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Source to sink in precolonial Jamaica: Tracing geochemistry and mineralogy from the rocks to the pots in understanding White Marl pottery production and exchange

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ABSTRACT

White Marl is the largest, most intensively inhabited late-precolonial site documented to date for Jamaica. Its size and structural organization suggests that it functioned as a major sociopolitical/economic hub among the increasingly complex chiefdoms in the Greater Antilles. The White Marl artifact assemblage is dominated by massive quantities of ceramics. To address the origin(s) of materials from which White Marl pottery was produced, geochemical and petrographic analyses were conducted on samples of ceramics and nearby sediments. Geochemical and petrographic data were used to constrain the provenance of the pottery using a source-to-sink model. We show that the sediments in the Rio Cobre adjacent to the site originated from the nearby Above Rocks Inlier and that most of the pottery was sourced from these sediments (two geochemical pottery groups). A third pottery group has a distinctive geochemistry from a location outside of the Rio Cobre drainage. Thin sections demonstrate that a recipe of 60% clay and 40% temper was consistently followed in pottery manufacture. Multielement plots are used to distinguish sources and principal component analyses to characterize and link sediments to pottery groups. Integrating geochemical and petrographic analyses of raw sediment and pottery samples in a source-to-sink framework is a powerful way to reconstruct ceramic production strategies and trade-and-exchange networks.

1. Introduction

Artifact assemblages among pottery-producing cultures are frequently dominated by massive amounts of sherds in a variety of overlapping contexts ranging from domestic household to ritual or ceremonial to refuse settings. Whether for the pots themselves or the contents of vessels, pottery has been viewed as a category of material culture that has circulated through local, regional, and interregional

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social and exchange networks (Arnold, 1980; Cau Ontiveros et al., 2019; Gomes et al., 2023; Hirth, 1996; Neff and Bove, 1999; Rice, 2015: 186–204; Wu et al., 2022). Exchange networks documented ethnographically and archaeologically have been important to build and reinforce social bonds and political alliances as well as to satisfy supply and demand relations (Earle, 1997; Helms, 1988; Kirch, 1984; Malinowski, 1961). Throughout prehistory in the Caribbean, hypothesized exchange networks have varied in geographic scale and in relation to migration or colonization patterns and the development of chiefdom political organizations (Boomert, 1987; Crock and Petersen, 2004; Hofman et al., 2007, 2008; Hofman and van Duijvenbode, 2011).

In order to accurately reconstruct these networks using pottery it is necessary to identify clay sources and their physicochemical properties, pottery production areas, and distinctive physicochemical properties of the pottery (Fowler et al., 2019; King, 1987; Redmount and Morgenstein, 1996; Tschegg et al., 2009). Once correspondence has been established between clay and temper sources and pottery, we may characterize pottery assemblages in terms of locally produced vessels versus those that were imported or exported. Sourcing studies have a long history in archaeology across classes of material culture, most notably lithics and ceramics (Glascock and Neff, 2003; Glascock et al., 1998; Hauser et al., 2008; Hermann et al., 2019; Neff, 2000, 2002, 2012; Neff et al., 2006; Stoltman et al., 2005; Wallis et al., 2016; Wu et al., 2022). The principle underlying sourcing studies is called the "provenance postulate", which states "that there exist differences in chemical composition *between* different natural sources that exceed, in some recognizable way, the differences observed *within* a given source" (Weigand et al., 1977: 24, emphases added). This form of analysis will be most robust using both elemental and mineralogical data from multiple natural sources and artifact assemblages at varying geographic scales and across islands in the case of archipelago regions (Neff, 2012).

Our investigation of Jamaican pottery is framed by a 'source-to-sink' model developed originally for geological and geomorphological studies (Martinsen et al., 2010; Meade, 1982; Skagit Climate Science Consortium, n.d.) (Fig. 1a). 'Source' refers to the original rocks, from which natural weathering processes generate sediments that are transported downstream in fluvial systems. 'Sinks' refer to the alluvial floodplains or deltas where sediments are ultimately deposited. Sediments contain the clays and sands potentially used in pottery production.

