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Patterns in the Clay: X-Ray and Gamma-Ray Geochemical Sourcing of Middle and Late Woodland Ceramics from Mulberry Island, Virginia

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A Thesis presented to the Graduate Faculty of The College of William and Mary in
Virginia in Candidacy for the Degree of
Master of Arts

Department of Anthropology

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APPROVAL PAGE

This Thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

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ABSTRACT

In the lower Chesapeake region, the Middle and Late Woodland periods witnessed the emergence of a complex geopolitical landscape. However, the specific exchange relationships and kinship networks which structured the lives of Virginia Algonquians remain only marginally understood. As a result, researchers have few means to refine the culture-histories of many Native archaeological locales of the period, and struggle to place these sites within the broader social landscape of Tsenacomacoh. Such is the case for Mulberry Island, situated along the James River in Virginia's Lower Peninsula. Despite comprehensive survey and stewardship of the island's archaeological record by the United States Air Force, an important question remains: was the island a hinterland, and if so, then whose?

Ceramic sourcing methods offer a viable means of addressing this gap. This study was designed to explore the possibility of exchange between the residents of Mulberry Island and Kiskiak, a large historically documented town within Virginia's Lower Peninsula, during the Middle and Late Woodland periods. By combining the data from empirically calibrated portable energy-dispersive X-Ray Fluorescence (XRF) and Gamma Ray Spectrometry (GRS), this study extends the reach of geochemical information that can be used to study precontact period ceramics nondestructively in Virginia and elsewhere, at a narrow geographic scale previously considered untenable.

Results suggest that highly localized geological variables, rather than simple geographic distance, provide sufficient chemical variation to differentiate ceramics by provenance. Although exchange was not identified between Mulberry Island and Kiskiak, informal exchange is posited for two sites within Mulberry Island, pointing to local social connectivity. Alternatively, comparison of the ceramics to field-collected raw clay samples suggest that differential clay mining practices took place between these sites. One sherd may represent an instance of individual experimentation with potting practice. The results represent a promising first step in refining the culture-history of Mulberry Island and other locales. Ultimately, the collective action of potting by task groups or localized communities of practice offers glimpses into a mosaic landscape of social identity which was complicated and granular, yet interconnected and continuous.

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Introduction

Tsenacomacoh, otherwise known as the Virginia Tidewater, is a diverse estuarine landscape defined by the Chesapeake Bay and its tributaries. Integrated with that landscape throughout the last 2,000 years of history was an equally diverse mosaic of Algonquian-speaking cultures organized into a complex geopolitical structure. Despite the evidence of social complexity typifying the archaeological record for this period, the specific exchange relationships and kinship networks which structured Tsenacomacoh are not well understood. Without robust data with which to map the spatial extent, frequency, or character of interaction between large population centers on the one hand and hypothesized hinterland areas on the other, researchers are left with limited tools to pinpoint the individual place-histories and cultural identities of many archaeological locales.

Mulberry Island, an eight-thousand-acre triangle of land whose boundaries are defined by three waterways, is one of many such locales. Today its shores are the fence lines of Fort Eustis, a base of the United States Air Force. Military occupation is just one brief iteration of the colonial project that transformed the landscape of the island through time. While the events of the last four centuries may have erased its Algonquian name, they did not erase the island's visual and symbolic integration within the wider geographic and political landscape of Tsenacomacoh. This integration manifests physically as an array of archaeological sites scattered across the landscape which predate European arrival. Ironically, acquisition of the island by the settler state spared the bulk of these sites from destruction by twentieth century mechanized plowing, providing a material foothold for Native decision-making power under settler law in the present. This event also precipitated long-term cultural resource management of the base. As such, the island is comprehensively surveyed and comprehensively understood by archaeologists (Beaudry 1976, Opperman and Polk 1989).

The Woodland period occupation of Mulberry Island spans nearly three thousand years of Virginia history (VDHR 2017:107-108). The period manifests archaeologically as a variety of ephemeral sites, such as small hunting locales and small camps. A limited handful of larger sites are typically understood as Middle Woodland (500 B.C.E. – 900 C.E.) seasonal basecamps, Late Woodland (900 C.E. – 1600 C.E.) hamlets, or some discontinuous combination of the two. At these sites, higher artifact densities, the presence of subsurface features, and an abundance of ceramics suggest residential stability (Blanton 1992:69-71). There is a prominent site type missing on the island: a town. This observation prompted the cultural resource program manager at Fort Eustis to pose a straightforward question (C. McDaid, personal communication, January 2023): Is the island a hinterland of a more densely populated center? If so, can the island be linked to a historically documented town?

Importantly, the framing of Mulberry Island's Native history by these town-versus-hinterland terms draws implicitly from colonists' attempts to delineate and define the Algonquian cultural landscape they encountered in the seventeenth century. At that moment in history, the political landscape consisted of the Powhatan confederacy, wherein a series of tributary chiefdoms and towns (in the eyes of colonists) were hierarchically organized under the governance of a paramount chief associated with a discrete, geographically marked center. This conceptual framework was undoubtedly carried forward into anthropological thinking and is especially salient in archaeological models of site hierarchies and settlement patterns. It is only recently that Chesapeake researchers have attempted to delineate "developments older than, distinct from, and counter to" the colonial narratives of this time (Gallivan 2016:15). Even so, those narratives remain latent in the center-hinterland model employed here. The supposition that Mulberry Island was a hinterland or that its residents thought of themselves as such is therefore a matter of informed speculation.

There are numerous anthropological approaches to refining the culture-history of a place. The route taken here is to elucidate social boundaries through space and time (Trigger 2006:278-313). Even within this approach, multiple independent lines of inquiry must agree before a single "boundary" is confidently drawn on the map. The phenomenon of social identity, furthermore, is far more complex than spatially oriented questions alone can capture (Meskell 2006). Despite these issues, even a crude understanding of precontact identity membership within Mulberry Island would offer considerable support to the Department of Defense mission of long-term cultural resource stewardship (DoD 2008).

This thesis employs two materials characterization methods to identify the presence or absence of exchange between the residents of Mulberry Island on the one hand and contemporaneous communities[1] in the surrounding region on the other. Exchange of material culture, in this case ceramic vessels, is taken as a proxy for social exchange, which is then used to explore potential hinterland-center relationships between Mulberry Island and larger regional population centers. The study explores insights into the cultural practice of potting as revealed through the chemical data. The two methods employed are portable energy-dispersive X-Ray Fluorescence (XRF) and

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[1] My use of the term *community* throughout this study refers to a group of people co-residing within a limited geographic area, whose activities leave remains that collectively form one or several closely clustered archaeological sites. This definition contrasts with definitions based on shared kinship, values, interests, identity, or status, among other variables (Agbe-Davies 2011:576).

Gamma-Ray Spectrometry (GRS). Both are nondestructive sourcing methods whose utility depends on sufficient natural variation in the chemical composition of clay deposits distributed across the landscape, among other sampling and instrument-specific variables. Thus, identifying movement of clay vessels between Mulberry Island and other sites within Tsenacomacoh rests on the presumed underlying geochemical diversity of coastal plain clays, for which baseline data is not previously documented at the scale in question. The study therefore explores several methodological issues: Does the Virginia coastal plain contain sufficient geochemical diversity to differentiate ceramic sources at the scale of a single peninsula? If so, is the precision and accuracy of portable energy-dispersive XRF, combined with the novel method of GRS, sufficient to capture this differentiation and channel it toward anthropological inquiry?

Due to these unknown baseline conditions, this study represents a preliminary first step toward understanding Mulberry Island's membership within its immediate geopolitical environs. First, it compares material from only one nearby population center, Kiskiak. This town is documented historically and archaeologically as a mid-sized polity dispersed across the necks of land overlooking Indian Field Creek (Blanton et al. 2005; Gallivan 2016). A variety of larger and smaller towns lay to the east, west, and south of Mulberry Island. Kiskiak was not chosen for its likelihood of social connection to Mulberry Island. Instead, it was chosen for its likelihood to be geochemically distinct from Mulberry Island. In this way, the choice of sites was methodologically, rather than anthropologically, focused. Second, the study employed a broadly inclusive sampling strategy to account for small collection sizes, resulting in generally poor chronological control. This prevents conclusive interpretation of Mulberry Island's political membership at any discrete moment in history. Third, this thesis does not foray into alternative lines of inquiry (for example, historical documentary research or oral historical research in collaboration with contemporary Virginia Tribes) that would be necessary to draw robust conclusions about political memberships.

Thus, although the impetus for this study is anthropological, its immediate goal is necessarily more limited to a proof-of-concept for the utility of ceramic geochemical sourcing at the scale of a single coastal plain peninsula. In other words, this study challenges the assumption that large distances spanning physiographic regional divides are necessary to provide sufficient chemical variation in clay composition for these sourcing methods to be useful. Ultimately, the larger goal of understanding Mulberry Island's Native political identity will require comparison to a longer list of regional population centers, better chronological control, quantification of precision and accuracy by sourcing method, and the pursuit of independent lines of evidence.

This study endeavors to align with generalized Native preferences regarding the study and treatment of archaeological objects by embracing non-destructive techniques. Nondestructive techniques strive to respect the material power of artifacts. Though they fit conveniently within the preservation paradigm of archaeological science, these methods also treat artifacts as potentially affirming resources that future generations may draw emotional validation from or employ politically (e.g. Gambrell in Dring et al. 2019:363-365). Applying nondestructive methods conceptually to the broader landscape of Mulberry Island, this study utilizes data generated exclusively by limited Phase II compliance testing, avoiding dependence on large-scale excavations that are necessarily destructive and are often at odds with the interests of community stakeholders (Ferris and Welch 2014). By combining the data from GRS and portable energy-dispersive XRF, this study bolsters the geochemical information that can be used to study precontact period ceramics nondestructively in Virginia and elsewhere, at a geographic scale previously considered untenable.

Finally, the study strives toward the ethical imperative of informed consent by the descendants of Woodland period communities. Toward this end and pursuant to applicable regulations (54 U.S.C. § 302706(b), 36 CFR § 800.2(c)(2)(ii)(D)), the initial outline for the study underwent the standard tribal consultation process for federal actions on Joint Base Langley-Eustis.[2]

Cultural context: The Middle and Late Woodland Chesapeake

The innovation of ceramic technology by Virginia Algonquians marked the start of the Woodland period circa 1100 B.C.E., although recent absolute dates from the Middle Atlantic suggest even earlier regional adoption (Egghart 2020a:86). Ceramic technology developed out of the Late Archaic tradition of steatite bowl production. Given that sedentism was not regionally adopted in the region for another 2,000 years, this transition in technology is not linked to a change in mobility. Early ceramics were likely functionally consistent with the earlier steatite bowls. They are thought to have provided both a durable means of cooking food and to have served as a status marker (Egghart 2020b:101). In the ensuing Early Woodland centuries, communities continued to practice seasonally mobile lifestyles, likely organized in small bands connected by decentralized kinship networks.

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[2] This effort involved the six federally recognized tribes that are considered consulting parties at this installation. Importantly, the group defined by these legal terms is far narrower than the ethically defined “descendant community” (Blakey 2020:191). Because the goals of this study are to refine the historic cultural associations of Mulberry Island, the project has potential political saliency regarding future consultation at the installation. This author cautions against use of this project toward such ends without consideration of the individual interests of regional tribes, both federally recognized and not.

In the Middle Woodland (500 B.C.E. – 900 C.E.), these bands began to coalesce into larger groups for part of the seasonal round, returning to the same places again and again and staying there for longer and longer. Observable in the regional database is a clear settlement pattern hierarchy that consists of small, ephemerally occupied resource collection locales or camps and more permanently occupied basecamps. Resource collection locales consist of low-density artifact scatters covering small areas, with assemblages dominated by lithic tools and debitage. Basecamps are larger and consist of denser artifact scatters with a higher prevalence of ceramics. To explain this, Blanton (1992:69-71) proposed two settlement models. In the logistical model proposed for the Middle Woodland I (500 B.C.E. – 200 C.E.), smaller parties disperse from large single family or corporate base camps established on a seasonal round. In the fusion-fission model proposed for the Middle Woodland II (200 C.E. – 900 C.E.), multiple family or corporate groups coalesce seasonally in resource-rich estuarine locales before again dispersing for the remainder of the round. The presence of storage features, identifiable activity areas, and occasional deeply stratified and horizontally extensive middens points to increased residential stability during this time, while subsistence practices shifted toward an overall intensification in wild food harvests and a focus on riverine and estuarine resources (Nash 2020:124, 135).

The Middle Woodland II is generally marked by the widespread adoption of crushed shell as potting temper in the lower coastal plain, perhaps signaling the arrival of Algonquian speakers (Gallivan 2016, Stewart 1992:9, Nash 2020:127). The cord-marked, shell-tempered ceramics dating to this period are referred to as Mockley ware (Egloff and Potter 1982:103-104). The shell tempering tradition remained widespread through the Late Woodland period. That some Middle Woodland sites hold ancestors interred in either ossuaries or as isolated bundle burials, as is the case at Mulberry Island, clearly indicates intentional return to places of significant social memory. It is no wonder that some of these basecamp locales, having already functioned for centuries as "persistent places" (Schlanger 1992:91) that fostered new forms of social organization, transformed over time into permanent settlements in the Late Woodland period.

The Late Woodland period (900 C.E. – 1600 C.E.) was marked by a shift to fully sedentary lifestyles, resulting in permanent towns and hamlets, some of which included palisade or ditch enclosures (Gallivan 2016:130-132) and many of which correspond to the locations of Middle Woodland basecamps. These settlements were located along major rivers, with travel by water via dugout canoe a well-established tradition by this point. Horticulture was practiced during this period, though it was supplemented with hunting, fishing, and foraging. Seasonal movement across the landscape continued in the form of hunting forays away from towns and hamlets, with Late Woodland temporary camps and resource procurement sites common throughout the regional archaeological record. Nevertheless, the cultural landscape had changed dramatically since the first ceramics were potted in the Early Woodland. Beginning likely in the Middle Woodland II and gaining momentum through the Late Woodland, the Chesapeake landscape was increasingly structured by ceremonial centers and chiefly lineages (Shephard and Gallivan 2020). The century of C.E. 1200 seems to mark a significant turning point after which ceramic styles suggest more bounded social networks, select settlements increased in size and began to host multicommunity feasts, and households held greater control over the storage of food (Shephard and Gallivan 2020:196). These points and others are generally interpreted as pointing to an increasingly politicized social landscape.

Theoretical context: Social boundaries, ceramics, and potting practice

At its core, this study is methodologically focused and descriptive in aim. Nevertheless, I align with the postprocessualist stance that there is no such thing as atheoretical archaeology, nor can or should there be (Hodder 1997). Although the research question posed to Mulberry Island appears simple and descriptive at first glance, it hides a host of theoretical positions beneath its surface. The bodies of relevant theory include the culture-historical tradition, the direct historical approach, theories of practice, social agency, and cultural evolution.

The cultural-historical tradition was the early twentieth-century cradle of Americanist archaeology (Trigger 2006). Culture-history is descriptive in agenda, aiming to empirically establish the temporal and spatial distributions of material remains of cultures (2006:310). The goal of reconstructing spatio-temporal sequences exemplifies archaeology as “handmaiden” (Noël Hume 1964) to prehistories without written documents, that is, as one more means to a historian’s end. Such was Binford’s (1962) critique that archaeology should turn away from history toward a quest for universal human processes. Culture-historians viewed interpretations as “matters of opinion,” arguing instead that “data constitute[s] the real and cumulative core of the discipline” (Trigger 2006:306). Despite these claims, culture-history rested on a philosophy of strict positivism, which may itself be considered an interpretive stance.

It was from these origins that the methods of typology and chronology, especially those based on ceramic style, emerged. These efforts took inspiration from Linnean phylogeny. At their worst, ceramic types are fully arbitrary and bear no meaning to the people who made them. At their best, types are more empirically grounded and are conceptualized as “the norms or ideal mental templates shared by group of artisans” (Trigger 2006:299). In this way, recurring attribute combinations are taken as types or styles that archaeologists employ to draw what they hope are non-arbitrary boundaries around groups of people, or “cultures” in the simple use of the term. This effort is easily problematized when one recognizes individual artistic agency (e.g. Lathrap 1983). Even after turning a blind eye to theoretical critiques, the revision of existing typologies becomes an increasingly difficult task as one encounters the staggering complexity of patterning in the archaeological record (Trigger 2006:285-286) and as compliance-driven fieldwork continues to generate data at an unsustainable pace (Ferris and Welch 2014).

For better or worse, ceramic typologies remain the backbone of Woodland period research in Tidewater Virginia. The typology in use today was laid out by Egloff and Potter (1982). This model conceptualizes regional ceramic patterning as “a three-dimensional puzzle of continuous style development” in which the three variables are “methods of manufacture, space and time” (1982:95). When “methods of manufacture” are broken down into temper type, temper volume, surface treatment, paste attributes, and vessel form, the number of dimensions in the puzzle jumps to somewhere between five and ten. Egloff and Potter’s typology was refined by Klein (1994), whose “absolute seriation” technique combined rigorous radiocarbon dating with statistical analysis of individual attributes to distill types. The method proposes means of assigning calendrical dates to assemblages rather than to individual sherds. Despite examples of their utility (Gallivan 2003), Klein’s methods have not yet been adopted at a widespread scale, and the potential that the approach could “revolutionize” culture-historical efforts in Virginia remains unrealized (Nash 2020:125).

Although several of Egloff and Potter's proposed types were debunked or discarded in the following decades, archaeologists working with legacy collections or small budgets are often fully reliant on the basics of this chronology for assigning dates to sites. Such is the case for this study. Others are skeptical of typological designations altogether, regarding them as "heuristic constructs" (Trigger 2006:298) and preferring to focus on individual attributes. For example, shell tempering is considered a hallmark of the period beginning in the Middle Woodland II and continuing through the Late Woodland centuries (Nash 2020:127) and its widespread adoption is considered by some as an indication of the arrival of Algonquian speakers in the region (Gallivan 2016, Herbert 2008).

Culture-historical research continues as the norm in Virginia and is especially needed for better baseline understandings of the Middle Woodland period (Nash 2020:124). My own project is no exception to this trend. In this sense I follow Trigger in asserting that while culture-history is not the end-all-be-all of archaeological interpretation, its "historical findings are the necessary prerequisites for…generalizations about the processes of change" (2006:313).

The goal of assigning a seventeenth-century-documented town affiliation to Mulberry Island enrolls another early archaeological tradition: the direct historical approach. Steward summarized the approach as follows: "Methodologically, the direct historical approach involves the elementary logic of working from the known to the unknown. First, sites of the historic period are located. These are preferably, but not necessarily, those of identifiable tribes. Second, the cultural complexes of the sites are determined. Third, sequences are carried backward in time to protohistoric and prehistoric periods and cultures. This approach has the crucially important advantage of providing a fixed datum point to which sequences may be tied" (1942:337).

While the general utility of this method is obvious, strong reservations are warranted in application to this study, which includes ceramics spanning the Middle through Late Woodland periods. Can the direct historical approach be extended >1000 years before present? Can it be extended "backward beyond the point where the trails of the known, historic peoples faded out" (1942:337), and beyond points of radical transformations in social/political/economic organization that reshaped Chesapeake societies approximately C.E. 1200 (Shephard and Gallivan 2020:196)?

Recent developments in theory have rebranded the direct historical approach under a nastier name: the backward-looking approach. Kassabaum's *A History of Platform Mound Ceremonialism* (2021) provides a robust discussion of the issues with the method, drawing critique heavily from time perspectivism and historical processualism. Although Kassabaum never explicitly calls out the direct historical approach by name, she identifies the "backward-looking view" (2021:18) as an analytical sequence that begins from the present and extends our understanding of archaeological phenomena backward through time. This order of operations is problematic because it enrolls the unreasonable notion that people in the past somehow anticipated future cultural forms and acted in deliberate reference to them. The method fits too conveniently into the goal of constructing origin-to-ending narratives that generate plot-like stories for material culture change. Because the backward-looking approach is logically unsound, it can (and already has) produced inaccurate portraits of the past.

Undertones of the backward-looking approach are apparent in precontact Chesapeake research when scholars seek to understand the Middle or Early Woodland periods only through comparison to Late Woodland standards, rather than on their own terms. Given the nature of my research question and broad sample, it would be easy to follow a similar path. This would involve an uncritical linking of Middle and Late Woodland geopolitical contexts, which may have been more different than similar. The Middle Woodland people involved in this study lived on Mulberry Island without knowledge of or reference to the social landscape of towns and hamlets 500+ years into the future. Nevertheless, their lifestyles incorporated a sense of permanence through repeated return to persistent places. Recognizing this issue of chronology aligns with Kassabaum's (2021) assertion that it is the practice of referencing the past that builds the future, not the practice of referencing the future that builds the past. Nevertheless, the direct historical approach cannot be fully disentangled from this study, given that colonial characterizations of the Chesapeake region remain latent in the center-periphery model. Under this model, densely populated locales are considered "towns" or "centers," while sparsely populated locales are by default considered hinterlands for lack of a large, temporally stable, discrete location of settlement. The model employed in this study thus boils down to a binary distinction between the presence or absence of a focal point of settlement, rather than a confident or meaningful understanding of residential demography across the landscape.

Finally, any study of ceramics must inevitably grapple with the dynamic balance between individual agency, cultural evolution, and production of material culture. Culture-historical studies within the Middle Atlantic often end with descriptions of spatial patterning in ceramic styles or recipes equated tentatively with social boundaries.

Commendably, scholars in the Chesapeake have avoided the mistake of collapsing style into decoration or surface treatment, a common practice elsewhere in the world (Dietler and Herbich 1998:237). Instead, they have paid due attention to style as the cumulative sum of techniques, including clay mining, refinement, temper selection and preparation, firing methods, social and symbolic atmospheres for these tasks, and other dimensions of practice (e.g. Spivey 2017). It seems that Chesapeake archaeologists, faced with the elegant minimalism of the Woodland potting tradition and finding no elaborate iconography to dissect for symbolism, were forced to turn away from things and toward techniques as their intellectual fodder. In this sense Dietler and Herbich's (1998:237) assertion that "the mediating process between things and society, and the key to understanding their reciprocal relationship, is technique" is well-realized in the region.

Studies seeking to identify social boundaries often rest on the notion of stable attributes, the result of technical skills that tend not to change over an individual's lifetime once learned. Cordage twist direction is considered a highly stable attribute (Hurley 1979 in Nash 2020:151), and its use to explore dimensions of kinship and gender in the Chesapeake region enjoys widespread acceptance (Nash 2020:151, Shepard and Gallivan 2020:192-193). Cordage twist direction preserved as impressions on ceramic surfaces are useful for identifying gendered "communities of practice" (Nash 2020:152). Studies employing the "communities of practice" model link women's labor to ceramic and textile production, and typically rely on ethnohistoric accounts. These studies seek to distinguish patri- or matrilineality, patri- or matrilocality, and labor along gendered lines. The success of these studies is often limited by implicit assumptions imported from the segmentary lineage model and Sahlins' "Big Man" model of social organization (Nash 2020:152). Communities of practice serve as a conceptual scale threshold to discuss minimum economic units, smaller than a settlement but larger and less specific than a household. Analysis at this sub-settlement yet super-household scale is channeled upward toward larger scale discussions of kinship lineality, population flows, and trade and exchange. For example, Herbert concluded the following from his analysis of North Carolina ceramics across the entire Woodland period: "… the regions in which specific pottery types are distributed represent areas where technological styles, consisting of both knowledge and practice, were passed down from one generation of women potters to the next. In essence, then, what are being mapped are enormous matrilineages, the breadths of which have been shaped by social practices that encouraged the faithful replication of crafted objects and by exogamy that served to export technological styles to neighboring communities" (2010:205).

