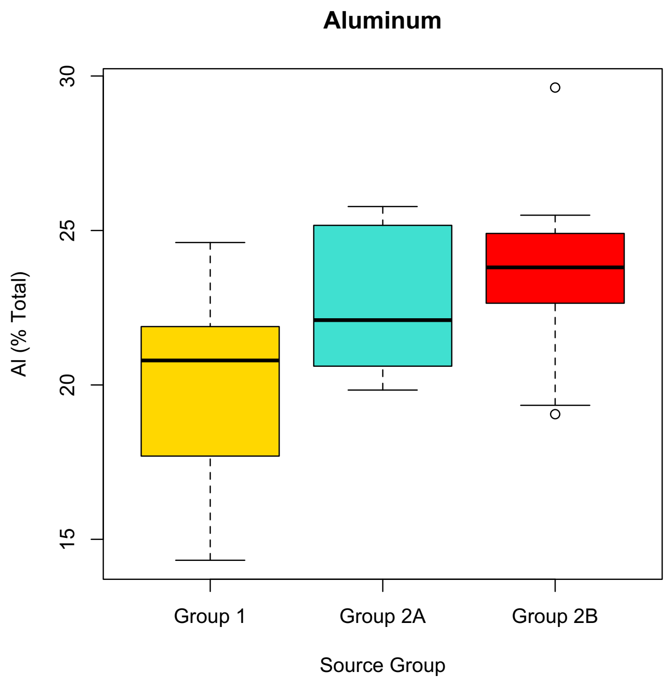

Fig. 7. Relative abundance of aluminum in samples by group, as proxy for clay mineral concentration.

consistent "recipe" for the production of spiculate pottery, with local variation across the peninsula according to underlying geological formations. Given this result, it is necessary to consider the natural resources that would have been available throughout prehistory for crafting pottery with these specific physical characteristics: fine chalky texture, high organic content, and sponge spicules. Specifically, does muck from Florida wetlands exhibit these properties?

The slow movement of water within wetland environments leads to preferential deposition of the finest clay and silt particles (Keller and Schell, 1993). This may explain why spiculate ware is so often free of sand-sized inclusions. In effect, wetlands serve as natural levigation ponds. To date, clay sampling procedures in Florida have overlooked these marshy deposits in favor of more readily accessible sampling sites, which has likely biased existing samples towards clayey deposits with more abundant grainy inclusions.

The results of XRD analysis confirm the presence of smectite as the primary clay mineral for spiculate ware. Smectite clays are common constituents of poorly-drained wetland soils in Florida (Harris, 2011:9). For pottery production, a smectite-dominant clay composition is unexpected. Smectite clays have a 2:1 crystalline structure that readily takes on large quantities of water. This can be disastrous, as subsequently high shrinkage causes warping and cracking of vessels as they dry. Generally, the low clay mineral concentration in the samples was surprising, as pottery is generally considered to be composed primarily of clay. However, "in terms of selection and use by potters…clays may be defined solely by their most salient property, plasticity" (Rice, 2015:60).

While smectite has been downplayed as an effective pottery clay, within wetland muck the organic material and sponge spicules may have mitigated the shrink-swell issues. Muck is high in organic compounds that form during the decomposition of plant and animal remains. These include natural binders like cellulose and lignin, and further decomposed compounds such as sugars and fatty acids (Keller and Medvedeff, 2016:178). Gertjejansen et al. (1983) found that fine grained mixtures of smectite clays and high organic materials were more successful in replicating Tchefuncte pottery samples than those produced with lower organic content.

In many situations, it is expected that the organic material will volatilize and escape from the pot during firing. Notably, within spiculate wares, carbon remains trapped within the fired body, indicating that the organics continue to provide structural support. The retention of carbon is in part due to the way in which smectite readily and strongly bonds to carbon. The small particle size of smectite also reduces pore spaces within the clay body necessary for volatilization (Rice, 2015:104).

Florida spiculate wares share some characteristics with Tchefuncte pottery, which is often derided as of poor quality (Gertjejansen et al., 1983:37). The main material difference is that the presence of spicules performs the critical function of opening material. As noted, spicule concentration can be up to 50% of the body. At this density, it would provide significant benefits to diminish crack propagation and shrinkage of a smectite/organic body during drying.

Previous studies attempting to explain St. Johns production have encountered problems matching the density of sponge spicules found in archaeological materials with raw clays, leading some to argue for intentional tempering with spicules (Rolland and Bond, 2003). There are several other possible explanations. First, sampling may have missed the ideal depositional environments (i.e., wetlands), or the best locations within wetlands. Running transects across temporarily dry shallow ponds in Florida, Schwandes and Collins (1994) found that the greatest density of sponge spicules and organic material was in the center of the ponds, places archaeologists typically would not venture.

Also, sponges are sensitive to environmental change, and may have experienced significant decline from prehistoric populations. Increasing inputs of sediments, fertilizers, and other anthropogenic materials are changing wetland ecosystems in ways that may inhibit sponge success (Bell et al., 2015). Freshwater sponges are understudied and easy to overlook. Most surveys of sponges in Florida have focused on spicules rather than living colonies (e.g., Conley and Schelske, 1993; Schwandes and Collins, 1994; but see Johnson, 1945). Rolland and Bond (2003) were unable to find living sponge colonies in the course of their northeast Florida survey.

6. Conclusions

Our evidence shows that St. Johns and related pottery was not produced only in the limited region of the St. Johns River, but made across the peninsula. While it seems that there were few completed pots of this type moving across these cultural zones, clearly there was shared and persistent technological and ecological knowledge about how to produce vessels with these characteristics. We have proposed that wetland muck deposits were used without addition or significant processing for the production of these wares. As this project continues, we will sample clayey material within wetlands to better understand the composition of muck deposits across the peninsula and their suitability for pottery production. We will also conduct replication experiments with natural and artificially amended clay bodies. This will make it possible to account for the effects of different proportions of specific clay minerals, organic compounds, and fine acicular inclusions.

Florida spiculate pottery has been a continual subject of study and debate for decades. Through this project, we bring new lines of evidence to critically evaluate some persistent suppositions. By determining that spiculate ware was produced independently in multiple regions we must reinterpret the significance of stylistic similarity and differences across time and space, and more carefully gauge what constitutes a trade ware vs. a local product. Furthermore, we must adopt a more ecological framework to better understand the technological choices of past potters.

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Declarations of interest

None.

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