We modified the model to distinguish between natural and cultural sinks. Natural sinks include the floodplain and delta deposits specified in the original model. Cultural sinks include the ceramic vessels manufactured from the clays collected from the drainage basin (Fig. 1b). Our investigation extends the usual pottery-sourcing studies by including the geological rock formations from which the alluvial clays were derived through natural weathering. The current study is based on geochemical and mineralogical data collected from the original source rocks, alluvial clay deposits, and pottery associated with the late prehistoric White Marl site located in the Rio Cobre valley, southcentral Jamaica (Fig. 2).

Previous studies in Jamaica have determined that geological inliers across the island possess distinctive and unique geochemical profiles, discussed below in Section 3. We argue that these distinctive geochemical signatures should be reflected in pottery produced from clays that formed from the weathered inlier rocks. In the current investigation, pottery groups were identified based on distinctive elemental distributions with support from petrographic data. A parallel

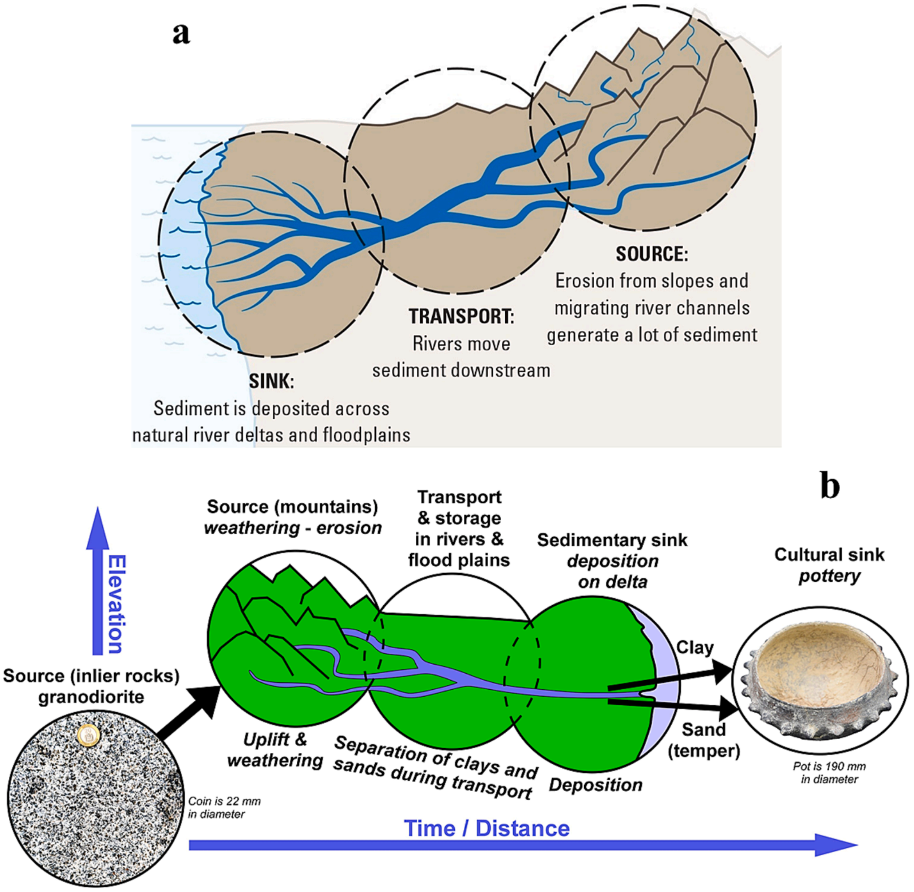


Fig. 1. (a) Original source-to-sink model (Skagit Climate Science Consortium, n.d.; www.skagitclimatescience.org/skagit-impacts/sediment/). 'Source' refers to the original rocks, from which natural weathering processes generate sediments that are transported downstream in fluvial systems. 'Sinks' refer to the alluvial floodplains or deltas where sediments are ultimately deposited, (b) Modified source-to-sink model, distinguishing natural from cultural sinks. In this investigation, cultural sinks are defined as the ceramic vessels manufactured from clays extracted from natural sinks.