Herbert (2010) took the notion of stable attributes further by adding a functionalist dimension to such skills. Herbert's study posited mechanisms of ceramic stylistic transmission across generations and between kin groups within the Woodland period in the North Carolina coastal plain. His approach rests on the notion that potting practices, including decorative choices, are subject to adaptive selection as both identity markers and as technologies that ensure the successful creation of an effective cooking vessel (2010:20). Successful potting thus enabled the potter both to eat dinner and to consolidate membership within a group. Herbert's logic is summarized as follows: "While the ceramic medium allows some variability, there are tolerance limits within each of these steps that, if violated, may result in vessel failure… As the knowledge necessary for success in these crafts was paramount to the knowledge necessary to survive, significant deviation from a successful tradition would likely have incurred risks. The same mimetic learning process that assured a certain consistency in replication of techniques … also resulted in the faithful replication of traits we recognize as ‘stylistic’ traditions” (2010:20).

Herbert’s perspective is admirable in its move beyond description and toward explanation. Nevertheless, his model is not useful for identifying individual agency or artistic choice. Under Herbert’s scheme, all decisions essentially boil down to risk aversion strategies. Agency is a critical theme in discussions of trade and exchange in the Woodland period Chesapeake. For instance, Stewart (2004:341) identifies Middle Woodland exchange as a “broad-based network” in which individual people act as semi-independent agents in creating networks of contact for the exchange of goods: “…contacts between real and fictive kin living in different settlements, fusion-fission cycles in settlement, the interaction of trading partners, feasting, bride wealth and exogamous marriage rules, and incidental gift-giving are some of the mechanisms which may have resulted in the movement of goods across the landscape.”

Postprocessualists embraced Bourdieu’s (1972/1977) theory of practice as a counter to mechanical models of human behavior, wherein cultural traits are the result of ecological responses to a physical-social environment (Binford 1962:218). Yet Binfordian processualism apparently did not equate to pure functionalism, since Binford considered some cultural traits to be nonfunctional and therefore irrelevant to adaptive selection: “Many formal characteristics of pottery are stylistic and tend to vary with tradition rather than utilitarian or mechanical factors” (Binford 1968:270 in Lathrap 1983:26). As critiqued by Dietler and Herbich (1998:238), “this basic conceptualization of ‘function’ and its relationship to form is naively oversimplified and severely limited… [this] highlight[s] the dangers of artificially separating style, function, and technology in this way and correlating these domains of material patterning with separate social and techno-utilitarian domains of action." In reality, the social and the utilitarian are two codependent branches of ceramic function, and it is not productive to isolate one from the other.

In some ways, Herbert's (2010) perspective joins an established body of literature that "view[s] it [material culture] largely as a medium of communication" and "emphasize[s] the manipulation of material symbols in strategies of group boundary maintenance, ideological representation of social relations, or cultural categorization" (Dietler and Herbich 1998:245). Lathrap's (1983) discussion of Shipibo-Conibo ceramic techniques likewise demonstrates this understanding of material culture as a medium for expression or communication. Like Herbert, Lathrap rejected the claim that style has no function: "Once one recognizes the possibility of play and of conscious attempts at progressive elaboration one also introduces the certainty that successive artistic productions of the same individual will change progressively over the individual artist's creative lifespan. One also introduces the certainty that particularly satisfying solutions of the aesthetic problems which are basic to a particular art style will be appreciated by other artists in the same tradition who are working on the same problems. Such solutions are likely to pass rapidly through all available communication networks. Art thus serves as a form of communication" (1983:26).

Lathrap's conception of stylistic tradition is a peculiar but valuable marriage between individual agency and cultural evolution. Lathrap recognizes individual artists' agency to "play" in a way that references prior traditional structures yet is not determined by those structures. In other words, the practice of ceramic production is "a train bringing along its own rails" (Bourdieu 1972/1977:79). This is very different than identifying anomalies in material culture as failures to conform to "norms" as culture-historians did (Trigger 2006:199), or as risks to adaptive fitness under Herbert's model. In many ways, Lathrap closely follows Bourdieu's (1972/1977) original theory of practice. Practices are "objectively 'regulated' and 'regular' without in any way being the product of obedience to rules… [practices can be] collectively orchestrated without being the product of the orchestrating action of a conductor" (Bourdieu, 1972/1977:72). At the same time, practices are "grammatically correct performances" (Lathrap 1983:27) that reproduce structures. In the case of ceramics, the structures are "communication networks" with functional consequences upon which evolutionary forces very well may act (1983:38).

Lathrap's (1983) model does not negate Herbert's conclusion that kinship systems, especially matrilineality and matrilocality, are the vectors through which styles move in the Middle Atlantic and that "what are being mapped are enormous matrilineages" (2010:205). The functionalism latent in both models is not without its red flags; in particular, the models might conflate action and intention via their tautological "effect of explaining the creation of material style as an intentional strategy exclusively for communicating material styles" or for communicating identity (Dietler and Herbich 1998:241). Both models conceive of ceramic production as an expressive act that performed kinship identity, and both are functionalist to differing degrees; the value that Lathrap's model adds is attention to agency without negating evolutionary theory. For better or worse, and despite the ethical hazards of its uncritical use, evolutionary thinking continues to inform archaeological reasoning (Prentiss 2019). While I intend for my own study to remain firmly planted in a culture-historical agenda, it is critical that I consider the ends to which the project may be used in future research.

Methodological context: Geochemical ceramic sourcing

X-Ray Fluorescence (XRF) and Gamma-Ray Spectrometry (GRS) are tools of significant power and significant limitation. These techniques are two of many methods recruited by archaeologists in material provenance studies of objects. XRF measures the total concentrations of elements in a sample, while GRS measures the trace amounts of certain gamma-emitting radionuclides in a sample. Application of these methods to ceramics, which are subject to significant chemical alteration beginning with their production and ending with their excavation, tends to complicate both measurement and analysis. Despite the challenges, the techniques have been applied to archaeological ceramics by scholars working in a variety of regions toward understanding practices of exchange, movement, resource management, and craft production.

The term “provenance studies” typically refers to any investigation aiming to identify either the place of an object’s manufacture or the place of raw material origin (Waksman 2017:148). Waksman provides a refined definition: “The place of manufacture of an artifact is defined as its origin, and the location where it was recovered archaeologically as its provenance. Provenance studies, as defined here, designate the procedures and reasoning that aim at attributing archaeological ceramics to their origin, and by extension to a predefined production, based on petrographic or chemical analysis” (2017:148-149).

In the case of ceramics produced by Woodland potters in the coastal Mid-Atlantic, the bulk of archaeological scholarship assumes that high-quality raw clay material is distributed homogeneously and abundantly across landscapes (Herbert and McReynolds 2008). Provenance studies have been used to test this assumption. Herbert and McReynolds (2008) experimentally evaluated raw clay materials across coastal North Carolina and found that high-quality clay is a geographically limited resource. However, their methods involved neither a clay refining process nor the applied knowledge and skill of Native potters.

A standard assumption in most provenance studies is that place of manufacture and place of raw material origin are one and the same. Thus, the act of production may be inferred from raw material origin. Given that unfired raw clay weighs approximately three times that of a completed vessel after firing, it is not strictly practical to transport raw material across long distances for later manufacture (Herbert and McReynolds 2008:5). Ethnographic data worldwide tend to support this.

Nevertheless, the validity of this assumption is questionable. Practices involving the transport of raw materials across landscapes to supply distant production workshops are common for other materials globally, in both recent and remote centuries. Lithic materials provide one example. Ethnographic data from a range of hunter-gatherer societies led researchers to note that people moving sporadically and unpredictably through landscapes tend not to transport lithic raw materials, while those moving cyclically or predictably through landscapes on a seasonal round tend to stockpile lithic raw materials in places disparate from their origin for later production into tools; this pattern is referred to as "provisioning of places" (Kuhn 1995 in Clarkson 491-492). We should keep in mind that an impractical practice under one economic order may be perfectly practical and sensible under another. One cannot assume that minimal transportation cost was the top priority for Woodland potters. If we reject the assumption that raw material origin and place of manufacture were always or usually the same, then prior provenance studies that only account for the regional exchange of finished vessels are undermined.

To this end, provenance studies are strongest when they include samples of definite local origin: wasters and kiln furniture fragments, for example (Waksman 2017:151). If such artifacts do not prove the local acquisition of raw materials, they at least provide a baseline link between a particular chemical signature and local production of vessels. Some sites have yielded fired clay lumps that seem to represent kiln furniture (M. Gallivan, personal communication, January 2024). Spivey (2017:44) recovered multiple wasters from a nineteenth century ceramic production site on the Pamunkey reservation. This suggests that wasters are not absent from the archaeological record; instead, their patchy representation is a matter of archaeological field methodology. When wasters or other definitively local fragments are not recovered, archaeologists assume that the compositional group of highest abundance represents local production, while groups with smaller representation in the sample represent vessels acquired by trade or exchange; this is often referred to as the "criterion of abundance" or "principle of local abundance" (Hall 2017:343, Minc and Sterba 2017:441). The criterion of abundance can be highly problematic when movement of pottery is high, when sample size is small, and when the chemical signatures of ceramics from other sites are unknown (Hall 2017:343).

XRF includes two types, both of which determine the elemental composition of objects by measuring secondary X-ray emission following excitation of the atoms in an object by photons (Shackley 2012:16). The resulting spectra, or frequencies of X-rays of varying intensity or wavelength, is the basis for determining the concentration of multiple elements. The two types of XRF include Wavelength-Dispersive XRF (WD-XRF) and

Energy-Dispersive XRF (ED-XRF). ED-XRF measures the intensity and energy of the fluoresced X-rays, while WD-XRF measures their wavelength (Hall 2017:347-350). A Compared to ED-XRF, WD-XRF is more costly but has better precision and detection limits for lighter elements and some rare earth elements. ED-XRF is a more recently developed technology and includes both desktop and portable instruments (Shackley 2012:37-38).

This study utilizes portable ED-XRF, often referred to as pXRF in archaeological literature, deployed in a nonportable desktop laboratory setting. All subsequent discussion of XRF in this document refers to this method. Portable ED-XRF has several disadvantages. It does not provide a complete elemental portrait of samples; it is only able to successfully measure about 10 to 15 elements in the mid-Z range, where Z denotes atomic number (Glascock 2012:171). It is less precise than WD-XRF, and the process of excitation and secondary fluorescence does not penetrate significantly beyond the surface of a ceramic sherd, which prevents a bulk characterization and renders analyses vulnerable to the conflating variable of post-depositional alteration. Sample surfaces should ideally be flat and homogenous, which is not the case for many Woodland ceramics depending on surface treatment, temper size, and paste consistency (Egloff and Potter 1982).

Although portable ED-XRF is more limited in its range of utility across the periodic table of elements, its accuracy may be refined through the process of empirical calibration using well-characterized standards (Shackley 2012:33), and its lower precision may be mitigated via large sample sizes. Furthermore, it is more time efficient and cost effective for most archaeological investigations. This is especially true for ceramic sourcing studies, since the elements which typically provide the best discriminating power between clay sources (see Schneider 2017:176) are securely accommodated within the range that portable ED-XRF can sufficiently capture. Ultimately, portable ED-XRF was selected over WD-XRF because it accommodates samples nondestructively, while WD-XRF only accommodates powdered samples. In the case of ceramics from the federally managed Mulberry Island, nondestructive techniques were the priority of the DoD and its consulting Tribes.

Unlike XRF, GRS produces an isotopic characterization. Specifically, it measures the abundance of the radioactive isotopes of radon (^{222}Rn), radium (^{226}Ra), uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K). Because gamma-rays are far more penetrating than x-rays, GRS characterizes the whole sample. The technique is nondestructive, but it is more time intensive and less accessible to non-specialists compared to XRF. Consistent sample geometry is required to directly measure absolute isotope quantities. For these reasons, GRS is not commonly employed in archaeological studies, though recent literature promises methodological improvements. Rodriguez et al. (2020) demonstrated two methods to mitigate the issue of diverse geometry in the case of archaeological ceramics from Brazil. This method involves employing ratios to indirectly measure absolute isotope quantities.

Regarding the chemical composition of both raw clay materials and ceramic fragments, provenance studies make two key assumptions. First, there is a consistent relationship between the chemical composition of the raw clay material and of the sherds (Hall 2017:343). Second, there is more variation between than within the raw material sources of interest, at least for certain elements (Montana 2017:88). Typical elements chosen for the discrimination of ceramic compositional groups are often rubidium (Rb), strontium (Sr), zirconium (Zr), and others in the alkali and alkaline earth metal families

(Schneider 2017:176). However, there is no universal list of discriminating elements for clays; the list is highly particular to each region (Shackley 2012:26). Furthermore, chemical variation has proven to be concerningly high within some singular clay deposits (Hall 2017:343); adding the variable of human modification as geological clay is transformed into ceramic raw material only further obscures any geographic signatures present, sometimes beyond the point of visibility.

The most obvious way that clays are culturally altered is through the addition of temper. Examples of tempering materials used by coastal plain Woodland potters include shell, sand, crushed quartz, and grog, to name a few (Egloff and Potter 1982). When temper type and density is consistent across one's sample, its overall effect is to simply dilute the signature of trace elements that distinguishes a clay source (Minc and Sterba 2017:441). Because of the nature of XRF measurement and the variable density of temper within any given sherd, tempering presents an issue for comparability of sample measurements. Fortunately, this issue can be successfully handled analytically. One option is to apply a Mahalanobis distance or filter, in which "the raw concentration data are first scaled by the measurement error; preliminary groups are then sharpened by removing any spread introduced by the addition of temper, using a dilution factor" (Minc and Sterba 2017:441). Another is to employ element ratios, rather than individual elements, as variables in the statistical analysis (Frahm 2018; Rieth, Rafferty, and Saputo 2007; Hein et al. 2004). It is important to note that the addition of temper is just one step in the practice of raw clay modification. For example, ethnographies of Pamunkey potters detail the steps of drying, pulverizing, sieving, filtering, and rehydrating (Pollard 1893 in Spivey 2017:193). These steps in a clay “recipe” all introduce unknown conflating variables into geochemical provenance studies.

Post-depositional changes to ceramic sherds are significant, but do not necessarily make provenance studies untenable. The processes that affect sherds include rehydration or rehydroxylation, absorption, leaching, and precipitation of new minerals (Schneider 2017). Ceramics made from calcareous and non-calcareous clays behave very differently after deposition (2017:175). Post-depositional processes tend to affect surfaces and old breaks more heavily than the interior (2017:162). To complicate matters, a given magnitude or type of post-depositional alteration cannot be assumed across a single site, since a sherd’s vulnerability to post-depositional change is affected by a number of culturally implicated factors including firing temperature, tempering method, vessel use over its life cycle, porosity, and stratigraphic context (2017:162).

Among previous archaeological ceramic provenance studies in the Mid-Atlantic region, there are four which used XRF to study Woodland Chesapeake societies or neighboring cultures, and none which used GRS. The relevant prior studies include three undergraduate honors theses (Steadman 2011; Crow 2011; Brown 2012) and one provenance study of North Carolina coastal plain ceramics (Herbert and McReynolds 2008).

Steadman’s (2008) study focused on the elaborately decorated Abbott zoned-incised ceramics recovered from the coastal plain of Virginia. Steadman applied Laser Ablation Inductively Coupled Plasma Mass Spectroscopy (LA-ICP-MS) analysis to a total of 114 sherds from both Virginia and New Jersey with the aim of establishing whether the Virginia vessels were produced locally or were transported across a large distance through exchange. The study concluded that the Virginia vessels were produced locally.

Crow's (2011) study concerned ceramics recovered from two Catawba sites in North Carolina. Crow obtained 16 reference samples in the form of raw unfired clays from both archaeological sites and two specific clay source pits used by contemporary Catawba potters. These samples were used to establish the groups to which four archaeological ceramic sherds from two sites were compared. X-Ray Diffraction (XRD) was applied to all samples, while only the ceramics were subjected to WD-XRF. Results suggested that a variety of clay source locations were utilized in the past, at least one of which was shared between communities at the two sites. However, all conclusions were highly tentative, owing to the very small sample size of archaeological sherds as well as the confounding effects of post-depositional alteration and clay processing.

Brown's (2012) study is the most relevant in terms of instrumental technique and spatiotemporal cultural context. Brown employed the basic premise that "homogeneity in raw materials… suggests specialization, while variation suggests household production or exchange" (2012:8). Brown applied portable ED-XRF to over 100 sherds from the Kiskiak and Moysonec sites, with Kiskiak ceramics comprising most of the sample. The analysis focused on dispersion as a measure of variation that might indicate household production or exchange. Brown noted that acidic depositional contexts produced higher overall element concentrations in the ceramics compared to alkaline ones, which preserve shell temper. Brown's analysis suggested an increase in variation of chemical signatures at the Middle Woodland II transition.

Finally, Herbert, McReynolds, and colleagues (2008) challenged the assumption that high-quality clay sources are distributed homogenously across the coastal plain landscape. To this end, clays were sampled across North Carolina and subjected to simple field-based assessments of quality. Clays in the Sandhills region were found to be of significantly lower quality. The authors interpret this to indicate that residents of the Sandhills relied on exchange for the procurement of vessels, or at least sought raw materials at far-flung sources, which would suggest contestation between communities over high-quality clay locales. Interpretation of data derived from Neutron Activation Analysis (NAA), XRD, and petrography supported these conclusions. The claim is further substantiated by the low frequency of reconstructable vessels and the high frequency of mend holes and repeatedly fired coil-seam failures recovered from the region's archaeological record. The authors call for future studies to delineate the specific practices by which Woodland people obtained vessels, and suggest a comparison of vessel size between imported and locally produced vessels.

These studies demonstrate several points. The presence of reference samples strengthens the power of a ceramic provenance study. Clay refinement, tempering, and post-depositional alteration must be estimated or controlled for. The prior studies evoke questions relevant to Mulberry Island and its place in the Woodland-period cultural landscape. Do areas lacking high quality clay sources, “clay deserts" so to speak, exist in Virginia, as posited for North Carolina (Herbert and McReynolds 2008)? If such regions exist, were vessels produced nonlocally, locally from local raw materials, or locally from nonlocal raw materials? Were potters in “clay deserts" able to nullify or mitigate the challenges of low quality clay sources by generating and applying skilled knowledge of the refining, tempering, or shaping process? Did the need for this knowledge in some areas but not in others produce differential craft specialization trajectories? A study covering a larger geographic footprint in Virginia may begin to address these and other questions.

Geographic context: Native places in Virginia's Lower Peninsula

The Tidewater region of Virginia is a dynamic, mosaic landscape that owes its character to the meanders and tidal fluctuations of estuarine tributaries through time. The Lower Peninsula is defined to the north and south by the York and James Rivers, respectively. These waterways provided the resources and services that made them a choice focus of settlement during the Middle and Late Woodland periods. Mulberry Island appends the southern shore of the peninsula, within the catchment of the James River. The town of Kiskiak lay northward along the York River. The two are separated by about 26 kilometers (10 miles) of flat to rolling terrain, with no continuous waterway providing readily available transportation corridor.

Kiskiak was by no means the easiest town to access from Mulberry Island. Travel eastward and westward to Kecoughtan or Paspahegh, respectively, probably presented far less effort via dugout canoe, especially if a traveler intended to bring along a ceramic pot. In this sense, Kiskiak is among the less likely candidates for the most socially connected town to Mulberry Island. Additionally, travel east or west perhaps provided the practical convenience of access to varying resource assemblages along the estuarine salinity gradient. Thus, Kiskiak was not selected for comparison in this study using the likelihood of ceramic vessel exchange as a criterion. Instead, it was selected because it is the closest town whose underlying clay resources were the likeliest to be chemically distinguishable from those of Mulberry Island.

Geological mapping of the Lower Peninsula provides some generalized context regarding the sediments underlying both Mulberry Island and Kiskiak. The sediments of the coastal plain are organized hierarchically into geological formations, units, and members. Despite decades of geomorphological research in the area, the topological particularities of some formations are still under revision and debate, and research efforts continue to grapple with a high amount of diversity in sediment composition and origin. Formations are often identified through morphological and topographic characteristics alone and have generally not been subject to baseline chemical comparisons. Formations are identifiable as large, flat expanses of consistent elevation. These are divided by scarps marking events of rapid marine transgression (Peebles et al. 1984). Alternating transgressions and regressions added localized complexity by creating stratigraphically younger deposits at topographically lower elevations than the preceding older strata (Hobbs 2009:10).

Mulberry Island is divided into two zones by the far westernmost occurrence of the Suffolk scarp, which otherwise forms the boundary between the Upland and Lowland Coastal Plain subprovinces of Virginia. The majority of Mulberry Island is within the lowland zone and is composed of Tabb formation sediments (Berquist 2001, Berquist 2013). Terrain within these areas is almost entirely flat, with well drained areas framed by gentle slopes and large, broad swaths of wetland or brackish marsh. Both Kiskiak and the far northernmost portion of Mulberry Island are situated in the uplands zone. Here the terrain is comprised of prominent, elevated terraces dissected by steep slopes leading into well-defined drainage ways. These vicinities contain overlying sediments belonging to the recently mapped Elsing Green formation, which is estuarine in origin (Berquist 2013).

At Kiskiak, but not at Mulberry Island, the Elsing Green sediments are underlain by the Yorktown formation, which is older and marine in origin (Berquist and Johnson 2002, Berquist 2013). These sediments are exposed along eroded banks and on the tops of low-lying terraces overlooking the embayed tributary of Indian Field Creek. Fringing all the sites of interest are deposits of younger Holocene alluvium which form narrow, sandy to muddy estuarine beaches at the water's edge.

Because these geological formations were generally not subject to baseline chemical characterization in prior research, it is not demonstrable that the clay deposits of interest to Woodland potters are chemically distinct by region. Instead, the study proceeded on the assumption that, given the geological diversity of the Virginia coastal plain, sufficient variation may exist to distinguish groups of ceramic samples by provenance.

Methods

The study incorporates collections from four archaeological sites (Table 1, Figure 1). Three sites are located on Mulberry Island: 44NN0024, 44NN0102, and 44NN0179. The fourth site, 44YO0693, is located along the banks of Indian Field Creek.

Table 1: Summary of study sites.

Site ID	Vicinity	Geological subprovince	Chronology	Type
44NN0024	Mulberry Island	Upland	EW – LW	Basecamp
44NN0102	Mulberry Island	Lowland	EW – LW, primary occupation in LW	Basecamp
44NN0179	Mulberry Island	Upland	EW – LW	Basecamp
44YO0693	Indian Field Creek	Upland	MW – Contact Period	Basecamp, "suburb" of the town of Kiskiak

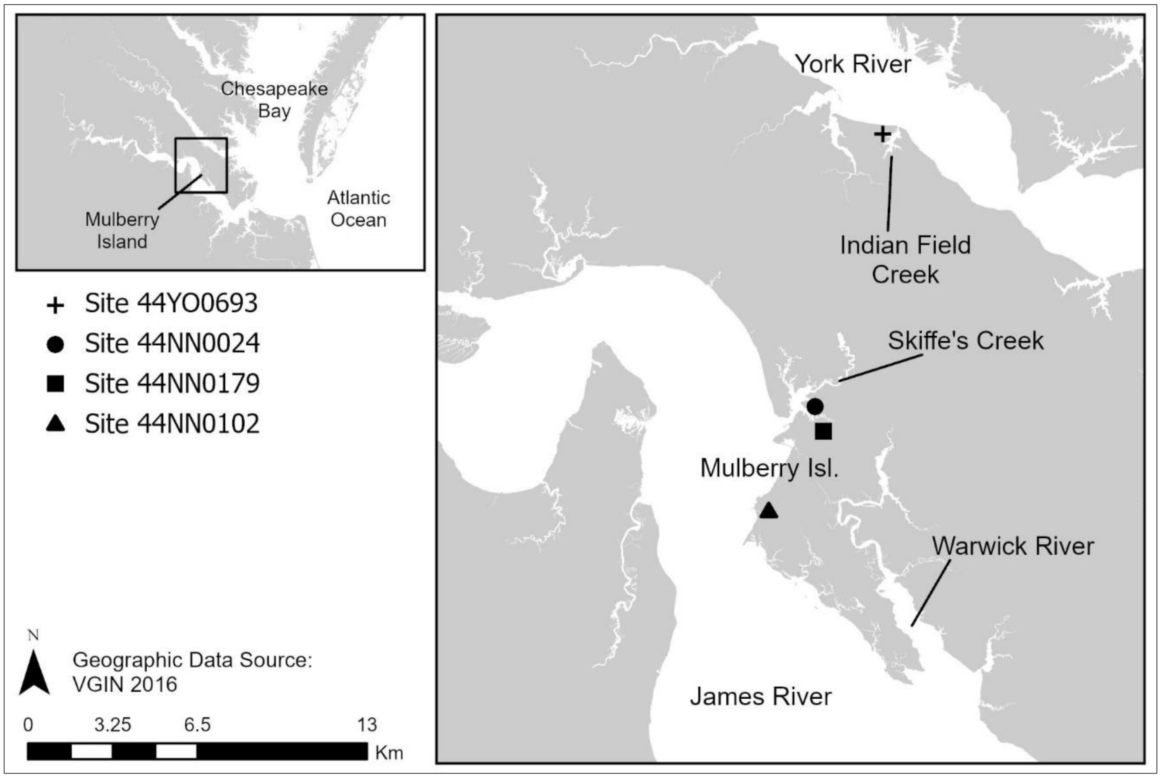

Figure 1: Map illustrating the generalized locations of the study sites in relation to Mulberry Island and Indian Field Creek.

The sites at Mulberry Island were selected for their relatively robust ceramic collections recovered during Phase II evaluation projects. The occupation of 44NN0024 spanned the Early through Late Woodland periods (Polk et al. 1988, Wilkins et al. 2015, Regan 2019). The site occupies the western tip of a large neck of land overlooking a large, embayed, tidal tributary to the west, with two smaller tributaries forming the boundaries of the landform to the north and south. Nearby to the southeast, site 44NN0179 is dispersed across three smaller, elevated terraces overlooking a lower-order tributary, which was artificially impounded in the twentieth century. The site contains Early through Late Woodland components, with the Late Woodland period emphasized in the ceramic assemblage (Regan et al. 2016). Both 44NN0024 and 44NN0179 are within the upland zone of Mulberry Island. This contrasts with site

44NN0102, which is in the geologically distinct lowland zone. This third site is situated on a flat, low-lying terrace overlooking a tidal tributary fringed by broad, brackish marsh, with the James River located less than half a kilometer to the west. The site contains Early through Late Woodland components (Koziarski et al. 2016).

The fourth site, 44YO0693, is located within NWSY and is considered a “suburb” of the dispersed community of Kiskiak. It is situated on an elevated neck of land overlooking the embayed tidal tributary of Indian Field Creek on three sides, with the site representing the core of the Kiskiak community, 44YO0002, located northeast across the tributary (Underwood et al. 2003, Blanton et al. 2005). The site contains Middle Woodland through Contact Period and later components. The site was included in the study for its environmental and archaeological similarity to 44NN0024. At both locations, terrain is characterized by large, flat terraces with steep banks leading down to sources of water on three sides. The embayed tributaries at both sites provided ready access to the major transportation corridors of the James and York Rivers. 44YO0693 contains a similar generalized archaeological signature to 44NN0024. At both sites, a small handful of utilitarian subsurface features such as hearths and small sheet shell middens were either documented during subsurface testing, observed on the surface, or considered likely given the presence of deep, undisturbed stratigraphy. At the same time, a robust quantity of ceramics was recovered from non-feature contexts, minimizing the likelihood of differential post-depositional chemical transformations to the ceramics.

The existing Phase II ceramic assemblage from each site was sampled to include all ceramics which could be visually identified as shell-tempered and were larger than approximately 3 cm^2 in surface area in order to permit XRF measurement (Appendix 1). This sampling method aimed to focus the study on those sherds that are generally diagnostic of the Middle through Late Woodland periods, during which shell tempering was widespread. As a precaution against post-depositional chemical transformation effects, the sample avoided sherds recovered from subsurface feature contexts.[3] The resulting sample totaled 130 sherds, with a minimum of 16 sherds represented from each site (Table 2). A range of surface treatment types are represented in the sample. The sample is dominated by sherds bearing only the voids from leached shell temper, while about 15% of the sherds contain varying amounts of intact, visible shell temper.

Table 2: Attribute summary of the ceramic sample for XRF analysis (n = 130).

Location		**Mulberry Island**			**Indian Field Creek**
Site		**44NN0024**	**44NN0102**	**44NN0179**	**44YO0693**
Temper	Intact Shell	8	9	0	2
	Voids Only	19	15	16	61
Surface Treatment	Cord Marked	5	1	0	13
	Net Impressed	2	4	0	6
	Fabric Impressed	3	10	13	4
	Incised	0	1	0	0
	Plain	1	0	0	3
	Simple Stamped	0	0	0	16
	Unidentifiable	16	8	3	21
Context	Shovel Test	20	5	1	17
	Test Unit	7	19	15	46
Total		**27**	**24**	**16**	**63**

A subsample of 36 sherds was selected for GRS analysis (Table *3*). The sample was stratified to include 15 sherds each from sites 44NN0024 and 44YO0693,

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[3] Subsurface features subject sherds to chemically different micro-environmental conditions compared to non-feature strata. For example, soils within shell-bearing features have been shown to have a higher cation exchange capacity (Cook-Patton et al. 2014), while organic-rich and heat-exposed features have their own chemical conditions.

considered the primary sites of interest to the study. An additional 3 sherds each were selected from sites 44NN0179 and 44NN0102. The GRS sample prioritized larger sherds to maximize the analytical signal to noise ratio.

Table 3: Attribute summary of the ceramic sub-sample for GRS analysis (n = 36).

Location		**Mulberry Island**			**Indian Field Creek**
Site		**44NN0024**	**44NN0102**	**44NN0179**	**44YO0693**
Temper	Intact Shell	8	0	0	0
	Voids Only	7	3	3	15
Surface Treatment	Cord Marked	4	1	0	7
	Net Impressed	1	0	0	2
	Fabric Impressed	3	2	3	3
	Incised	0	0	0	0
	Plain	1	0	0	0
	Simple Stamped	0	0	0	3
	Unidentifiable	6	0	0	0
Context	Shovel Test	12	0	0	4
	Test Unit	3	3	3	11
Total		**15**	**3**	**3**	**15**

To provide a contextual baseline, I sampled 5 raw clay sediments each at 44NN0024 and 44YO0693 (Appendix 1). I collected samples of clay subsoil at a depth approximately 40 cm +/- 10 cm below the ground surface from the tops of the terraces using a 10 cm diameter hand auger. I collected samples from the deeply deposited clay beds, currently exposed along eroding bluffs at the terrace margins, with a hand trowel from points approximately 1 m +/- 50 cm above mean sea level. The 10 sediment samples were freeze dried, pulverized, and packed into 25mL acrylic discs sealed with wax to allow saturation of radon. Following GRS analysis, I transferred these samples to open-bottom plastic cups lined with Prolene® thin-film for XRF analysis.

Finally, 2 historical bricks from archaeological brickyard sites 44NN0014 and 44NN0015, both located in the lowland zone of Mulberry Island to the east of Site 44NN0102 and situated along the Warwick River, were incorporated into the XRF analysis for contextual support. The bricks are not strictly comparable to the Woodland ceramics given the differences in the ceramic versus brick manufacturing process. However, because these bricks are confidently linked to their clay deposits of origin, they strengthen the study by serving as a parallel set of reference samples and help to assess the level of chemical variation present across the landscape of Mulberry Island.

I analyzed all ceramic, sediment, historical brick, and calibration standard samples with a Bruker Tracer 5i portable XRF instrument featuring an expanded 40 mm^2 SSD detector. The instrument was secured in a desktop mount with a sample platform window to facilitate contact-free measurement, and a steel safety cap was placed over the applicable samples during radiation.[4] I irradiated ceramics and bricks once per side for a total of 2 measurements. Sediments and calibration standards were irradiated once. I irradiated for a total of 150 seconds through air at a voltage setting of 45kV, at a current setting of 40μA, and through a custom multilayered filter comprised of 75μm of Cu and 25μm of Ti. We chose these configurations to better capture those elements of interest in the upper mid-Z range which generally provide the best source of differentiation in studies of ceramic provenance (Schneider 2017:176). A layer of 4μm-thick Prolene® thin-film lay below samples for consistency and to eliminate cross-contamination. Spectra were digitally recorded using Bruker Instrument Tools software,

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[4] One ceramic sherd, sample ID 45, was too large to fit below the cap. The sample was analyzed without the cap and is value preserved in the final data set.

and the resulting files were formatted using CalToolkit and S1PXRF software (Bruker 2016, Appendix 2).

The GRS sample subset was analyzed by Dr. James Kaste of the William and Mary Department of Geology using Mirion Industries Broad Energy Intrinsic Germanium Detectors (BE5030 and BE6530) with ultra-low background cryostats housed inside 1134 kg (2500 lb) lead shields with a 3 mm interior copper liner. He counted samples for a duration of100 ksec to 200 ksec each to ensure uncertainties below 6% at Σ = 2. Spectra were collected with Genie software (Mirion Industries 2023). He calculated signal ratios using the net peak intensities at 63 keV (U), 186 keV (U, Ra), 911 keV (Th), and 1461 keV (K) (Appendix 3). For the clay sediment samples, we obtained precise determination of 226Ra at 352 keV, and determined precise geometric efficiencies by gamma counting certified U-Th-K reference materials (CRM DH1a, DL1a) in an identical counting geometry to the unknown sediments. This approach follows that employed by Rodriguez et al. (2020:4-5), although we employed a higher resolution Intrinsic Ge Detector instead of a scintillation detector.

The Bricks and Rocks for Instruments' Ceramic Calibration (BRICC) set is a collection of 20 well-characterized historical brick and geological specimens mounted in 32mm epoxy discs, made freely available to researchers on a loan basis by the Yale Archaeological XRF ExoLab (Frahm et al. 2022). We measured the 18 specimens compositionally appropriate to this study on one side. I processed the resulting spectra in CloudCal, an open-source, R-based application for empirical XRF data calibration (Drake 2018). For each element of interest, a scatterplot of instrument-estimated versus known specimen values was generated, and a calibration curve was fitted using the Lucas-Tooth algorithm. This nonlinear method allows for various means of normalization, as well as slope and intercept adjustments according to the interactions of elemental peaks. Models with r^2 values greater than or equal to 0.90 and with a maximum of 6 removed outliers were fit to 15 elements (Table 2, Figure 2, Appendix 2).[5] I transformed all unknown sample XRF spectra using the calibration curves for these elements within the CloudCal application, resulting in a dataset comprised of fourteen XRF-counted elemental composition variables (Appendix 3). Statistical analysis was conducted using R (R Core Team 2022).

Table 4: Summary of calibrated elements and corresponding parameters for Lucas-Tooth calibration models.

Element Name	**Element Symbol**	**Atomic Number (Z)**	**Correlation (r^2)**	***n* (BRICC specimens)**
Potassium	K	19	0.969	17
Calcium	Ca	20	0.977	18
Titanium	Ti	22	0.954	18
Chromium	Cr	24	0.918	12
Manganese	Mn	25	0.976	18
Iron	Fe	26	0.932	17
Cobalt	Co	27	0.944	13
Zinc	Zn	30	0.978	17
Gallium	Ga	31	0.948	18
Rubidium	Rb	37	0.985	17
Strontium	Sr	38	0.990	17
Yttrium	Y	39	0.985	18
Zirconium	Zr	40	0.971	16
Niobium	Nb	41	0.966	18

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[5] The removal of outliers from the Lucas-Tooth regression follows CloudCal application documentation by its developer Lee Drake (2018) as well as standard statistical analysis practice.

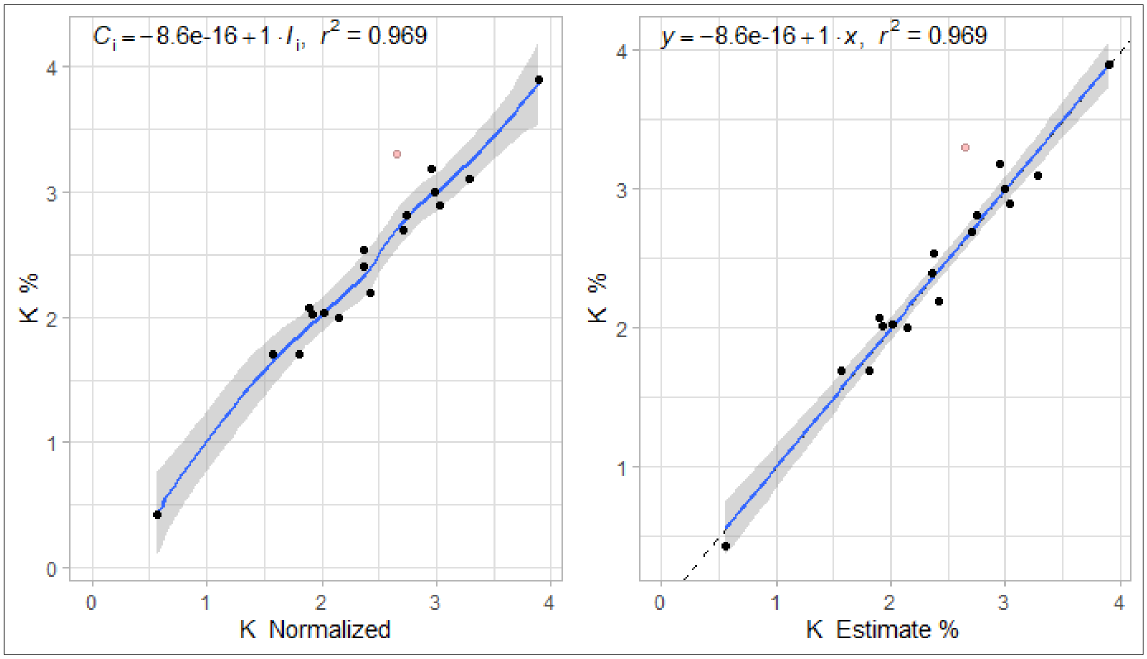

Figure 2: Example of a calibration curve (blue) fit to the estimated versus known values of potassium within the BRICC samples (black points), with one outlier (pink) removed to improve model fit.

Results

The compositional variables generated by the XRF analysis consist of absolute quantities of fourteen elements for all ceramic sherds and clay samples (Appendix 3). The compositional data generated by the GRS analysis differs for clay samples and ceramic sherds (Appendix 4). The ceramic sample GRS dataset is comprised of semiquantitative peak area ratios. This use of signal ratios follows the method outlined by Rodriguez et al. (2020:4-5) for obtaining estimates of absolute isotope ratios despite the inconsistent geometry of archaeological ceramics. Constant geometry was maintained for the clay samples, resulting in a dataset of absolute isotope quantities.

The XRF-counted element values were consistently larger for sherd exterior surfaces compared to interior surfaces (Figure 3). The effect is attributed to differential signal strengths produced by the convex and concave surfaces of the sherds. This geometric effect is mitigated when the element quantities for each sherd are normalized to its XRF-measured iron content (Figure 4). Because some interior surfaces could not be measured due to distance from the X-Ray source, and because this normalization provides a control for geometric effects, all subsequent analyses were conducted on the exterior surface data, comprised of thirteen elements normalized to iron concentration. Therefore, artifact geometry is not considered to have a substantial impact on the study results.

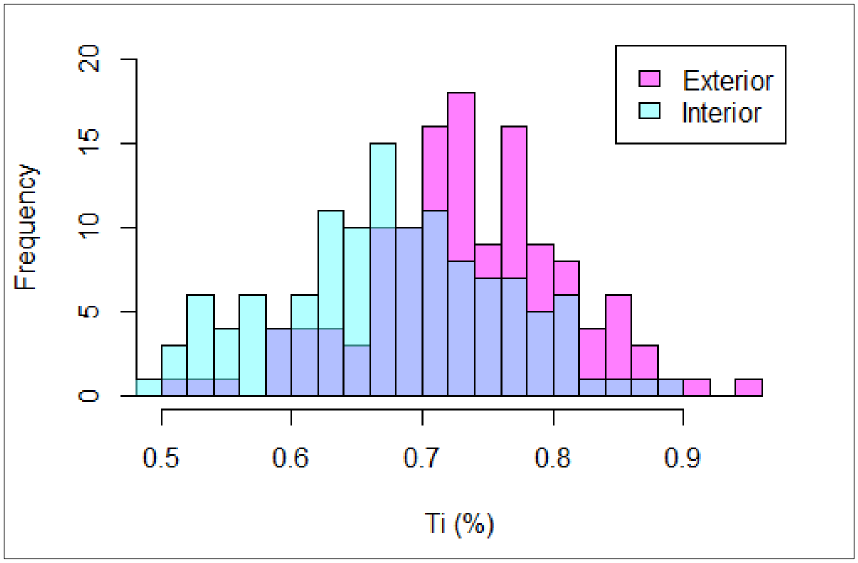

Figure 3: Histogram demonstrating the difference between XRF-counted titanium values for exterior and interior surfaces without normalization.

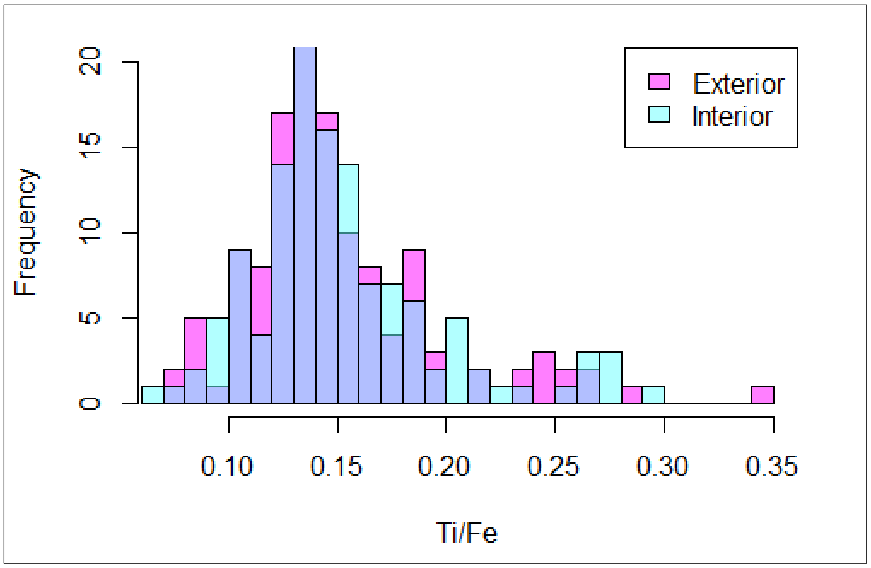

Figure 4: Histogram demonstrating the difference between XRF-counted titanium values for exterior and interior surfaces, following normalization to iron concentration.

The use of element ratios for ceramic provenance analysis has the additional benefit of minimizing the effects of temper density when the two elements constituting a ratio are not differentially abundant within the temper itself (Frahm 2018:19). However, without independent characterization of the temper fragments, the effect of temper within the element ratios is not fully eliminated. In light of small sample sizes and non-normal distributions (Figure 5), the nonparametric two-sample Kruskal-Wallis test was employed to assess the effect of intact shell temper density on each element ratio. Potassium, calcium, manganese, cobalt, zinc, and strontium vary significantly with the presence of intact shell, while the remaining elements are not significantly impacted by temper (Table 5).

Table 5: Summary of the results of Kruskal-Wallis tests for differences in median element concentration between sherds with intact shell temper (n=19) and sherds with voids (n=111), conducted for each XRF-counted element variable. Shaded elements vary significantly with temper presence at the 0.05 level.

Element	**Element symbol**	**K-W test p-value**		**K-W chi-squared statistic**	
		Non-normalized values	Fe-normalized values	Non-normalized values	Fe-normalized values
Potassium	K	0.004	0.015	8.087	5.930
Calcium	Ca	< 0.001	< 0.001	30.211	28.251
Titanium	Ti	0.989	0.945	< 0.001	0.005
Chromium	Cr	0.742	0.270	0.109	1.219
Manganese	Mn	< 0.001	< 0.001	16.508	16.885
Iron	Fe	0.898	NA	0.017	NA
Cobalt	Co	0.021	0.025	5.329	5.006
Zinc	Zn	0.021	0.053	5.307	3.742
Gallium	Ga	0.203	0.060	1.619	3.540
Rubidium	Rb	0.119	0.229	2.430	1.447
Strontium	Sr	< 0.001	< 0.001	2.430	21.313
Yttrium	Y	0.194	0.344	1.687	0.894
Zirconium	Zr	0.159	0.382	1.980	0.763
Niobium	Nb	0.082	0.278	3.033	1.175

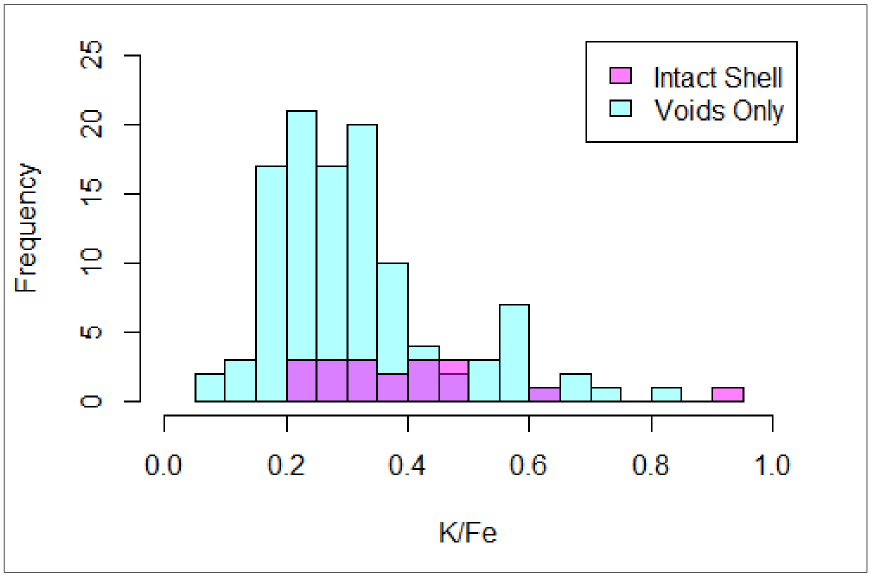

Figure 5: Histogram demonstrating the difference between XRF-counted, Fe-normalized potassium values for sherds with intact shell and those with voids only.