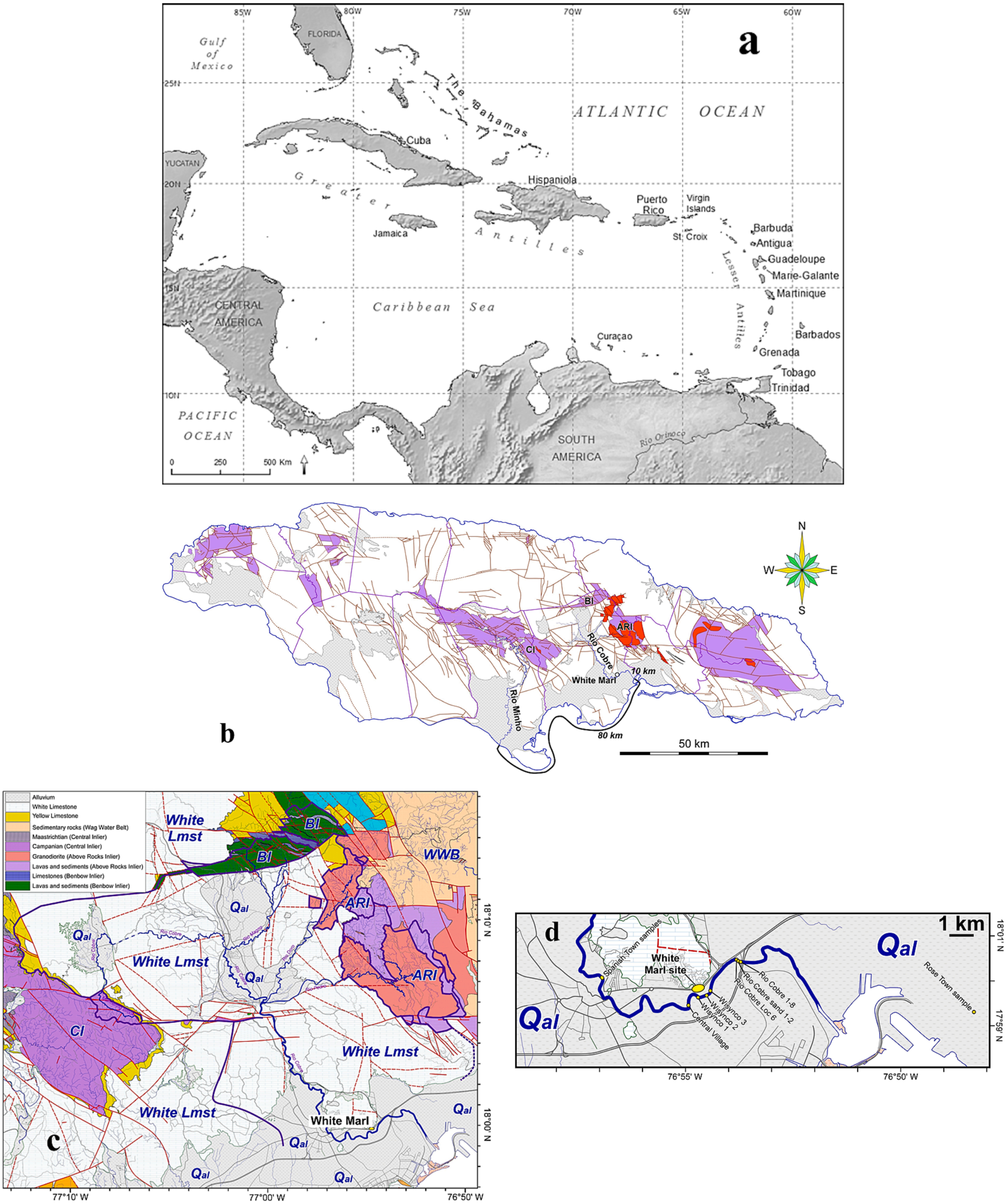


Fig. 2. (a) Map of the Caribbean Basin, (b) Geological map of Jamaica showing (1) the major Cretaceous inliers across the island, with the three inliers highlighted in this paper (CI, Central; BI, Benbow, ARI, Above Rocks), faults (narrow red lines), major areas of alluvial sediments (grey), and granodiorites (red) and (2) the canoe travel distance between White Marl and the mouth of the Rio Minho (from Mitchell, 2020: Fig. 2), (c) Detail of Fig. 2b showing the Rio Cobre drainage in relation to the Above Rocks Inlier (from Mitchell, 2015), (d) Detail of Fig. 2c showing the locations of the White Marl site and sediment samples collected from the Rio Cobre catchment.

set of analyses traced shifts in geochemistry from original source materials (weathered igneous and volcanic sedimentary rocks in geological inliers) through to alluvial sediments or natural sinks in the Rio Cobre drainage basin to the cultural sinks represented by pottery samples. This is a pilot project for a larger island-wide study currently underway of pottery from 16 additional prehistoric sites and associated clay deposits across Jamaica.