Scatterplots of element ratios provide insights into chemical signatures driven by geographic provenance. The clearest differentiation is provided by a limited array of elements. The ceramics from Site 44NN0102, the only site within the lowland zone of Mulberry Island, contain significantly higher iron-normalized values of manganese (one-sided t = 5.58, $p < 0.005$, df = 34.80)[6] compared to all remaining ceramics (Figure 6, Figure 7). The ceramics from site 44NN0179 exhibit significantly higher concentrations of potassium (one-sided $t = 2.90$, $p = 0.004$, df = 17.29)[7] and titanium (one-sided $t = 5.49$, $p > 0.005$, df = 16.36)[8]. For all sites, the ranges of these elements overlap substantially. Sample 100 is an outlier in relation to the remaining sherds from site 44NN0102, clustering instead with the sherds from site 44NN0179.

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[6] Test was conducted on $\log_{10}$-transformed variables to correct for severely right-skewed distributions.

[7] Test was conducted on natural log-transformed variables to correct for highly right-skewed distributions.

[8] Test was conducted on approximately normal distributions.

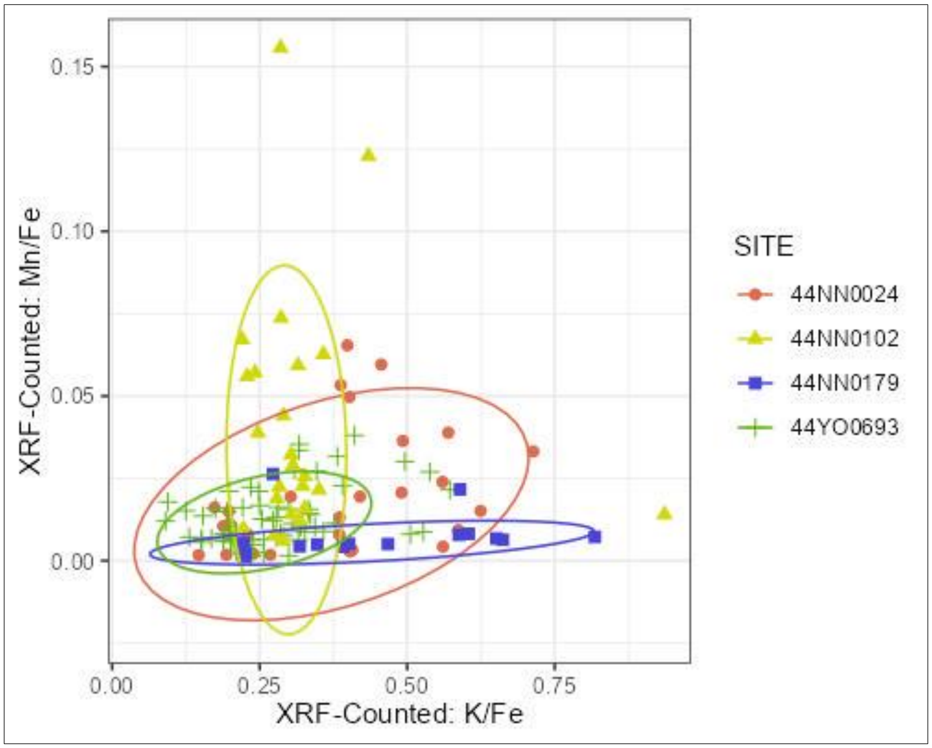

Figure 6: Scatterplot of iron-normalized potassium versus manganese for ceramic sherds, including 90% confidence ellipses by site.

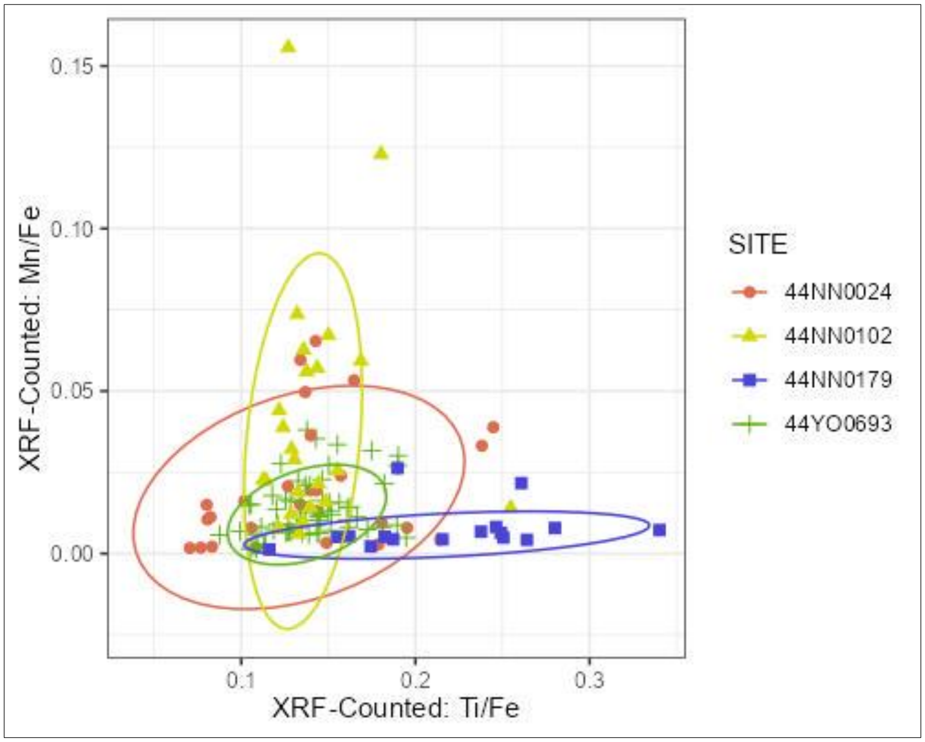

Figure 7: Scatterplot of iron-normalized titanium versus manganese for ceramic sherds, including 90% confidence ellipses by site.

Clustering was likewise observed in the GRS results (Figure 8). This differentiation is driven primarily by the signal ratios incorporating potassium. Together, the GRS and XRF results emphasize the apparent role of potassium in distinguishing regional geographic provenance. The signal ratio for ^{40}K captured by the GRS analysis provides differentiation between Mulberry Island and Indian Field Creek. In contrast, the estimates of total K captured by the XRF analysis fully overlap, differing only by way of range (Figure 9).

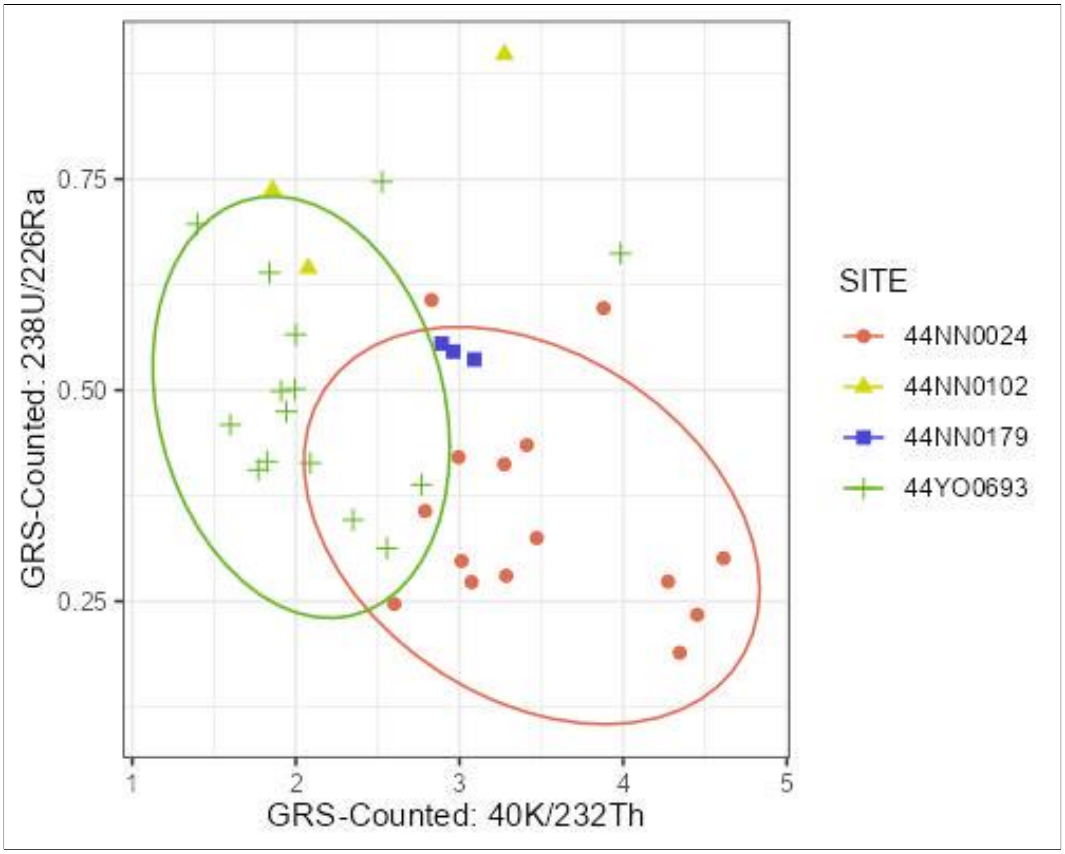

Figure 8: Scatterplot of two GRS-counted signal ratio variables, including 90% confidence ellipses.

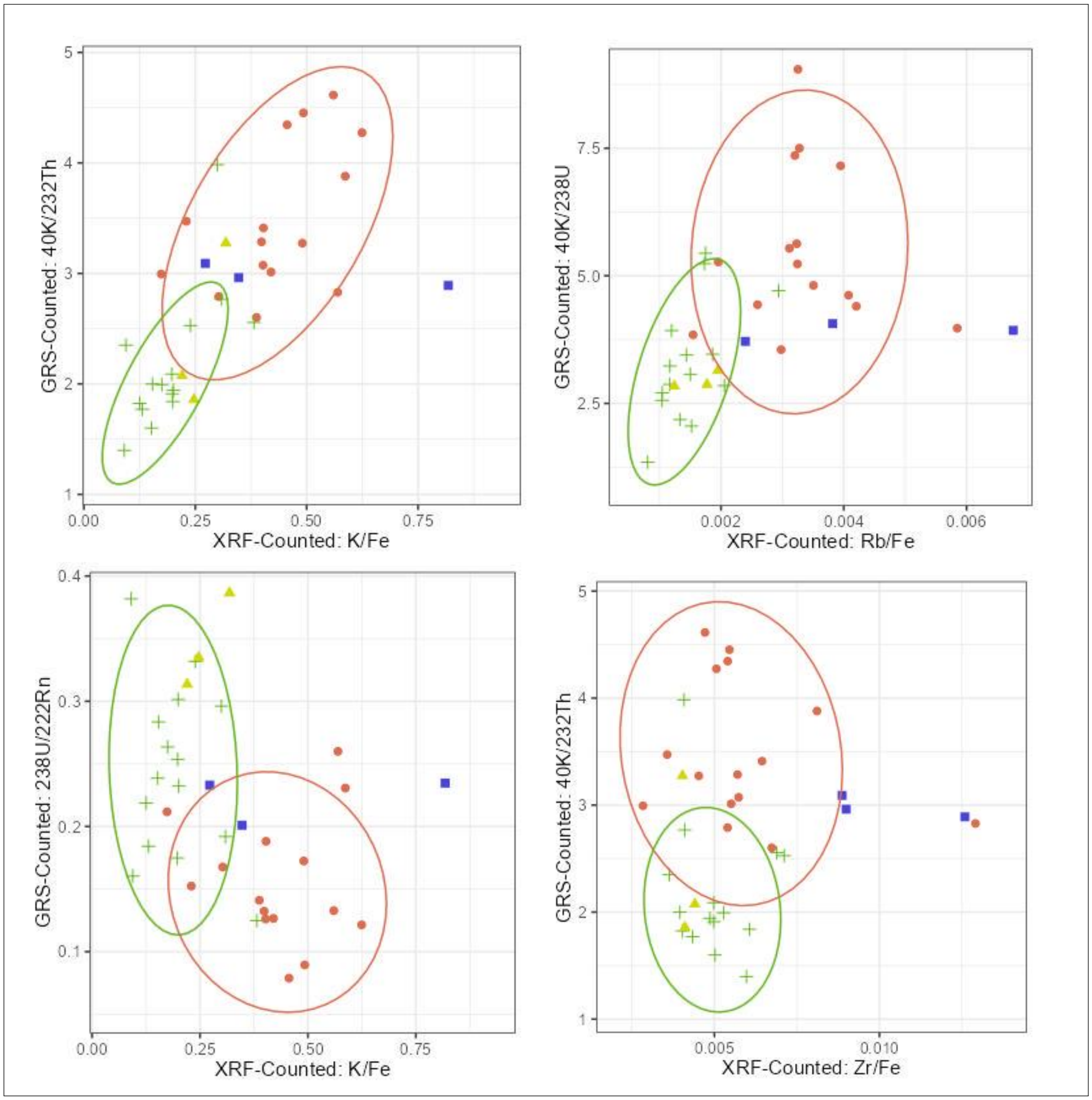

Figure 9: Scatterplots of selected iron-normalized XRF quantities versus GRS isotope signal ratios, including 90% confidence ellipses.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy represents “the ratio of the squared correlation between variables to the squared partial correlation between variables” (Kaiser 1970 in Field et al. 2012:769). It is one of several metrics used to assess the suitability of a dataset for factor analyses such as principal components analysis (PCA). The overall Kaiser-Meyer-Olkin (KMO) value for the data is of middling quality at 0.715, and all variables yielded KMO values greater than or approximately equal to 0.5.[9] These metrics indicate that factor analysis is probably appropriate.

PCA was conducted on all thirteen XRF-counted, iron-normalized variables. Although the ceramics from sites 44YO0693 and 44NN0024 cluster well within the biplot of the first two components, the clusters are not strongly differentiated into clear compositional groups, and the first two components only explain approximately 60% of the latent variation (Figure 10). Samples 100, 16, and 25 represent outliers in relation to the clusters. Instead of aligning with the sherds from their sites of origin, they align with the sherds from 44NN0179. Including the four GRS-counted variables in the procedure improves the clustering effect substantially, although the resulting truncated sample size renders the subsample unsuitable for multivariate techniques (Figure 11). Nevertheless, both PCA biplots are consistent with individual element ratio comparisons, indicating that localized geological factors, not generalized river basins, are more likely responsible for chemical differentiation between sites.

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[9] The variable of iron-normalized manganese yielded a KMO value of 0.448.

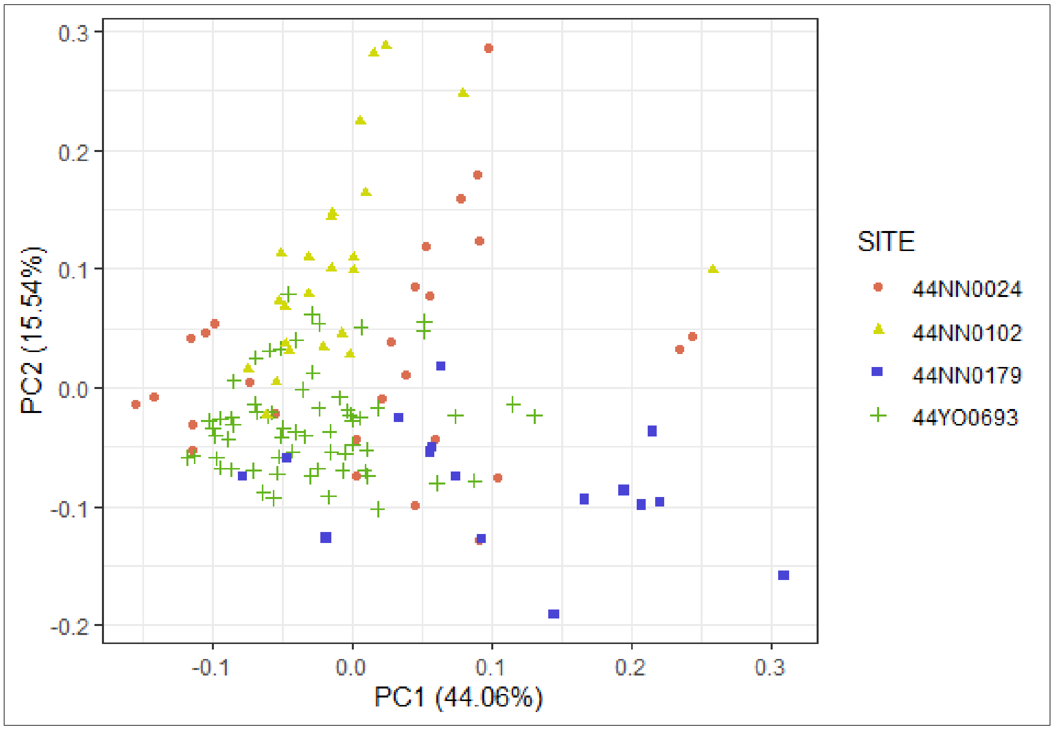

Figure 10: Biplot of the first two principal components identified for the thirteen XRF-counted, iron-normalized variables (n = 130).

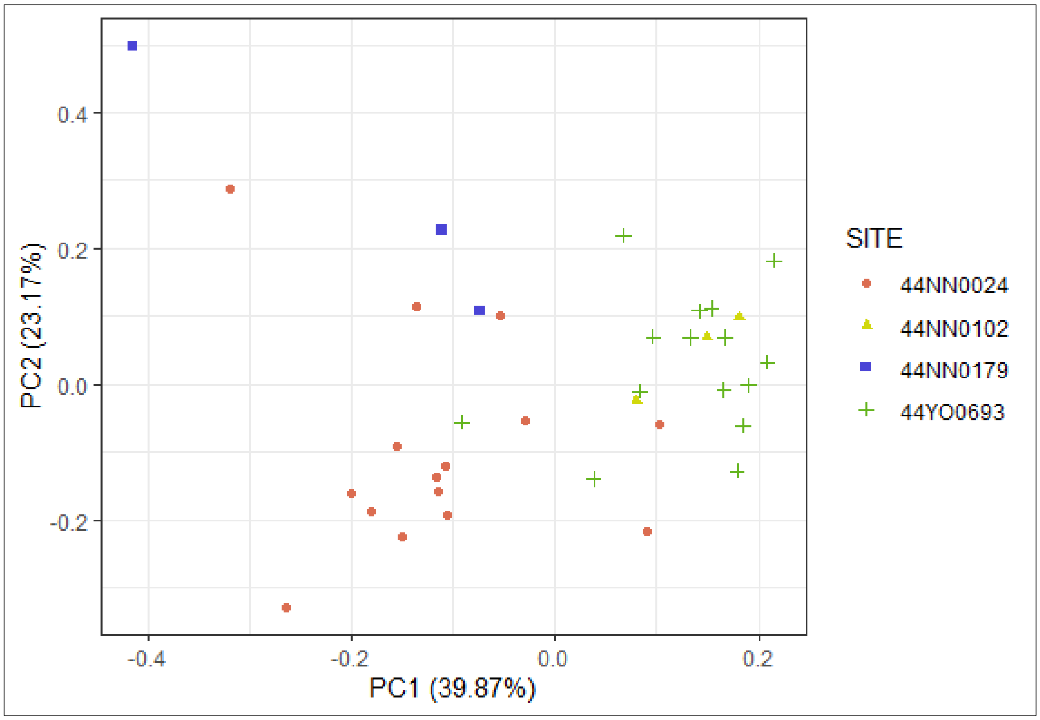

Figure 11: Biplot of the first two principal components identified for the eighteen XRF and GRS counted variables (n = 36).

Results for the ten field-collected clay samples and the two historical bricks provide tentative insights into the ceramic clustering patterns. The samples augered from the tops of the terraces are best differentiated from those collected from the clay banks by their titanium, chromium, and zirconium content. At both 44NN0024 and 44YO0693, the chemical signatures of samples collected from the banks are highly consistent with those observed for archaeological ceramics. On the other hand, the samples augered from the tops of the terraces tended to have higher concentrations of titanium and zirconium, with lower concentrations of chromium. These samples were more chemically consistent with the cluster of ceramics from 44NN0179.

In general, the historical bricks, the source material for which originated in the lowlands zone of Mulberry Island, are chemically consistent with the ceramic sherds. However, their association with either the bank-collected or augered clay samples is ambiguous. While their titanium content would suggest association with the bank-collected samples, their rubidium, zirconium, and chromium content suggest closer association with the clays underlying the upland portions of the terraces.

Together with the archaeological ceramics, the field-collected clay samples and historical brick results emphasize the role of highly localized geological variables in the chemical variation. This variation is not driven by drainage, but by vertically and horizontally complex geological strata comprising the various clay veins from which ceramic raw material was collected.

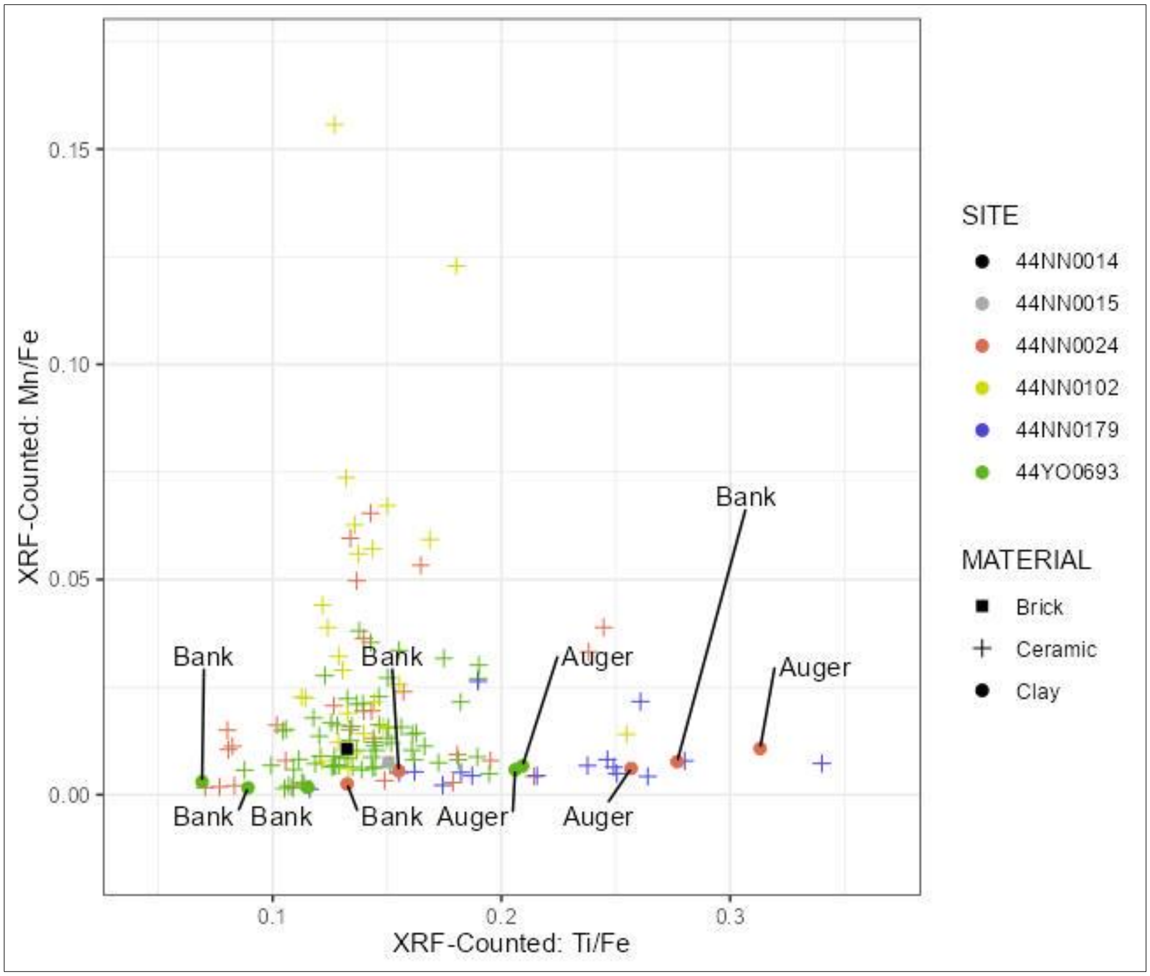

Figure 12: Scatterplot of XRF-collected titanium versus manganese content for sherds, bricks, and clay samples.

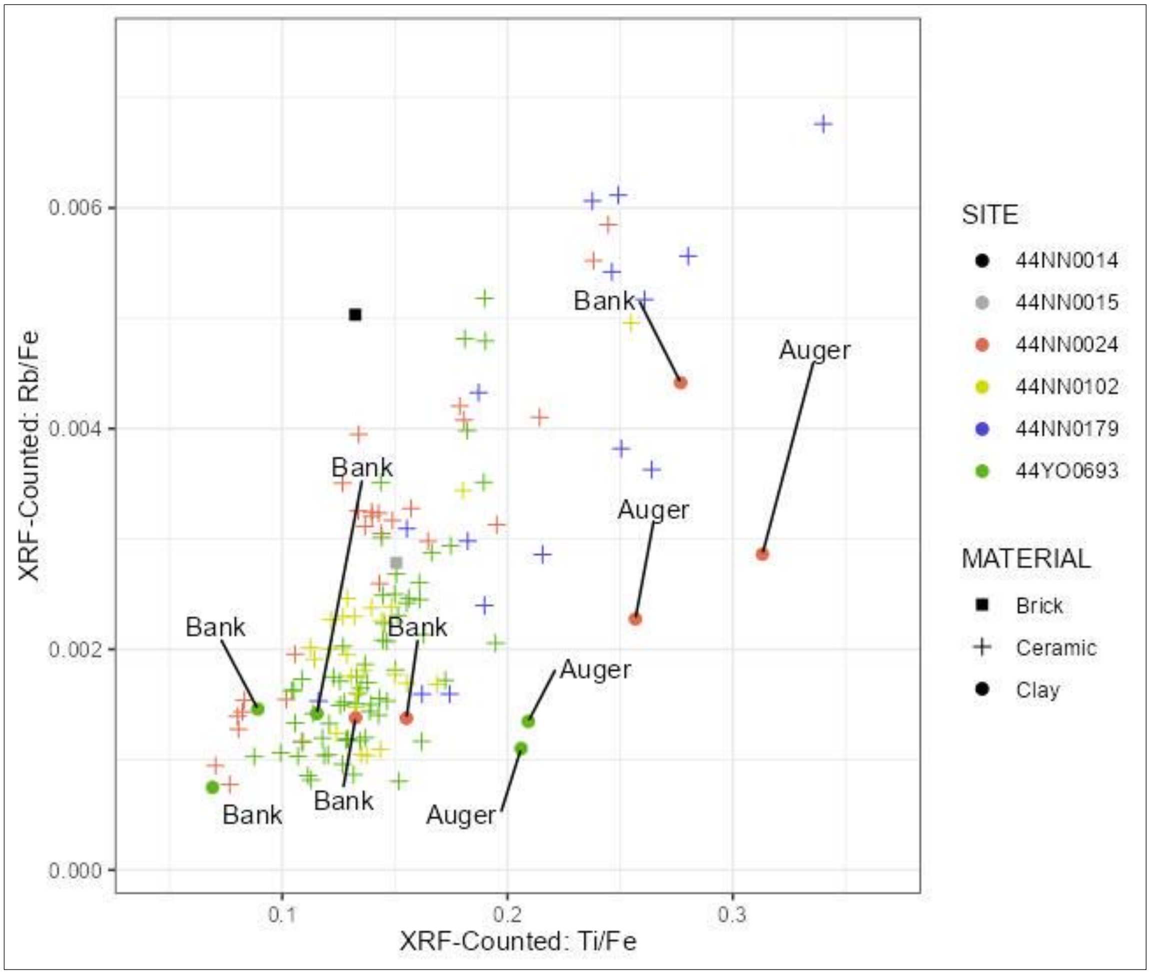

Figure 13: Scatterplot of XRF-collected titanium versus rubidium content for sherds, bricks, and clay samples.

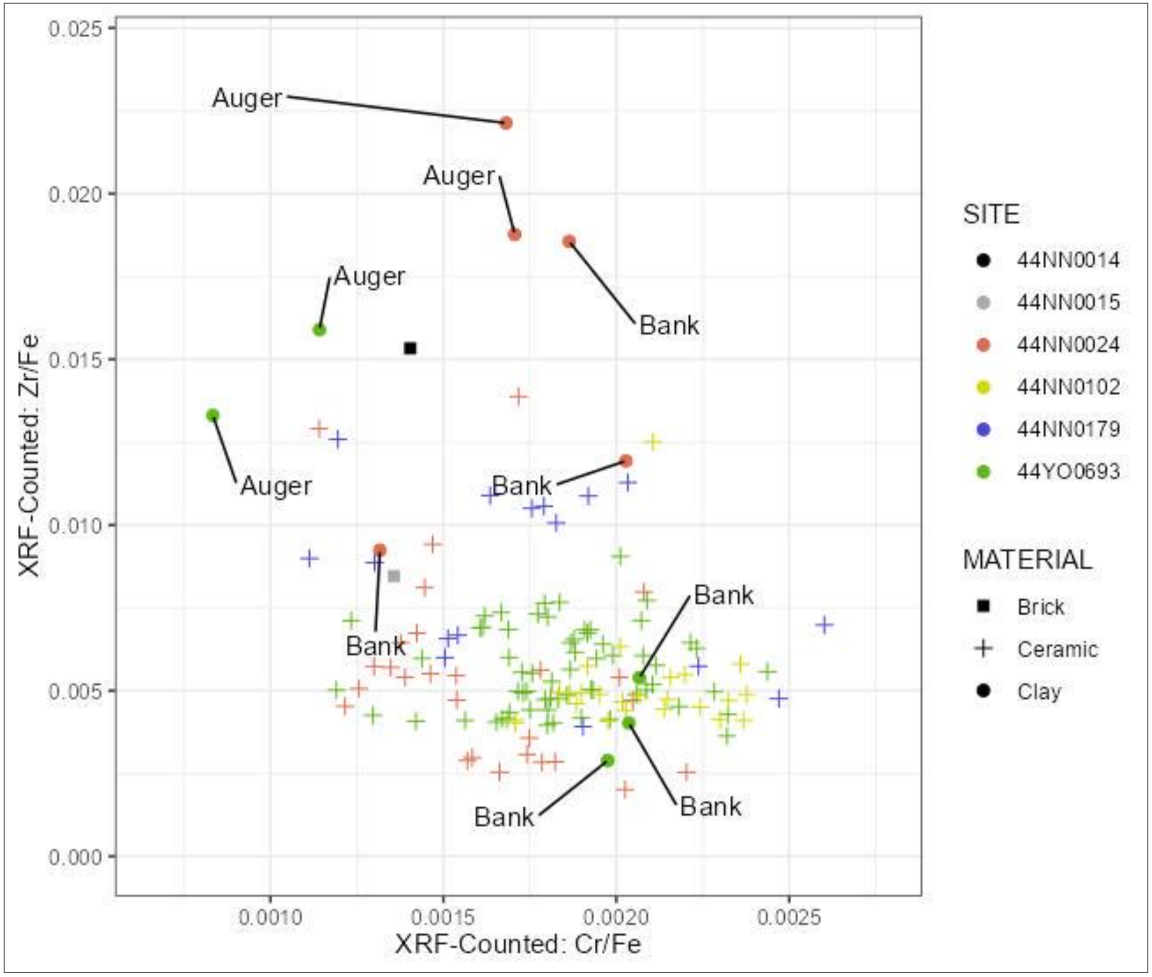

Figure 14: Scatterplot of XRF-collected chromium versus zirconium content for sherds, bricks, and clay samples.

Discussion

Considered in conjunction, the XRF and GRS results demonstrate that the chemical signatures of ceramics found at relatively proximate coastal plain sites have different chemical signatures. The sites with the best observed differentiation via XRF were not located in different river basins, but were all located on Mulberry Island, within a radius of about 4 kilometers (2.5 miles). Thus, the differentiation is not driven by geographic distance, but instead by highly localized geological variables. This differentiation at a small geographic scale was achieved by a) empirically calibrating the XRF data, b) controlling for the conflating effects of temper density and sherd geometry, and c) recognizing that a limited handful of elements drive the differentiation, while others obscure it. Through XRF alone, Sites 44NN0024 and 44YO0693 are indistinguishable; however, by combining the XRF and the GRS data for these sites, the ceramics form distinct clusters with relatively small overlap in their ranges. Ultimately, however, the chemical signatures observed for the sites in this study were not quantitatively distinct enough to provide a reliable means of discerning trade between Mulberry Island and Kiskiak. The same result would probably hold true for comparisons between Mulberry Island (underlain by the Tabb and Elsing Green formations), Kecoughtan (Tabb formation), and Paspahegh (Berquist 2013). XRF ceramic studies comparing the Middle Peninsula to more geologically disparate regions in Tidewater, such as the Eastern Shore Peninsula (Nassawaddox, Omar, and Wachapreague formations) or the interior coastal plain to the south and east (Bacon’s Castle and Charles City formations) may yield stronger differentiation (Mixon et al. 1989). Future studies should target geologically distinct population centers, rather than those which are simply distant from the locale of interest, in order to achieve the most productive results. Results may also be improved by incorporating more precise methods such as WD-XRF or NAA, especially given the low atomic weight of the key element, potassium. This would require at least partial destruction of samples.

Within the XRF results, one sherd, Sample ID 100, merits special attention. Found at Site 44NN0102, the sherd fell well outside the 90% confidence interval for the ceramics of this site. Instead, it clustered well with the 44NN0179 ceramics. Compared with the remaining 44NN0102 sherds, this sherd’s paste has a distinct color and a somewhat less sandy texture (Figure 15). This may indicate that the raw material for the Sample 100 vessel originated at or near site 44NN0179 and was then brought to site 44NN0102, either as raw clay or as a finished vessel. The sherd is undecorated, with only voids where shell temper was once intact. It was found within a shovel test, undifferentiated from the remaining sherds sampled from this site in terms of depositional context.

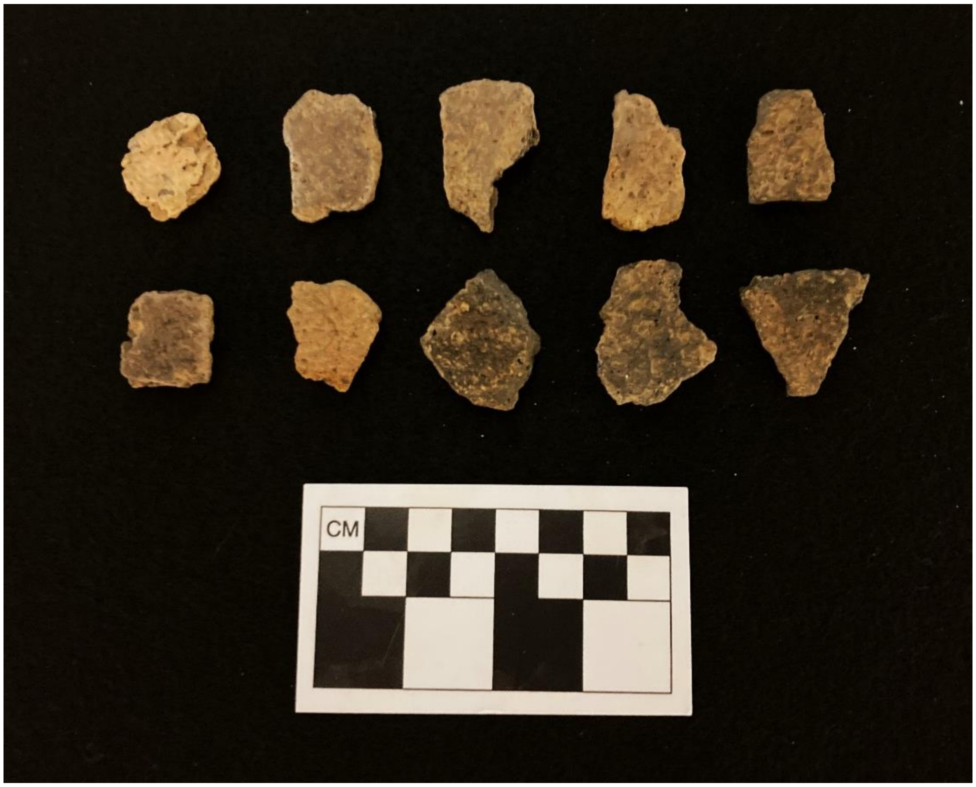

Figure 15: Photo showing Sample ID 100 (top left) in relation to a random selection of sherds from Site 44NN0102.

If this sherd does represent an instance of transport across the landscape of Mulberry Island, its nondescript style and depositional context do not point to a culturally prescribed or otherwise atypical event such as formal trade between two distinct communities. Perhaps a potter decided to travel a few kilometers farther afield for clay or took advantage of a clay vein encountered during an unrelated excursion. Perhaps the sherd was brought in its final form as a simple, utilitarian vessel. Though merely speculative, the details of the sherd seem to emphasize matters of everyday life that would point to informal social connectivity across the island.

An alternate interpretation arises considering the raw clay sample data. First, there is no mapped geological difference between sites 44NN0024 and 44NN0179, raising questions as to the origin of chemical differentiation between these two sites in the XRF results. Second, only the ceramics from 44NN0179, plus sherd 100 from 44NN0102, align with the chemical signature of the clay samples augered from the inland terraces. In contrast, most of the ceramics have signatures consistent with the clay samples collected from the exposed banks. Finally, site 44NN0179 is the only sampled site overlooking a small, interior tributary, while the remaining sites are located along large, embayed tributaries subject to higher storm wave energy and tidal fluxes, which create tall, exposed bluffs or shallow cut-banks from which clay is easily gathered. No bluffs of this kind are found at site 44NN0179.

These observations suggest that variation in the cultural practice of clay mining, rather than variation in geographic provenance linked to geological variables, is responsible for the different chemical signature observed for site 44NN0179. By this interpretation, potters at 44NN0024, 44NN0102, and 44YO0693 typically gathered clay along the cut-banks of large tributaries, in the same way documented ethnographically for Pamunkey potters (Pollard 1893 in Spivey 2017:193). In contrast, potters at 44NN0179 seem to have mined clay from interior borrow pits. Given the lack of bluffs or pronounced cut-banks located at this site, this practice was probably a matter of practicality. Even so, the functional aspects of a practice such as clay mining cannot be entirely separated from the socially salient underpinnings of Algonquian landscape management. This is especially relevant given ethnohistoric and oral historical evidence that clay mining was traditionally a group activity, seasonally prescribed to the springtime. The opening of a clay vein was an important community event which marked "the occasion of a great feast. The whole tribe, men, women and children were present and each family took home a portion of the clay" (Pollard 1893:17 in Spivey 217:192).

The ceramic chemical results show strong continuity in the practice of clay mining from river banks from the Middle Woodland period through the twenty-first century. Yet evidence of experimentation and diversification of practices is also found within the data. The anomalous sherd, Sample ID 100, may have been an experimental vessel made from clay taken from an interior borrow pit at 44NN0102, thus aligning with sherds from site 44NN0179 in chemical signature. Site chronology may relate to the compositional contrast observed for site 44NN0179, which is the only sampled site with a prevalent Late Woodland component. It is possible that the widespread shifts in sedentism and technology marking the Middle to Late Woodland transition were linked to experimentation with different means of gathering clay. It is also possible that the inferred difference in cultural practices at this site indicates a group of newcomers to the island during the Late Woodland, speaking to broader population shifts in the region.

Conclusion

The chemical variation in Woodland period ceramics from proximate coastal plain sites is substantial enough to provide a foundation for continued archaeological inquiry. Successful documentation of this variation requires sensitivity to issues of temper, sherd geometry, post depositional alteration, and underlying geological formations at both the sampling and analysis stages of the research design. The latter two sources of variation, whether they are targeted in the study or present a source of conflation, would persist even when incorporating more precise techniques such as WD-XRF or NAA, although these methods would better resolve the effects of temper and sherd geometry. For these reasons, no single sourcing method is a one-size-fits-all solution to understanding movement and social connectivity in the Woodland Chesapeake. Furthermore, the vertical diversity of coastal plain geology complicates matters of interpretation.

The results of this study present two viable but mutually exclusive interpretations. The first is that geographic provenance drives the observed chemical differentiation of ceramics; the outlier sherd from 44NN0102 represents an instance of movement across the local landscape. The second is that the cultural practice of clay sourcing drives the chemical differentiation of ceramics; thus, the outlier sherd represents an instance of experimentation or deviation from the culturally prescribed method of gathering clay from stream banks. The second interpretation is strengthened considering the field-collected clay reference sample results.

The possibility that cultural practices could conflate the results of sourcing studies in this way is noteworthy. It challenges archaeologists to rethink the assumption that high-quality clay is available everywhere, or that there was one universal means of gathering it. The coastal plain is far from geologically simple. Its topologies are still under debate by regional geomorphologists, with subtle scarps and formations yet to be named. Surely this demonstrates that Woodland potters faced a range of clay resources from which to choose. The physical experience of collecting clay brings such matters of choice to the forefront of archaeological inquiry. What specific clay texture might a Middle Woodland potter seek out? What terrain would they be willing to navigate if it meant accessing a certain vein? How and why did clay gathering develop into a community-wide event, and how common was this practice regionally? In these situations, would the accessibility of a vein take priority, at the expense of clay quality or other considerations? These questions are undoubtedly related to the traditional knowledge held by Algonquian potters today. Future studies would be strengthened by consultation with potters to explore these questions.

Finally, creative combinations of multiple chemical sourcing methods offer a viable path toward refining Mulberry Island's Native cultural history and identity membership. This is true whether provenance or practice drives the clear differentiation in ceramic chemistry. Although this study did not identify evidence of trade between Mulberry Island and Kiskiak, it differentiated these sites chemically via GRS, despite high geological consistency and a lack of differentiation achievable through XRF alone. It also illuminated movement of materials or experimentation in potting practices that took place internally on the island. Future studies should test for exchange between Mulberry Island and other population centers, with attention toward those which are sufficiently differentiated according to the mapped geology of the area. While refining the island's culture history will ultimately be a complex task, it is one which promises significant insights.

The collective action of potting by task groups or localized communities of practice offers glimpses into a complicated and granular broader landscape of social identity. These details of practice and social relationships are masked by the prominently labeled centers on colonial-era maps of the region. While this study did not connect a hypothesized hinterland to its center, it demonstrates that those more sparsely populated locales in the Chesapeake held their own diversity of cultural identities. Far from existing in isolation, these communities formed a continuous, connected, mosaic patchwork that comprised the social fabric of Tsenacomacoh.

Appendix 1: Sample Inventory

Sample ID	Site	Material	Excavation Unit	Excavation Unit ID	Fort Gregg-Adams Accession	WMCAR Context Number	Shell Temper	Secondary Temper	Surface Treatment	Surface Treatment Group	Weight (g)	GRS
1	44NN0024	Ceramic	STP	I23, S50/E400	2124	NA	Voids	None visible	Unidentifiable	Unidentifiable	2.9668	N
2	44NN0024	Ceramic	STP	I23, S50/E400	2124	NA	Voids	None visible	Unidentifiable	Unidentifiable	2.416	N
3	44NN0024	Ceramic	TU	I-23-1	2492	NA	Voids	None	Net Impressed	Net Impressed	10.4519	N
4	44NN0024	Ceramic	STP	S760/E760	2283	NA	Voids	Sand	Fabric Impressed	Fabric Impressed	5.3268	Y
5	44NN0024	Ceramic	STP	S760/E760	2283	NA	Shell and voids	Sand	Fabric Impressed	Fabric Impressed	4.3285	Y
6	44NN0024	Ceramic	STP	S920/E880	2296	NA	Voids	Fine sand	Plain	Plain	4.0116	Y
7	44NN0024	Ceramic	STP	S150/E400	2138	NA	Voids	None visible	Unidentifiable	Unidentifiable	2.0646	N
8	44NN0024	Ceramic	TU	S1000/E1032	2461	NA	Shell and voids	Fine sand	Cord Marked	Cord Marked	4.2036	Y
9	44NN0024	Ceramic	STP	S760/E800	2285	NA	Shell and voids	None visible	Plain or unidentifiable	Unidentifiable	3.9649	Y
10	44NN0024	Ceramic	STP	S760/E800	2285	NA	Shell	None visible	Unidentifiable	Unidentifiable	3.0788	Y
11	44NN0024	Ceramic	STP	S760/E800	2285	NA	Shell	None visible	Cord Marked or unidentifiable	Unidentifiable	3.4523	Y
12	44NN0024	Ceramic	STP	S760/E800	2285	NA	Shell	None visible	Net Impressed	Net Impressed	12.5046	Y
13	44NN0024	Ceramic	STP	S760/E800	2285	NA	Voids	None visible	Net Impressed or Unidentifiable	Unidentifiable	2.743	Y
14	44NN0024	Ceramic	STP	S440/E320	2240	NA	Voids	None visible	Scraped and unidentifiable	Unidentifiable	4.7334	Y
15	44NN0024	Ceramic	TU	S597/E487	2424	NA	Voids	Fine sand	Cord Marked or unidentifiable	Unidentifiable	8.6493	Y
16	44NN0024	Ceramic	TU	I-23-1	2483	NA	Voids	None visible	Unidentifiable or incised	Unidentifiable	3.0506	N
17	44NN0024	Ceramic	STP	S1000/E1000	2299	NA	Voids	Fine sand and grog	Cord Marked	Cord Marked	5.479	Y
18	44NN0024	Ceramic	TU	S762/E724	2336	NA	Voids	Sand	Fabric Impressed	Fabric Impressed	7.5396	N
19	44NN0024	Ceramic	STP	S800/E720	2288	NA	Voids	None visible	Unidentifiable	Unidentifiable	3.3741	N
20	44NN0024	Ceramic	STP	S800/E720	2288	NA	Voids	None visible	Net Impressed or Unidentifiable	Unidentifiable	4.8816	N
21	44NN0024	Ceramic	STP	S800/E720	2288	NA	Voids	Grog? Or none visible	Unidentifiable	Unidentifiable	9.7878	N
22	44NN0024	Ceramic	STP	S560/E320	2254	NA	Voids	Grog? Or sand	Unidentifiable	Unidentifiable	2.3272	N
23	44NN0024	Ceramic	STP	S150/E350	2135	NA	Voids	Sand	Unidentifiable	Unidentifiable	7.2143	N
24	44NN0024	Ceramic	TU	S762/E724	2339	NA	Voids	Fine sand	Cord Marked or Cord Wrapped Stick	Cord Marked	4.8324	N
25	44NN0024	Ceramic	TU	S762/E724	2339	NA	Voids	Sand	Eroded	Unidentifiable	2.9735	N
65	44NN0024	Ceramic	STP	S1000/E1040	2300	NA	Shell and voids	None visible	Cord Marked	Cord Marked	5.1207	Y
66	44NN0024	Ceramic	STP	S1000/E1040	2300	NA	Shell and voids	Fine sand	Cord Marked	Cord Marked	2.9481	Y
26	44YO693	Ceramic	STP	E333	NA	E046	Voids	Sand	Plain or unidentifiable	Unidentifiable		N
27	44YO693	Ceramic	STP	E435	NA	E082	Voids	Fine sand	Plain or unidentifiable	Unidentifiable	2.0722	N
28	44YO693	Ceramic	STP	E353	NA	E052	Voids	Fine sand	Simple Stamped	Simple Stamped	4.5063	Y
29	44YO693	Ceramic	STP	E337	NA	E048	Voids	Fine sand	Simple Stamped	Simple Stamped	4.6691	N
30	44YO693	Ceramic	STP	E337	NA	E048	Voids	Sand	Simple Stamped	Simple Stamped	4.3004	N
31	44YO693	Ceramic	STP	E341	NA	E050	Voids	Fine sand	Net Impressed	Net Impressed	11.0715	Y
32	44YO693	Ceramic	STP	E341	NA	E050	Voids	Fine sand	Net Impressed	Net Impressed	14.4111	Y
33	44YO693	Ceramic	STP	E341	NA	E050	Voids	Fine sand	Net Impressed	Net Impressed	8.9745	N
34	44YO693	Ceramic	STP	E341	NA	E050	Voids	Fine sand	Net Impressed	Net Impressed	6.9405	N
35	44YO693	Ceramic	STP	E341	NA	E050	Voids	Fine sand	Net Impressed	Net Impressed	10.1061	N
36	44YO693	Ceramic	STP	E430	NA	E077	Voids	Sand	Cord Marked	Cord Marked	19.0911	Y
37	44YO693	Ceramic	STP	E430	NA	E077	Voids	Fine sand	Cord Marked	Cord Marked	12.8552	N
38	44YO693	Ceramic	STP	E430	NA	E077	Voids	Fine sand	Cord Marked	Cord Marked	9.3934	N
39	44YO693	Ceramic	STP	E430	NA	E077	Voids	Sand	Unidentifiable	Unidentifiable	16.2417	N
40	44YO693	Ceramic	STP	E430	NA	E077	Voids	Sand	Unidentifiable	Unidentifiable	7.4085	N
41	44YO693	Ceramic	STP	E313	NA	E041	Voids	None visible	Plain or unidentifiable	Unidentifiable	6.1431	N
42	44YO693	Ceramic	STP	E313	NA	E041	Voids	None visible	Unidentifiable	Unidentifiable	4.1819	N
43	44YO693	Ceramic	TU	3	NA	018	Voids	None visible	Unidentifiable or Simple Stamped	Unidentifiable	4.5551	N
44	44YO693	Ceramic	TU	3	NA	018	Voids	Fine sand	Plain or unidentifiable	Unidentifiable	6.1692	N
45	44YO693	Ceramic	TU	3	NA	020	Voids	Fine sand	Fabric Impressed	Fabric Impressed	43.8795	Y
46	44YO693	Ceramic	TU	3	NA	019	Voids	Fine sand	Fabric Impressed	Fabric Impressed	14.8446	Y
47	44YO693	Ceramic	TU	3	NA	019	Shell and voids	Grog? Or none visible	Net Impressed	Net Impressed	9.6409	N
48	44YO693	Ceramic	TU	3	NA	019	Voids	None visible	Fabric Impressed	Fabric Impressed	4.4785	N
49	44YO693	Ceramic	TU	3	NA	019	Voids	Fine sand	Simple Stamped	Simple Stamped	7.2036	Y
50	44YO693	Ceramic	TU	3	NA	019	Voids	Fine sand	Simple Stamped or Incised	Simple Stamped	2.6883	N
51	44YO693	Ceramic	TU	3	NA	019	Voids	None visible	Simple Stamped	Simple Stamped	3.547	N
52	44YO693	Ceramic	TU	3	NA	019	Voids	Sand	Unidentifiable or Simple Stamped	Unidentifiable	2.2396	N

53	44YO693	Ceramic	TU	3	NA	019	Voids	None visible	Unidentifiable	Unidentifiable	3.0659	N
54	44YO693	Ceramic	TU	3	NA	019	Voids	None visible	Plain or unidentifiable	Unidentifiable	2.1123	N
55	44YO693	Ceramic	TU	1	NA	008	Voids	Fine sand	Simple Stamped	Simple Stamped	4.4282	Y
56	44YO693	Ceramic	TU	1	NA	010	Voids	None visible	Plain or simple stampled	Plain	3.0674	N
57	44YO693	Ceramic	TU	1	NA	010	Voids	Fine sand and grog	Cord Marked	Cord Marked	7.5839	Y
58	44YO693	Ceramic	TU	1	NA	010	Voids	None visible	Unidentifiable	Unidentifiable	6.1763	N
59	44YO693	Ceramic	TU	1	NA	009	Voids	Fine sand	Plain or unidentifiable	Unidentifiable	3.9387	N
60	44YO693	Ceramic	TU	1	NA	009	Voids	Sand	Fabric Impressed	Fabric Impressed	16.5613	Y
61	44YO693	Ceramic	TU	1	NA	009	Voids	Fine sand	Simple Stamped	Simple Stamped	10.5404	N
62	44YO693	Ceramic	TU	1	NA	009	Shell and voids	None visible	Simple Stamped	Simple Stamped	5.3916	N
63	44YO693	Ceramic	TU	1	NA	009	Voids	None visible	Plain	Plain	3.3687	N
64	44YO693	Ceramic	TU	1	NA	009	Voids	Sand	Plain	Plain	6.6068	N
67	44YO693	Ceramic	TU	5	NA	053	Voids	Sand	Cord Marked or unidentifiable	Unidentifiable	2.8745	N
68	44YO693	Ceramic	TU	5	NA	053	Voids	Fine sand	Cord Marked	Cord Marked	31.4018	Y
69	44YO693	Ceramic	TU	2	NA	012	Voids	Fine sand	Cord Marked or Unidentifiable	Unidentifiable	2.9298	N
70	44YO693	Ceramic	TU	2	NA	012	Voids	None visible	Simple Stamped	Simple Stamped	3.7614	N
71	44YO693	Ceramic	TU	2	NA	012	Voids	Fine sand	Simple Stamped	Simple Stamped	4.172	N
72	44YO693	Ceramic	TU	2	NA	002	Voids	Fine sand	Unidentifiable	Unidentifiable	2.5424	N
73	44YO693	Ceramic	TU	2	NA	015	Voids	Fine sand	Simple Stamped	Simple Stamped	3.9201	N
74	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Cord Marked	Cord Marked	5.2155	Y
75	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Simple stamped or unidentifiable	Unidentifiable	3.8002	N
76	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Simple stamped or unidentifiable	Unidentifiable	3.0491	N
77	44YO693	Ceramic	TU	2	NA	013	Voids	Sand	Simple stamped or unidentifiable	Unidentifiable	3.5395	N
78	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Simple Stamped	Simple Stamped	2.635	N
79	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Simple Stamped	Simple Stamped	6.1569	N
80	44YO693	Ceramic	TU	2	NA	013	Voids	Sand	Unidentifiable	Unidentifiable	6.1492	N
81	44YO693	Ceramic	TU	2	NA	013	Voids	Fine sand	Simple Stamped	Simple Stamped	8.4177	N
82	44YO693	Ceramic	TU	2	NA	014	Voids	Crushed Quartz	Cord Marked	Cord Marked	15.066	Y
83	44YO693	Ceramic	TU	2	NA	014	Voids	Fine sand	Simple Stamped	Simple Stamped	4.8126	N
84	44YO693	Ceramic	TU	2	NA	014	Voids	Coarse sand	Unidentifiable	Unidentifiable	3.9529	N
85	44YO693	Ceramic	TU	2	NA	014	Voids	Coarse sand	Cord Marked	Cord Marked	3.5259	N
86	44YO693	Ceramic	TU	2	NA	014	Voids	Crushed Quartz	Cord Marked	Cord Marked	4.8617	N
87	44YO693	Ceramic	TU	2	NA	014	Voids	Crushed Quartz	Cord Marked	Cord Marked	10.958	Y
88	44YO693	Ceramic	TU	2	NA	014	Voids	Crushed Quartz	Cord Marked	Cord Marked	7.6624	Y
89	44YO693	Ceramic	TU	2	NA	014	Voids	Coarse sand	Cord Marked	Cord Marked	3.8499	N
90	44YO693	Ceramic	TU	2	NA	014	Voids	Coarse sand	Cord Marked	Cord Marked	5.5449	N
91	44NN0102	Ceramic	TU	5	4098.05	NA	Voids	Fine sand	Unidentifiable	Unidentifiable	7.1047	N
92	44NN0102	Ceramic	TU	5	4099.09	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	5.4718	Y
93	44NN0102	Ceramic	TU	5	4099.10	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	5.012	N
94	44NN0102	Ceramic	TU	8	4110.02	NA	Voids	Fine sand	Cord Marked	Cord Marked	4.1366	Y
95	44NN0102	Ceramic	STP	910N/1000E	4019.03	NA	Voids	Fine sand	Net Impressed	Net Impressed	3.5224	N
96	44NN0102	Ceramic	TU	4	4095.09	NA	Voids	None visible	Unidentifiable	Unidentifiable	3.2671	N
97	44NN0102	Ceramic	TU	4	4094.11	NA	Voids	Fine sand	Net Impressed	Net Impressed	5.9228	N
98	44NN0102	Ceramic	TU	4	4095.04	NA	Voids	Fine sand	Net Impressed	Net Impressed	3.1404	N
99	44NN0102	Ceramic	TU	4	4095.05	NA	Shell and voids	None visible	Fabric Impressed	Fabric Impressed	4.2272	N
100	44NN0102	Ceramic	STP	990N/1037.5E	4088.03	NA	Shell and voids	None visible	Plain or unidentifiable	Unidentifiable	2.9192	N
101	44NN0179	Ceramic	TU	9	1098.31	NA	Voids	None visible	Fabric Impressed	Fabric Impressed	5.6933	Y
102	44NN0179	Ceramic	TU	2	1066.313	NA	Voids	None visible	Plain or unidentifiable	Unidentifiable	3.0244	N
103	44NN0179	Ceramic	TU	7	1087.32	NA	Voids	None visible	Fabric Impressed	Fabric Impressed	4.6993	N
104	44NN0179	Ceramic	TU	7	1086.317	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	10.4702	Y
105	44NN0179	Ceramic	TU	7	1087.318	NA	Voids	None visible	Fabric Impressed	Fabric Impressed	5.568	N
106	44NN0179	Ceramic	TU	9	1098.309	NA	Voids	Fine sand or grog	Fabric Impressed	Fabric Impressed	12.8891	N
107	44NN0179	Ceramic	TU	7	1087.316	NA	Voids	Fine sand or grog	Fabric Impressed	Fabric Impressed	8.1354	N
108	44NN0179	Ceramic	TU	7	1087.318	NA	Voids	None visible or grog	Fabric Impressed	Fabric Impressed	3.6772	N
109	44NN0102	Ceramic	STP	887.5N/1015E	4090.01	NA	Shell	None visible or grog	Eroded	Unidentifiable	1.8626	N
110	44NN0102	Ceramic	TU	4	4095.07	NA	Voids	Fine sand or grog	Fabric Impressed	Fabric Impressed	9.6394	Y
111	44NN0102	Ceramic	TU	4	4095.07	NA	Voids	Fine sand or grog	Fabric Impressed	Fabric Impressed	3.0945	N
112	44NN0179	Ceramic	STP	955N/1210E	1018.3	NA	Voids	Fine sand or grog	Fabric Impressed then smoothed	Fabric Impressed	3.2181	N
113	44NN0102	Ceramic	TU	4	4095.15	NA	Voids	None visible or grog	Unidentifiable	Unidentifiable	3.0037	N
114	44NN0179	Ceramic	TU	10	1101.315	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	16.1703	N

115	44NN0102	Ceramic	TU	4	4095.06	NA	Voids	Fine sand or grog	Net Impressed	Net Impressed	4.6293	N
116	44NN0179	Ceramic	TU	10	1101.316	NA	Voids	None visible	Unidentifiable	Unidentifiable	3.7039	N
117	44NN0179	Ceramic	TU	7	1085.321	NA	Voids	Fine sand or grog	Fabric Impressed	Fabric Impressed	4.4265	N
118	44NN0179	Ceramic	TU	7	1085.322	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	3.3601	N
119	44NN0179	Ceramic	TU	2	1070.3	NA	Voids	None visible	Fabric Impressed and incised	Fabric Impressed	2.4817	N
120	44NN0102	Ceramic	TU	4	4095.08	NA	Shell and voids	Fine sand	Fabric Impressed	Fabric Impressed	5.4483	N
121	44NN0102	Ceramic	TU	4	4095.08	NA	Shell and voids	Fine sand	Fabric Impressed	Fabric Impressed	4.83	N
122	44NN0102	Ceramic	TU	4	4095.08	NA	Shell and voids	Fine sand	Fabric Impressed	Fabric Impressed	6.5171	N
123	44NN0102	Ceramic	TU	4	4095.08	NA	Shell and voids	Fine sand	Fabric Impressed	Fabric Impressed	4.4364	N
124	44NN0102	Ceramic	TU	4	4095.11	NA	Voids	None visible	Unidentifiable	Unidentifiable	3.1671	N
125	44NN0102	Ceramic	TU	4	4095.12	NA	Voids	Fine sand or grog	Plain or unidentifiable	Unidentifiable	4.6156	N
126	44NN0102	Ceramic	STP	910N/1000E	4019.04	NA	Voids	Fine sand or grog	Plain or unidentifiable	Unidentifiable	3.4734	N
127	44NN0102	Ceramic	TU	1	4082.03	NA	Shell	Fine sand	Fabric Impressed	Fabric Impressed	2.1177	N
128	44NN0179	Ceramic	TU	9	1097.316	NA	Voids	None visible	Plain or unidentifiable	Unidentifiable	2.875	N
129	44NN0102	Ceramic	STP	730N/1015E	4025.01	NA	Shell	Fine sand or grog	Incised	Incised	3.0374	N
130	44NN0179	Ceramic	TU	4	1076.304	NA	Voids	Fine sand	Fabric Impressed	Fabric Impressed	9.8429	Y
1001	44NN0024	Clay	Auger	NA	NA	NA	NA	NA	NA	NA	NA	Y
1002	44NN0024	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1003	44NN0024	Clay	Auger	NA	NA	NA	NA	NA	NA	NA	NA	Y
1004	44NN0024	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1005	44NN0024	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1008	44YO0693	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1009	44YO0693	Clay	Auger	NA	NA	NA	NA	NA	NA	NA	NA	Y
1010	44YO0693	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1011	44YO0693	Clay	Bank	NA	NA	NA	NA	NA	NA	NA	NA	Y
1012	44YO0693	Clay	Auger	NA	NA	NA	NA	NA	NA	NA	NA	Y
1013	44NN0014	Brick	Surface Collection	NA	NA	NA	NA	NA	NA	NA	NA	N
1014	44NN0014	Brick	Surface Collection	NA	NA	NA	NA	NA	NA	NA	NA	N
1015	44NN0015	Brick	Surface Collection	NA	NA	NA	NA	NA	NA	NA	NA	N
1016	44NN0015	Brick	Surface Collection	NA	NA	NA	NA	NA	NA	NA	NA	N

Appendix 2: XRF Data

Sample ID	K (ext.)	Ca (ext.)	Ti (ext.)	Cr (ext.)	Mn (ext.)	Fe (ext.)	Co (ext.)	Zn (ext.)	Ga (ext.)	Rb (ext.)	Sr (ext.)	Y (ext.)	Zr (ext.)	Nb (ext.)	K (int.)	Ca (int.)	Ti (int.)	Cr (int.)	Mn (int.)	Fe (int.)	Co (int.)	Zn (int.)	Ga (int.)	Rb (int.)	Sr (int.)	Y (int.)	Zr (int.)	Nb (int.)
1	1.6584	0.3816	0.7966	0.0179	0.0193	11.3068	0.0015	0.0131	0.004	0.0107	0.0064	0.0026	0.0337	0.0023	1.2173	0.2739	0.7189	0.0121	0.0231	6.424	-1.00E-04	0.0084	0.0029	0.0075	0.0062	0.0025	0.0269	0.002
2	1.8812	0.2454	0.7037	0.01	0.0642	4.8839	0.0011	0.0112	0.0029	0.0149	0.0074	0.0042	0.023	0.0026	1.3936	0.2563	0.8022	0.0201	0.0281	11.4762	9e-04	0.016	0.0039	0.007	0.0054	0.0027	0.0276	0.002
3	1.9837	0.1468	0.804	0.0163	0.0132	7.3991	2e-04	0.0113	0.0036	0.0086	0.0034	0.0034	0.0188	0.002	0.7564	0.0916	0.558	0.0215	0.0238	7.2929	-9.00E-04	0.0175	0.0033	0.0063	0.0035	0.0028	0.0144	0.0014
4	2.8023	0.6178	0.7868	0.0077	0.1197	5.0047	0.0018	0.0121	0.002	0.0164	0.0071	0.008	0.0236	0.0027	2.2797	0.7994	0.6929	0.0075	0.4835	4.4684	0.0026	0.0105	0.0019	0.0153	0.008	0.009	0.0207	0.0024
5	3.2809	0.6015	0.7031	0.0066	0.0795	5.2551	0.001	0.0108	0.0019	0.0171	0.0071	0.0072	0.0266	0.0026	2.7106	0.8441	0.6976	0.0076	0.1224	5.1157	0.0011	0.0115	0.002	0.0163	0.0071	0.0086	0.0215	0.0025
6	1.6387	0.2844	0.7272	0.0056	0.0115	4.0667	2e-04	0.0098	0.0021	0.0171	0.0059	0.0047	0.0262	0.0027	1.2459	0.1837	0.6404	0.0068	0.0116	3.6533	2e-04	0.0112	0.0021	0.0158	0.0072	0.0073	0.0231	0.0024
7	2.1504	0.2207	0.8525	0.0225	0.0201	11.1096	5e-04	0.0111	0.0041	0.0086	0.0053	0.0027	0.0224	0.0019	1.6444	0.1882	0.6501	0.011	0.0481	4.5142	7e-04	0.0113	0.003	0.0121	0.007	0.0035	0.0207	0.0021
8	1.7418	1.1209	0.7408	0.0064	0.2397	4.4968	0.0027	0.0158	0.0018	0.0134	0.0115	0.0094	0.0303	0.003	1.0352	0.9359	0.6655	0.0058	0.1347	3.3218	0.0015	0.0142	0.0018	0.0105	0.0117	0.0102	0.0246	0.0022
9	1.9493	1.7046	0.6629	0.0063	0.2409	4.8477	0.0024	0.0185	0.0024	0.0151	0.0174	0.0082	0.0278	0.0028	1.6088	1.2845	0.7626	0.0098	0.1741	4.9421	0.0021	0.0164	0.0024	0.0131	0.015	0.0145	0.0266	0.0027
10	2.0963	1.0507	0.6978	0.0073	0.0972	4.9916	0.0018	0.0198	0.002	0.0162	0.0148	0.0081	0.0275	0.0028	1.5909	1.4346	0.7297	0.0098	0.3406	5.0196	0.003	0.0182	0.0021	0.0146	0.018	0.0122	0.0263	0.0028
11	2.7832	1.7629	0.7194	0.0069	0.1173	5.6755	0.0018	0.0138	0.0023	0.0199	0.018	0.0083	0.0257	0.0028	2.237	1.7443	0.7473	0.0077	0.0808	5.2967	0.0012	0.0138	0.002	0.0214	0.0163	0.0088	0.0241	0.0026
12	1.4458	0.9389	0.6841	0.0096	0.093	4.7779	7e-04	0.0146	0.0026	0.0124	0.0142	0.0091	0.0258	0.0024	0.633	0.5205	0.5534	0.008	0.2742	3.2097	0.001	0.0154	0.0016	0.0034	0.0135	0.0111	0.0173	0.0017
13	1.9226	1.085	0.6885	0.0065	0.3154	4.8227	0.0028	0.0199	0.002	0.0156	0.014	0.0099	0.0275	0.0026	1.7972	1.3238	0.7687	0.0093	0.3259	5.8448	0.003	0.0181	0.0021	0.0135	0.015	0.0134	0.0285	0.0029
14	1.0887	0.2197	0.6385	0.0112	0.1013	6.2736	0.0021	0.0181	0.0032	0.0097	0.0071	0.0139	0.0178	0.0023	1.2211	0.28	0.6844	0.0127	0.1435	7.2573	0.0023	0.0172	0.0035	0.0103	0.0071	0.0169	0.0193	0.0025
15	1.5515	0.7746	0.7132	0.0118	0.0535	6.7494	2e-04	0.0262	0.0022	0.0132	0.0072	0.0094	0.0241	0.0022	1.0028	1.0341	0.5455	0.0112	0.0835	5.5579	-2.00E-04	0.0345	0.002	0.0093	0.0072	0.0085	0.0198	0.0018
16	1.8799	0.2691	0.6548	0.0137	0.0166	7.865	8e-04	0.0123	0.0033	0.0121	0.0035	0.0024	0.0242	0.0022	0.8723	0.0807	0.5218	0.012	0.0095	4.5028	-0.0015	0.01	0.0028	0.0055	0.0039	0.0023	0.0171	0.0014
17	2.4744	0.4162	0.7622	0.0061	0.0392	4.2177	0.0012	0.0158	0.002	0.0172	0.0067	0.0097	0.0342	0.003	1.9735	0.367	0.7209	0.0046	0.0247	4.124	2e-04	0.0086	0.002	0.0138	0.0064	0.0061	0.0355	0.0025
18	1.5973	0.6791	0.6862	0.0032	0.109	2.8042	0.002	0.0057	0.0016	0.0164	0.0097	0.0049	0.0362	0.0024	1.2077	0.5076	0.5922	0.0033	0.0196	2.3237	-4.00E-04	0.0037	0.0018	0.0111	0.0106	0.0043	0.0348	0.0021
19	1.7883	0.8766	0.7259	0.0165	0.1356	9.0495	0.0032	0.0149	0.0035	0.0126	0.0098	0.0043	0.0258	0.0023	1.5559	0.6926	0.7122	0.0137	0.0652	6.6563	0.0013	0.0145	0.003	0.0118	0.0099	0.0044	0.0232	0.002
20	1.8004	0.8122	0.7709	0.0159	0.1003	9.5644	0.0024	0.0133	0.0032	0.0122	0.0098	0.0042	0.0243	0.0022	1.2275	0.5358	0.6956	0.0175	0.4454	6.9531	0.003	0.0153	0.0026	0.009	0.0094	0.0065	0.0217	0.0018
21	1.7596	0.8007	0.7294	0.0139	0.0995	8.8552	0.0026	0.0154	0.0028	0.0127	0.009	0.0041	0.0256	0.0022	0.7278	0.2749	0.5363	0.018	0.2554	4.9946	9e-04	0.0142	0.0023	0.0036	0.0079	0.0052	0.0149	0.0013
22	2.1708	0.242	0.7942	0.0095	0.0175	5.3338	0.0013	0.0106	0.0028	0.0169	0.0054	0.0064	0.03	0.0025	1.5336	0.1797	0.7982	0.0154	0.0255	6.3923	3e-04	0.01	0.0032	0.0085	0.0048	0.0065	0.0246	0.002
23	1.9678	0.1699	0.7519	0.0073	0.015	3.5097	0.0013	0.0067	0.002	0.0144	0.0029	0.007	0.028	0.0024	2.1072	0.2102	0.7351	0.0064	0.0175	3.5886	6e-04	0.0052	0.0023	0.0189	0.0051	0.0067	0.0288	0.0025
24	1.4153	0.5873	0.7175	0.0054	0.0291	3.6753	4e-04	0.0049	0.0019	0.0115	0.0086	0.0039	0.0346	0.002	1.3624	0.5622	0.7107	0.0072	0.0429	3.4509	0.001	0.0051	0.0019	0.0115	0.0089	0.0043	0.0365	0.002
25	2.1193	0.7418	0.7073	0.0051	0.0985	2.9697	0.0023	0.0042	0.0019	0.0164	0.0114	0.0039	0.0412	0.0024	2.055	0.8627	0.8388	0.0053	0.0549	3.0191	0.002	0.0032	0.0018	0.016	0.0099	0.0043	0.0457	0.0024
26	1.8487	0.5785	0.8102	0.0109	0.0493	5.6585	0.0012	0.0199	0.0023	0.0088	0.01	0.0049	0.0285	0.0024	1.2892	0.4148	0.7862	0.011	0.0418	4.699	7e-04	0.0086	0.0021	0.0074	0.009	0.0045	0.0294	0.002
27	1.7431	0.3006	0.8124	0.0121	0.0515	6.1064	0.0017	0.0109	0.0025	0.0107	0.0051	0.0045	0.0253	0.0025	1.4121	0.2346	0.8126	0.0103	0.0799	4.9174	0.002	0.0102	0.003	0.0094	0.006	0.0053	0.0232	0.0023
28	1.5457	0.5778	0.7079	0.0065	0.1283	4.0488	0.0014	0.0163	0.0018	0.0119	0.0101	0.0027	0.0279	0.0024	1.3198	0.6496	0.6715	0.0059	0.0712	3.6868	5e-04	0.0196	0.0023	0.0158	0.0093	0.0029	0.0261	0.0022
29	1.4598	0.3122	0.7349	0.0081	0.0472	4.5677	0.0011	0.0118	0.0021	0.0119	0.0036	0.0041	0.0334	0.0021	1.3013	0.2783	0.7632	0.0089	0.0534	4.3123	0.0017	0.0171	0.002	0.0124	0.0037	0.0045	0.0409	0.0021
30	1.7023	0.3318	0.7692	0.0092	0.0797	5.106	0.0029	0.0171	0.0022	0.0137	0.0046	0.0068	0.0369	0.0025	1.3446	0.301	0.7038	0.0091	0.0324	4.6813	8e-04	0.0089	0.0022	0.012	0.0054	0.0102	0.0279	0.0021
31	0.8685	0.2156	0.6679	0.009	0.079	4.9634	9e-04	0.0104	0.0025	0.0058	0.0051	0.009	0.0262	0.0023	0.7838	0.2112	0.6528	0.011	0.0725	5.3357	0.0011	0.0135	0.0031	0.0072	0.0059	0.0062	0.0218	0.0021
32	0.9086	0.114	0.6282	0.0084	0.0262	4.5233	-6.00E-04	0.0068	0.0023	0.0065	0.0053	0.0053	0.022	0.0021	0.54	0.0791	0.506	0.0087	0.0471	3.6323	-7.00E-04	0.0083	0.0023	0.0061	0.0053	0.0079	0.0192	0.0017
33	1.3484	0.3311	0.8022	0.0103	0.0345	4.6512	0.0014	0.0092	0.0025	0.008	0.0059	0.0114	0.03	0.0024	1.0467	0.24	0.6272	0.0109	0.0299	4.5123	6e-04	0.0087	0.0029	0.0085	0.0062	0.0087	0.0255	0.0018
34	1.3624	0.3413	0.7785	0.0104	0.0367	5.7717	0.0018	0.0097	0.0024	0.0095	0.006	0.0104	0.0255	0.0025	1.02	0.2786	0.6259	0.0134	0.0356	6.4601	7e-04	0.0108	0.0026	0.0082	0.0057	0.0075	0.0234	0.0019
35	1.2147	0.2884	0.7161	0.0111	0.0528	6.4262	0.0016	0.01	0.0034	0.0055	0.0061	0.0111	0.0357	0.0027	0.8411	0.2003	0.6489	0.0099	0.0567	3.8176	0.0011	0.0114	0.0024	0.0048	0.0054	0.0092	0.0255	0.0019
36	1.6438	0.1932	0.5974	0.0078	0.0085	5.4903	-7.00E-04	0.0081	0.0022	0.0095	0.0029	0.0022	0.0224	0.0019	0.3408	1e-04	0.4202	0.0052	0.0234	2.7322	-0.0021	0.0071	0.0018	0.0024	0.0025	0.0021	0.0147	0.0012
37	1.5203	0.1844	0.6748	0.0099	0.0145	5.9287	3e-04	0.0055	0.0028	0.0084	0.003	0.0022	0.0246	0.0016	1.0416	0.1261	0.5206	0.0084	0.0118	4.3271	-3.00E-04	0.0064	0.0018	0.0064	0.0021	0.0022	0.0224	0.0013
38	1.3478	0.2647	0.6004	0.0074	0.0081	5.7078	3e-04	0.0069	0.0021	0.0093	0.0034	0.0021	0.0243	0.0016	1.0671	0.1075	0.5241	0.0109	0.0106	5.3514	-9.00E-04	0.0083	0.0021	0.006	0.0026	0.0022	0.0178	0.0012
39	1.202	0.197	0.5814	0.0094	0.0114	5.4324	-4.00E-04	0.0053	0.0021	0.0056	0.0018	0.0021	0.0268	0.0013	1.3968	0.1705	0.5819	0.011	0.0101	6.5696	-7.00E-04	0.007	0.0024	0.007	0.002	0.0021	0.022	0.0013
40	1.2332	0.2203	0.6633	0.0103	0.017	5.883	-1.00E-04	0.0061	0.0025	0.0048	0.0021	0.0022	0.026	0.0017	1.0181	0.1922	0.6768	0.013	0.019	6.43	-8.00E-04	0.0098	0.0028	0.0044	0.0028	0.0021	0.0223	0.0015
41	1.4649	0.4761	0.883	0.0138	0.0576	6.706	0.002	0.0123	0.0035	0.0058	0.0065	0.0062	0.0328	0.0024	1.2498	0.3911	0.8028	0.0146	0.0385	5.1713	4e-04	0.0093	0.0028	0.005	0.0078	0.0046	0.0238	0.002
42	1.1816	0.7377	0.727	0.0131	0.0383	5.7368	8e-04	0.0123	0.0031	0.0055	0.0063	0.006	0.0285	0.0015	1.4706	0.465	0.8171	0.0124	0.0291	5.4046	5e-04	0.0099	0.0028	0.0058	0.0074	0.0046	0.0273	0.002
43	2.0588	0.3521	0.7374	0.0073	0.0329	4.0712	0.0017	0.0102	0.0026	0.0196	0.0055	0.0049	0.0311	0.0025	1.5801	0.3017	0.7142	0.0074	0.0284	3.6994	0.001	0.0067	0.0028	0.0163	0.0059	0.0039	0.0247	0.0022
44	2.4299	0.3179	0.7732	0.0081	0.0915	4.2446	0.0024	0.0122	0.0028	0.0169	0.0064	0.004	0.029	0.0018	1.1492	0.2051	0.6697	0.0086	0.074	3.157	0.0013	0.0086	0.0027	0.0115	0.0056	0.0041	0.0238	0.0019
45	0.8723	0.3271	0.7076	0.0087	0.0353	4.3718	-2.00E-04	0.0082	0.0019	0.0051	0.0064	0.0104	0.0265	0.0022	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
46	0.9913	0.2224	0.697	0.0087	0.1055	4.9979	0.002	0.0068	0.0024	0.0075	0.0061	0.0125	0.0249	0.0025	0.2676	0.032	0.4404	0.009	0.1112	3.2228	-4.00E-04	0.0088	0.0022	0.0025	0.0053	0.0097	0.0152	0.0014
47	1.5235	0.346	0.7941	0.0121	0.0881	5.4198	0.0031	0.0084	0.0027	0.0083	0.0062	0.012	0.034	0.0024	0.8857	0.2359	0.5767	0.0143	0.0285	4.6517	0.0013	0.0152	0.0028	0.0082	0.0067	0.0088	0.0219	0.0019
48	1.4604	0.3318	0.734	0.0122	0.098	5.846	0.003	0.0089	0.0028	0.01	0.0065	0.0148	0.0293	0.002	1.2128	0.305	0.7118	0.0112	0.0419	5.4391	0.002	0.0147	0.0025	0.0087	0.0063	0.0088	0.0275	0.0022

Sample ID	K (ext.)	Ca (ext.)	Ti (ext.)	Cr (ext.)	Mn (ext.)	Fe (ext.)	Co (ext.)	Zn (ext.)	Ga (ext.)	Rb (ext.)	Sr (ext.)	Y (ext.)	Zr (ext.)	Nb (ext.)	K (int.)	Ca (int.)	Ti (int.)	Cr (int.)	Mn (int.)	Fe (int.)	Co (int.)	Zn (int.)	Ga (int.)	Rb (int.)	Sr (int.)	Y (int.)	Zr (int.)	Nb (int.)
49	1.1632	0.3281	0.947	0.006	0.0237	4.864	7e-04	0.01	0.0022	0.01	0.0078	0.0043	0.0346	0.0029	0.6711	0.1939	0.6064	0.0065	0.0451	3.7758	-2.00E-04	0.0077	0.0022	0.0069	0.0075	0.0046	0.0259	0.002
50	1.2574	0.2332	0.6779	0.0087	0.0595	4.5194	0.002	0.0095	0.0025	0.0113	0.0072	0.004	0.0309	0.0021	1.2421	0.2075	0.7003	0.0079	0.0491	3.8817	9e-04	0.008	0.0026	0.0094	0.0075	0.0029	0.0252	0.002
51	2.1454	0.3115	0.771	0.0078	0.0357	4.0696	0.0011	0.0085	0.0026	0.0143	0.0059	0.0046	0.0274	0.0024	1.7832	0.2098	0.758	0.0082	0.0401	3.3437	9e-04	0.0072	0.0023	0.0138	0.0063	0.0045	0.0245	0.0022
52	1.9869	0.3138	0.7615	0.0083	0.1206	4.0052	0.0028	0.0126	0.0025	0.0192	0.0074	0.0071	0.0285	0.0026	1.7813	0.3416	0.7053	0.007	0.0819	3.7978	0.0024	0.0131	0.0022	0.0189	0.0078	0.0052	0.0376	0.0021
53	1.4725	0.2891	0.6712	0.0097	0.029	4.6684	0.0012	0.0179	0.002	0.0164	0.0067	0.0048	0.0283	0.0022	1.1466	0.1895	0.5836	0.0087	0.0557	4.0423	8e-04	0.0081	0.0025	0.0124	0.0067	0.0042	0.0245	0.0019
54	2.0989	0.3626	0.7404	0.0065	0.1052	3.8992	0.0026	0.0114	0.0026	0.0202	0.0079	0.0065	0.0287	0.0025	1.5954	0.2254	0.6485	0.0074	0.0457	3.5108	0.0013	0.0103	0.0027	0.015	0.0081	0.005	0.0221	0.0014
55	1.0702	0.6936	0.7414	0.0093	0.0559	5.4201	7e-04	0.0158	0.0027	0.0101	0.0092	0.0044	0.027	0.0023	1.0773	0.6635	0.7177	0.0088	0.0541	5.4159	5e-04	0.0157	0.0027	0.0101	0.0091	0.0044	0.0264	0.0023
56	2.4655	0.4971	0.8274	0.0127	0.2285	6.0041	0.0027	0.0121	0.0027	0.0102	0.0075	0.0053	0.0346	0.0016	2.1033	0.4487	0.8953	0.013	0.207	6.405	0.0027	0.0136	0.0032	0.0081	0.0073	0.0052	0.029	0.0017
57	0.6947	0.631	0.5876	0.0101	0.0843	5.5567	5e-04	0.0134	0.0021	0.0074	0.0053	0.0071	0.0224	0.002	0.5655	0.4877	0.6014	0.0121	0.1458	5.7712	6e-04	0.0113	0.0021	0.0056	0.005	0.0049	0.0175	0.0018
58	1.2313	0.8759	0.6607	0.0116	0.0942	6.332	0.002	0.011	0.0026	0.0103	0.0055	0.0076	0.0301	0.0016	0.8933	0.5591	0.7355	0.0133	0.0704	5.7188	0.0021	0.0132	0.0025	0.0076	0.0044	0.0069	0.0286	0.0014
59	1.5948	0.5466	0.8774	0.0124	0.135	6.4138	0.0024	0.0163	0.0027	0.0077	0.0067	0.0036	0.0322	0.0017	1.146	0.4846	0.6865	0.0119	0.1502	4.9474	0.0022	0.0133	0.0026	0.007	0.0081	0.0036	0.0241	0.0013
60	1.997	0.7821	0.7935	0.0101	0.1787	6.4615	0.0013	0.033	0.0027	0.0113	0.0066	0.0046	0.0265	0.0025	0.5578	0.2156	0.4959	0.0092	0.0416	3.4868	-0.0012	0.0188	0.002	0.0049	0.0057	0.0037	0.0146	0.0014
61	1.2988	0.7682	0.7529	0.0143	0.0946	5.8682	0.0015	0.0129	0.0025	0.0069	0.0092	0.0063	0.0327	0.0021	1.0384	0.7756	0.6795	0.0105	0.0899	4.6959	0.0011	0.0128	0.0022	0.0073	0.0109	0.0052	0.0231	0.0018
62	1.2962	0.8576	0.7312	0.0128	0.123	5.5113	0.0016	0.0131	0.0027	0.0083	0.0129	0.0046	0.0236	0.0013	1.4916	0.9518	0.7527	0.0113	0.2077	5.8333	0.0028	0.0233	0.0024	0.0111	0.0128	0.0045	0.0308	0.002
63	1.9436	0.4179	0.8756	0.0129	0.2167	6.1306	0.0028	0.0249	0.0025	0.0086	0.0082	0.0044	0.0318	0.0022	1.3331	0.6228	0.8144	0.0105	0.1238	5.8305	0.0023	0.0166	0.0028	0.0113	0.0081	0.0045	0.0297	0.0023
64	1.8736	0.5154	0.812	0.0106	0.1467	5.4042	0.0029	0.0308	0.0026	0.0098	0.0083	0.0048	0.0346	0.0018	0.836	0.3833	0.5736	0.0113	0.0439	4.0119	0	0.015	0.0029	0.0062	0.0079	0.0047	0.0203	0.0014
65	2.2758	0.7597	0.646	0.0071	0.1679	4.6192	0.0015	0.0145	0.0019	0.0148	0.0125	0.0058	0.0252	0.0024	1.5018	1.5393	0.618	0.0082	0.1207	3.9687	5e-04	0.011	0.0021	0.0155	0.0129	0.0069	0.0245	0.002
66	2.0683	2.3308	0.6075	0.0063	0.2701	4.5343	0.002	0.0118	0.0019	0.0179	0.0202	0.0055	0.0245	0.0022	1.6005	0.8566	0.6001	0.0078	0.1351	3.8987	0.001	0.0138	0.0024	0.0158	0.0154	0.0063	0.0229	0.0021
67	1.2364	0.2742	0.7102	0.0099	0.0525	5.8754	0.001	0.0117	0.0026	0.0078	0.0045	0.0043	0.0244	0.0014	1.2268	0.3342	0.6548	0.0117	0.0609	6.301	0.0016	0.0122	0.0028	0.0089	0.0046	0.0046	0.0295	0.0015
68	0.3713	0.1312	0.6227	0.0059	0.0493	4.1026	0	0.0139	0.0018	0.0033	0.0023	0.0032	0.0245	0.0018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
69	1.386	0.2793	0.7234	0.0085	0.0726	4.6291	0.0022	0.0096	0.0025	0.0114	0.0055	0.003	0.0355	0.0014	0.9264	0.1956	0.6233	0.0089	0.1873	4.8185	0.0029	0.0099	0.0024	0.008	0.0051	0.0028	0.0261	0.001
70	1.1333	0.2064	0.6171	0.0082	0.0287	4.0762	5e-04	0.0096	0.0024	0.0094	0.003	0.0037	0.0369	0.0013	1.1154	0.2424	0.6849	0.0087	0.0266	3.9574	4e-04	0.0085	0.0025	0.0101	0.0038	0.0031	0.0334	0.0013
71	1.6864	0.2905	0.8084	0.0081	0.0707	5.0195	0.0015	0.0182	0.0025	0.0123	0.0037	0.0031	0.0347	0.0024	1.0155	0.2105	0.6312	0.0105	0.1155	4.4724	0.0017	0.0139	0.0028	0.0101	0.0042	0.0032	0.0298	0.0012
72	2.1193	0.2905	0.7516	0.0104	0.0526	5.9178	0.0013	0.0216	0.0028	0.012	0.003	0.0029	0.0327	0.0016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
73	1.6769	0.2817	0.7086	0.0079	0.0504	4.8783	0.0018	0.008	0.0026	0.0109	0.0031	0.0041	0.0354	0.0016	1.2867	0.3196	0.7643	0.0095	0.1107	5.0264	0.0023	0.0088	0.0028	0.0128	0.0038	0.0057	0.0352	0.0015
74	0.4025	0.0719	0.503	0.0099	0.0761	4.2672	0	0.0151	0.0018	0.0051	0.0044	0.0062	0.0155	0.0015	0.9926	0.2207	0.6219	0.0117	0.0951	6.8591	0.0018	0.0186	0.0026	0.0122	0.0054	0.0059	0.0245	0.002
75	1.1988	0.2979	0.6743	0.0087	0.0297	4.6574	8e-04	0.0135	0.0026	0.0116	0.0039	0.0054	0.03	0.0016	1.342	0.218	0.6132	0.0103	0.0168	4.2265	4e-04	0.0116	0.0027	0.0112	0.005	0.0055	0.0298	0.0014
76	2.0359	0.2925	0.7631	0.0098	0.1188	5.2114	0.0026	0.0197	0.0026	0.0108	0.0027	0.0046	0.0321	0.0018	1.1193	0.1546	0.5739	0.0116	0.0564	3.8428	7e-04	0.0094	0.0025	0.0071	0.0033	0.0057	0.0236	0.0012
77	1.4789	0.383	0.7789	0.0127	0.0738	5.8214	0.0019	0.006	0.0028	0.0093	0.0034	0.0119	0.0263	0.0018	1.4324	0.3592	0.7516	0.0089	0.0681	5.0234	0.002	0.0061	0.0025	0.012	0.0039	0.0079	0.0388	0.0016
78	1.9213	0.2166	0.7362	0.0095	0.0577	5.0882	0.0014	0.0165	0.0026	0.0106	0.003	0.0032	0.0287	0.0015	1.435	0.2254	0.7775	0.0101	0.0907	5.3294	0.0021	0.0172	0.0028	0.0111	0.0032	0.0038	0.0293	0.0015
79	1.1129	0.3345	0.5885	0.0069	0.0498	4.0834	0.0013	0.012	0.0025	0.0123	0.0047	0.0051	0.0245	0.002	1.7768	0.4172	0.7836	0.0106	0.1097	4.9669	0.0026	0.0091	0.0027	0.0127	0.0049	0.0055	0.0303	0.0018
80	1.5177	0.2552	0.744	0.009	0.1607	4.793	0.003	0.0792	0.0026	0.0116	0.0038	0.0071	0.0314	0.0015	1.4859	0.2268	0.6224	0.0099	0.1571	4.4549	0.0025	0.0306	0.0024	0.0127	0.0045	0.012	0.0282	0.0017
81	1.4846	0.22	0.725	0.0093	0.0639	4.4529	0.0012	0.0102	0.0026	0.0095	0.0034	0.0059	0.0344	0.0014	0.7125	0.1245	0.5689	0.0087	0.0268	3.4786	-1.00E-04	0.0099	0.0025	0.007	0.0035	0.0049	0.0205	0.001
82	0.829	0.2342	0.6969	0.0065	0.0367	5.4596	0.0012	0.0073	0.0026	0.0083	0.003	0.0065	0.0274	0.0026	0.3363	0.0574	0.5133	0.0111	0.0416	4.4596	-0.0013	0.0084	0.002	0.0028	0.0025	0.0067	0.0149	0.0016
83	1.2854	0.262	0.6999	0.0071	0.0474	4.2061	0.001	0.0062	0.0024	0.0121	0.0037	0.0112	0.0288	0.0017	1.3376	0.3074	0.723	0.0088	0.0996	4.4539	0.0017	0.0066	0.0027	0.0123	0.0047	0.0076	0.0267	0.0015
84	1.16	0.3125	0.6728	0.0127	0.0439	7.6776	0.0017	0.0127	0.0032	0.0079	0.0037	0.0098	0.0311	0.0022	1.2574	0.2684	0.6746	0.0079	0.0435	4.8762	0.0016	0.0067	0.0024	0.0112	0.0033	0.0111	0.0258	0.0016
85	0.8545	0.2129	0.5308	0.0082	0.0272	4.2212	4e-04	0.0051	0.0021	0.0063	0.0021	0.0105	0.0252	0.0012	1.1301	0.2786	0.6261	0.0119	0.043	5.8726	0.0016	0.0076	0.0028	0.0092	0.004	0.0145	0.0287	0.0024
86	1.1517	0.2491	0.6671	0.0116	0.0357	6.1095	0.0014	0.0092	0.0027	0.0071	0.0029	0.0088	0.0255	0.0016	1.1937	0.2793	0.68	0.0115	0.1263	6.1739	0.0028	0.0086	0.0031	0.011	0.0034	0.0091	0.0283	0.0016
87	0.9149	0.1827	0.715	0.0107	0.0808	5.9411	9e-04	0.0094	0.0025	0.0062	0.005	0.0068	0.0235	0.0022	1.351	0.2356	0.6744	0.0123	0.0936	6.2527	0.0016	0.0098	0.0024	0.0089	0.0053	0.0087	0.0266	0.0023
88	0.7813	0.1428	0.7084	0.0101	0.0428	5.9709	7e-04	0.0091	0.0025	0.0062	0.0024	0.009	0.0259	0.0024	0.6495	0.0865	0.6071	0.0083	0.0412	4.6289	3e-04	0.0087	0.0023	0.006	0.0026	0.0055	0.0258	0.0017
89	1.2192	0.2349	0.7195	0.013	0.0494	7.2455	0.0018	0.0129	0.0031	0.0077	0.0032	0.0056	0.0343	0.0015	1.1345	0.2424	0.682	0.0144	0.0785	7.8502	0.0014	0.012	0.0034	0.0092	0.0032	0.0069	0.0295	0.0017
90	1.125	0.3118	0.7705	0.0108	0.0406	5.9676	0.0023	0.0213	0.0027	0.0071	0.0027	0.0047	0.0285	0.0017	0.9092	0.178	0.6233	0.0099	0.034	4.9045	7e-04	0.0084	0.0024	0.0055	0.0021	0.0049	0.0223	0.001
91	1.5362	0.5866	0.8224	0.0115	0.2891	4.875	0.0029	0.0118	0.0025	0.0082	0.0086	0.0042	0.0283	0.0015	1.2243	0.5696	0.6915	0.0112	0.0585	4.5992	9e-04	0.0114	0.0026	0.0068	0.0085	0.0034	0.0236	0.0018
92	1.6349	0.8048	0.8208	0.0113	0.2571	6.6175	0.0024	0.0118	0.0031	0.0082	0.0089	0.0034	0.0272	0.0026	1.4477	0.7363	0.8157	0.0131	0.4761	6.3412	0.0027	0.0102	0.0026	0.0081	0.0079	0.004	0.0273	0.0025
93	1.624	1.0264	0.6908	0.0101	0.1723	5.3606	0.002	0.0097	0.0027	0.0132	0.0127	0.0032	0.0247	0.0016	0.8927	0.714	0.5693	0.0097	0.2967	4.5168	0.0024	0.0092	0.0025	0.0108	0.0115	0.0034	0.0217	0.0014
94	1.9582	0.3653	0.7915	0.0105	0.0747	6.1491	9e-04	0.0109	0.0023	0.012	0.0043	0.0041	0.0248	0.0026	1.498	0.242	0.6729	0.0113	0.1274	5.4968	8e-04	0.0094	0.0021	0.0078	0.0035	0.0043	0.0202	0.0022
95	1.4821	0.7404	0.6841	0.0107	0.3816	5.1782	0.0027	0.0114	0.0027	0.0119	0.0092	0.0029	0.0251	0.0015	1.7342	0.7197	0.7414	0.0116	0.1105	5.8233	0.0022	0.0101	0.0027	0.0113	0.0093	0.003	0.0286	0.0018
96	1.4063	0.7651	0.8518	0.0145	0.0605	6.3036	0.001	0.0159	0.0026	0.0066	0.0071	0.0035	0.026	0.0023	1.2357	0.5178	0.6721	0.0132	0.0419	5.0216	6e-04	0.0175	0.0028	0.0068	0.0077	0.0033	0.0226	0.0014
97	1.6406	1.1073	0.7801	0.0101	0.1286	5.022	0.0029	0.0093	0.0022	0.0085	0.0098	0.0043	0.0318	0.0015	0.6139	0.5453	0.474	0.008	0.3535	3.3612	0.0023	0.0096	0.0021	0.0056	0.0096	0.0034	0.0195	0.0014
98	1.8468	0.8254	0.7605	0.0101	0.1133	5.2692	0.0017	0.0101	0.0028	0.0119	0.0107	0.0032	0.0303	0.0017	1.4433	0.6167	0.7338	0.0101	0.0802	4.8625	0.0011	0.0106	0.003	0.0099	0.0101	0.0033	0.0273	0.002
99	1.7087	0.6964	0.7778	0.0113	0.0833	5.2398	0.0019	0.0138	0.0028	0.0125	0.0101	0.0032	0.0283	0.0023	0.9487	0.3904	0.6619	0.0088	0.0925	4.4485	0.0014	0.0136	0.0026	0.0089	0.0091	0.0034	0.0262	0.0014
100	2.8895	1.5725	0.7864	0.0065	0.0433	3.0868	0.0019	0.009	0.0016	0.0153	0.011	0.0047	0.0386	0.0027	2.4764	1.6647	0.7641	0.0056	0.0697	2.8272	0.0019	0.0129	0.0022	0.013	0.012	0.0052	0.0304	0.002
101	2.1899	0.2556	0.9106	0.0032	0.0194	2.6772	0.0022	0.0106	0.0018	0.0181	0.0047	0.0044	0.0337	0.0034	1.4477	0.2092	0.7695	0.0031	0.0175	2.6175	0.0018	0.0123	0.0019	0.0178	0.0057	0.0041	0.0307	0.0029
102	2.2052	0.552	0.733	0.0071	0.024	4.7191	0.0018	0.0151	0.0029	0.0146	0.0078	0.0036	0.0283	0.0019	1.1492	0.4436	0.6701	0.0058	0.0129	3.3767	0.001	0.0104	0.0027	0.012	0.0083	0.0034	0.0239	0.0016
103	1.5311	0.4839	0.73	0.0053	0.0205	2.606	0.001	0.008	0.0022	0.0145	0.0083	0.0047	0.0294	0.0022	1.5718	0.5876	0.7246	0.005	0.0192	2.7624	0.0013	0.0084	0.0025	0.016	0.01	0.0045	0.0294	0.0018
104	1.1555	0.263	0.833	0.0037	0.0164	3.3255	-1.00E-04	0.0111	0.0018	0.0127	0.0067	0.0044	0.0299	0.0025	0.8946	0.2474	0.6613	0.0048	0.0087	3.2901	-0.001	0.0114	0.0022	0.0114	0.0071	0.004	0.0233	0.0021
105	2.0244	0.5104	0.7617	0.005	0.0195	3.0578	0.0012	0.0089	0.0023	0.0187	0.0079	0.0046	0.0333	0.0026	1.3726	0.4446	0.6484	0.0047	0.0216	2.3746	0.0013	0.0088	0.0022	0.0135	0.0083	0.0042	0.029	0.0021

Sample ID	K (ext.)	Ca (ext.)	Ti (ext.)	Cr (ext.)	Mn (ext.)	Fe (ext.)	Co (ext.)	Zn (ext.)	Ga (ext.)	Rb (ext.)	Sr (ext.)	Y (ext.)	Zr (ext.)	Nb (ext.)	K (int.)	Ca (int.)	Ti (int.)	Cr (int.)	Mn (int.)	Fe (int.)	Co (int.)	Zn (int.)	Ga (int.)	Rb (int.)	Sr (int.)	Y (int.)	Zr (int.)	Nb (int.)
106	0.9913	0.2088	0.7217	0.011	0.0237	4.4533	8e-04	0.0095	0.0024	0.0071	0.0043	0.0042	0.0212	0.002	0.7272	0.1109	0.54	0.0108	0.0525	3.7894	7e-04	0.0108	0.0022	0.005	0.0039	0.0037	0.0168	0.0015
107	1.9652	0.3718	0.7173	0.0053	0.0204	3.0182	0.0019	0.0107	0.0019	0.0183	0.0058	0.0049	0.0317	0.0026	1.1135	0.1861	0.5843	0.0057	0.021	2.2306	9e-04	0.0076	0.0025	0.0118	0.0061	0.005	0.0236	0.0017
108	1.7017	0.3704	0.8134	0.0067	0.0191	4.3456	0.0018	0.0149	0.0029	0.0188	0.007	0.0053	0.029	0.0025	1.0671	0.2034	0.5369	0.007	0.0114	3.6399	7e-04	0.0117	0.0023	0.0123	0.0073	0.0039	0.0284	0.002
109	1.8086	3.7819	0.6305	0.0113	0.127	5.5994	0.0018	0.0106	0.0021	0.0113	0.0191	0.0051	0.0261	0.0019	1.8163	1.7328	0.6243	0.0115	0.137	5.7213	0.0022	0.0118	0.0023	0.0138	0.012	0.0062	0.0274	0.0021
110	1.1199	0.7607	0.7625	0.0103	0.3413	5.0811	0.0024	0.0182	0.0021	0.009	0.0091	0.0038	0.0224	0.0022	0.7711	0.4057	0.6848	0.0106	0.1623	4.1817	2e-04	0.0112	0.0021	0.0061	0.0084	0.0042	0.018	0.0019
111	1.7978	0.8593	0.7656	0.0126	0.1697	5.8652	0.0025	0.0139	0.0024	0.0103	0.0093	0.0037	0.0278	0.0023	1.435	0.6499	0.8433	0.0153	0.1063	6.3853	0.0014	0.0093	0.0028	0.0058	0.0076	0.0051	0.0257	0.0021
112	1.9041	0.3548	0.8424	0.0059	0.07	3.2302	0.0034	0.0211	0.0019	0.0167	0.0048	0.0058	0.0325	0.0031	1.3198	0.2695	0.785	0.0062	0.0531	2.9482	0.0035	0.0327	0.002	0.016	0.0049	0.0065	0.0326	0.0027
113	1.554	0.9122	0.6848	0.0107	0.0442	5.6361	0.001	0.009	0.0024	0.0113	0.0098	0.0027	0.0277	0.0022	1.2237	0.6892	0.6246	0.01	0.0506	4.7367	8e-04	0.0087	0.0022	0.0092	0.0094	0.0029	0.0247	0.002
114	1.1415	0.1912	0.7712	0.0076	0.0124	2.9213	0.0015	0.0096	0.0038	0.0106	0.0046	0.0042	0.0204	0.0022	0.4172	0.0679	0.5167	0.0077	0.0126	2.4996	3e-04	0.0147	0.0038	0.0056	0.0039	0.0041	0.0148	9e-04
115	1.5699	0.8055	0.7232	0.0101	0.0734	5.1765	0.0014	0.0097	0.0028	0.0123	0.0104	0.0028	0.0253	0.0017	1.1925	0.5757	0.6264	0.0102	0.0643	4.5703	0.001	0.0082	0.0026	0.0103	0.0098	0.0032	0.0249	0.0014
116	1.0193	0.2546	0.787	0.0101	0.0099	4.5139	5e-04	0.0076	0.0039	0.0072	0.0042	0.0041	0.0259	0.0019	0.9531	0.18	0.8797	0.0113	0.0086	4.1178	0.0012	0.0122	0.0041	0.0083	0.0043	0.0049	0.0219	0.0019
117	1.7946	0.2823	0.7316	0.0057	0.0243	2.97	0.0014	0.0106	0.0019	0.0161	0.0059	0.004	0.0323	0.0022	1.7023	0.362	0.7917	0.0062	0.0303	3.3361	0.0016	0.0095	0.0022	0.016	0.0065	0.0039	0.0343	0.0026
118	1.1002	0.3538	0.7462	0.0062	0.0152	3.4622	8e-04	0.0108	0.0018	0.0099	0.0079	0.0026	0.0366	0.0016	1.1536	0.4131	0.6703	0.0058	0.0162	3.9344	9e-04	0.0119	0.0018	0.0106	0.0074	0.0025	0.0376	0.0018
119	1.7774	0.3887	0.8073	0.0067	0.0229	4.4273	0.0019	0.0147	0.0026	0.0132	0.0073	0.0055	0.0291	0.0026	1.5336	0.4026	0.7441	0.0071	0.0226	4.3201	0.0016	0.0115	0.0028	0.0135	0.0073	0.0045	0.0259	0.0024
120	1.4108	0.7675	0.8478	0.0146	0.3452	6.166	0.0028	0.0173	0.0026	0.0064	0.0074	0.0042	0.0253	0.0022	1.4815	0.6367	0.7528	0.0132	0.0267	5.6415	5e-04	0.0151	0.0027	0.0078	0.0078	0.0032	0.0255	0.0016
121	1.4356	0.7435	0.8523	0.0141	0.3388	5.9322	0.0034	0.0178	0.0029	0.0065	0.0072	0.0041	0.029	0.0021	1.3395	0.5619	0.7005	0.0126	0.0254	4.6581	4e-04	0.0126	0.0026	0.0071	0.0075	0.0032	0.0225	0.0014
122	1.6425	0.7682	0.7537	0.0127	0.0341	5.6629	7e-04	0.0161	0.0029	0.0091	0.0081	0.0035	0.0255	0.0017	1.4127	0.6415	0.7343	0.0121	0.0264	4.7869	4e-04	0.014	0.0027	0.0079	0.0084	0.0033	0.0253	0.0019
123	1.5502	0.7614	0.7367	0.0129	0.1051	5.5506	0.0015	0.0172	0.0029	0.0082	0.0077	0.0033	0.0261	0.0016	1.2568	0.5693	0.6673	0.0114	0.0144	5.1163	5e-04	0.0151	0.0025	0.008	0.0073	0.0029	0.0245	0.0016
124	1.4706	1.7582	0.6172	0.0093	0.2233	5.0684	0.0024	0.0105	0.0027	0.0115	0.0114	0.0031	0.025	0.0021	1.286	0.7936	0.6476	0.0122	0.1043	5.3733	0.0019	0.0113	0.0026	0.0121	0.0104	0.0038	0.0245	0.0021
125	1.7342	0.9196	0.7003	0.0121	0.1375	6.1252	0.0021	0.0127	0.0029	0.0117	0.0104	0.0026	0.025	0.0015	0.864	0.4795	0.5615	0.0098	0.1383	4.2825	0.0015	0.0134	0.0024	0.008	0.0097	0.0029	0.0198	0.0012
126	1.4413	0.7028	0.6413	0.0111	0.7862	5.0498	0.0039	0.0179	0.0028	0.0116	0.0089	0.003	0.0277	0.002	1.6871	0.7302	0.7105	0.0119	0.1208	5.879	0.002	0.015	0.0027	0.01	0.0085	0.003	0.0278	0.0017
127	2.0963	0.9105	0.8699	0.009	0.593	4.8261	0.0037	0.0111	0.0022	0.0166	0.012	0.0042	0.0238	0.0027	1.1645	0.6035	0.5492	0.0089	0.1659	4.2071	0.0024	0.0098	0.0024	0.014	0.0103	0.0037	0.0229	0.002
128	1.6272	0.385	0.8423	0.0138	0.0094	7.2496	0.0012	0.0067	0.0049	0.0111	0.0036	0.0034	0.0284	0.0021	0.9786	0.1865	0.6904	0.0065	0.0101	3.6792	5e-04	0.0064	0.0034	0.0104	0.0039	0.0025	0.0278	0.0014
129	1.9417	1.0057	0.7368	0.0116	0.34	5.4241	0.0028	0.0131	0.0023	0.0098	0.0221	0.0036	0.0241	0.0014	1.6985	0.7533	0.6499	0.0091	0.3357	4.6937	0.0032	0.0115	0.0021	0.0128	0.0169	0.0035	0.0282	0.0021
130	0.7959	0.5283	0.5542	0.0038	0.0769	2.9205	4e-04	0.0069	0.0015	0.007	0.0092	0.0037	0.0259	0.0018	1.1072	0.7411	0.6552	0.0034	0.0274	3.5153	-2.00E-04	0.0073	0.0015	0.0101	0.0094	0.0037	0.0302	0.0021
1013	1.6425	1.8805	0.7668	0.0034	0.0366	3.2565	0.0043	0.0083	0.0014	0.0109	0.0118	0.0024	0.0491	0.0014	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1014	0.6985	2.3701	0.3395	0.0036	0.0273	2.5634	0.0033	0.0039	0.0014	0.0129	0.0145	0.0025	0.0393	0.0015	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1015	2.8144	0.7106	0.694	0.006	0.0426	4.8864	0.0039	0.0186	0.0029	0.0154	0.0093	0.003	0.0442	0.0017	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016	2.6113	0.7191	0.8657	0.0078	0.0432	5.7474	0.0045	0.0113	0.0025	0.016	0.0096	0.0031	0.0486	0.0018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1001	0.8309	0.1695	0.6771	0.0045	0.0161	2.6373	-3.00E-04	0.0044	0.0014	0.006	0.0063	0.0027	0.0495	0.0016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1002	1.5572	0.2441	0.6341	0.0063	0.0119	4.7847	-3.00E-04	0.0066	0.002	0.0066	0.0057	0.0021	0.0442	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1003	0.8901	0.1563	0.6891	0.0037	0.0236	2.2007	1e-04	0.0057	0.0012	0.0063	0.0059	0.0051	0.0487	0.0018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1004	1.4038	0.2461	0.6656	0.0087	0.0237	4.2904	-2.00E-04	0.007	0.0017	0.0059	0.0073	0.0032	0.0512	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1005	1.8455	0.3216	0.6832	0.0046	0.0189	2.468	5e-04	0.0029	0.0017	0.0109	0.0103	0.0025	0.0458	0.0018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1008	1.4223	0.243	0.5353	0.0153	0.0232	7.7455	-1.00E-04	0.0088	0.0025	0.0058	0.0065	0.0021	0.0224	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1009	1.0486	0.2654	0.7147	0.0039	0.0228	3.4161	4e-04	0.0051	0.0013	0.0046	0.0028	0.0022	0.0543	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1010	1.6298	0.2071	0.5562	0.0127	0.01	6.2372	1e-04	0.0096	0.0027	0.0091	0.0054	0.0023	0.0251	0.0015	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1011	1.2676	0.16	0.5696	0.0102	0.0084	4.9357	-7.00E-04	0.0082	0.0021	0.007	0.0045	0.0022	0.0266	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1012	0.9315	0.2925	0.6921	0.0028	0.0195	3.3593	3e-04	0.0052	0.0013	0.0037	0.0025	0.0022	0.0447	0.0013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix 3: GRS Data

Sample ID	40K/232Th	40K/238U	238U/222Rn	238U/226Ra	40K (Bq/kg)	226Ra (Bq/kg)	234Th (Bq/kg)
4	4.613697	7.50057	0.132779	0.300881	NA	NA	NA
5	4.274097	9.04534	0.121426	0.27333	NA	NA	NA
6	3.411301	4.40316	0.188152	0.435026	NA	NA	NA
8	2.601408	3.552877	0.141029	0.246817	NA	NA	NA
9	3.073392	5.538072	0.126087	0.272626	NA	NA	NA
10	3.012524	5.230769	0.126548	0.29762	NA	NA	NA
11	3.273412	4.812034	0.172453	0.412326	NA	NA	NA
12	2.789878	4.433351	0.167644	0.356838	NA	NA	NA
13	3.285551	5.628144	0.132298	0.280153	NA	NA	NA
14	2.993928	3.844416	0.211702	0.420592	NA	NA	NA
15	3.471955	5.270604	0.152377	0.324913	NA	NA	NA
17	3.879806	4.619173	0.230668	0.597218	NA	NA	NA
18	2.828695	3.972721	0.259978	0.606806	NA	NA	NA
28	2.556074	4.706898	0.124751	0.312538	NA	NA	NA
31	1.993592	3.23253	0.26346	0.501238	NA	NA	NA
32	1.942226	3.44762	0.232288	0.474823	NA	NA	NA
36	3.983663	5.237249	0.296068	0.661881	NA	NA	NA
45	1.839335	2.872793	0.301432	0.639197	NA	NA	NA
46	1.910275	3.070714	0.253628	0.499016	NA	NA	NA
49	2.527771	2.848369	0.331778	0.746929	NA	NA	NA
55	2.088187	3.463032	0.174831	0.413619	NA	NA	NA
57	1.823741	2.182138	0.218706	0.415631	NA	NA	NA
60	2.767765	5.442697	0.191921	0.387986	NA	NA	NA
65	4.452395	7.357099	0.089442	0.233963	NA	NA	NA
66	4.345317	7.154665	0.078874	0.188967	NA	NA	NA
68	1.39763	1.346949	0.381811	0.696804	NA	NA	NA
74	2.349776	3.926489	0.16037	0.346463	NA	NA	NA
82	1.600082	2.056013	0.238562	0.459037	NA	NA	NA
87	1.999256	2.706266	0.283447	0.565957	NA	NA	NA
88	1.770329	2.558785	0.184179	0.405647	NA	NA	NA
92	1.857809	2.839308	0.334965	0.737395	NA	NA	NA
94	3.275	3.145191	0.386493	0.897866	NA	NA	NA
101	2.891022	3.931291	0.234649	0.555241	NA	NA	NA
104	2.961864	4.063119	0.200975	0.545704	NA	NA	NA
110	2.075455	2.87021	0.313573	0.644498	NA	NA	NA
130	3.090492	3.714511	0.232985	0.53644	NA	NA	NA

Sample ID	**40K/232Th**	**40K/238U**	**238U/222Rn**	**238U/226Ra**	**40K (Bq/kg)**	**226Ra (Bq/kg)**	**234Th (Bq/kg)**
1001	25.5	6.410839	NA	0.94	271.68	42.41	42.38
1002	48.1	11.70563	NA	0.83	333.71	34.88	28.51
1003	28.5	6.355828	NA	0.95	299.37	47.53	47.1
1004	48.8	12.57013	NA	0.91	351.1	28.87	27.93
1005	50.9	11.88434	NA	0.9	488.17	41.63	41.08
1008	45.2	4.643909	NA	1.79	301.68	35.4	64.96
1009	22.7	5.99415	NA	0.87	173.57	28.17	28.96
1010	35.8	11.22819	NA	0.73	393.14	46.3	35.01
1011	41.4	10.06171	NA	0.89	326.55	36.89	32.45
1012	21.7	6.020013	NA	0.86	125.12	21.1	20.78

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