Our paper is organized in five major sections: (1) the archaeological history and context of the White Marl site is summarized, emphasizing its local and regional significance, (2) the geological context of White Marl is addressed with particular focus on the geochemistry of the Rio Cobre watershed, (3) the field and laboratory sampling and analytical methods are detailed, (4) results of the analyses are discussed and integrated, and (5) conclusions are offered regarding the local dynamics of pottery production in connection with White Marl and the potential for applying the source-to-sink model across Jamaica and more widely throughout the Caribbean.

2. Archaeological history and context of the White Marl site

White Marl is a deep well-stratified site continuously occupied for approximately 800 years (Fig. 3). Howard (1950, 1956, 1965) conducted the earliest excavations in the site, in which he recovered at least four burials and documented 2-m deep midden deposits. Out of 11 radiocarbon dates, 9 dated to c. AD1200–1500 and 2 to c. AD900 (Silverberg et al., 1972: 39, Fig. 6). More recent excavations confirm that the major occupations of the site date to c. AD1200–1500, including directly dated burials (Elliott et al., 2022: Table 1; Mickleburgh et al., 2018: Table 1; Shev et al., 2022: 8).

To date, White Marl is the largest most complexly organized prehistoric site documented for Jamaica, consisting of human burials, decorated ceramic vessels, huge amounts of everyday ceramics, a variety of animal and plant remains, and two sets of mounded midden deposits each arranged in a circular pattern (Elliott et al., 2022; Howard, 1950; Siegel et al., 2023: Fig. 6; Silverberg et al., 1972) (Fig. 4). Howard (1965) and Rouse (1992) designated White Marl as the type site for the White Marl archaeological complex within the Meillacan Ostionoid cultural subseries identified in portions of the Greater Antilles.

Fig. 3. Stratigraphic layering documented in Excavation Unit T2-11. Photograph by Zachary J. M. Beier.

The site appears to have functioned as a local hub or focal point for the evolving social and political dynamics that developed across the Greater Antilles in the last few hundred years prior to Columbus's arrival (Allsworth-Jones, 2008; Curet and Stringer, 2010; Jamaica National Heritage Trust, 2020; Oliver, 2009; Ostapkowicz, 2015; Siegel, 1991, 1999, 2004, 2010a, 2010b). The site's archaeological history has been detailed elsewhere (Siegel et al., 2023) and only the most recent work will be reviewed here. In 2016, 2018, and 2019 rescue archaeological fieldwork was conducted in advance of planned expansion of the Mandela Highway that bisects the site (Jamaica National Heritage Trust, 2016, 2018a, 2018b, 2020; Ramdial, 2017; Walters et al., 2018, 2019a, 2019b). This work was sponsored jointly by the Jamaica National Heritage Trust (JNHT) and the University of the West Indies, Mona Campus (UWI, Mona). Leiden University assisted in the 2016 and 2018 field seasons. A substantial amount of midden material and 12 human burials were recovered. Combined with earlier excavations, 28 human burials are now documented for the site and many more are no doubt still in the ground. This work revealed a diverse diet based on a range of terrestrial resources collected or cultivated by the inhabitants of White Marl, including the first direct evidence of cacao (*Theobroma cacao*) consumption in the Indigenous West Indies (Mickelburgh et al., 2018). There is also increasing evidence for the management and possible domestication of Jamaican hutias (*Geocapromys brownie*), small terrestrial rodents (Shev et al., 2022). Analysis of charcoal particulates collected from sediment samples suggests active landscape management through controlled burns by the village residents (Elliott et al., 2022).

The cumulative field investigations carried out in White Marl clearly indicate that the settlement was an important center or hub of social, political, religious, and economic activities with regional and potentially interregional connections, and it has been suggested that the settlement was the residence for a "paramount cacique" (Jamaica National Heritage Trust, 2020: 10). Local and regional evidence collected to date indicates that from c. AD900 to 1600 the Indigenous communities in Jamaica were integrated in increasingly complex sociopolitical, ideological, and cosmological systems across the island, the Greater Antilles, and perhaps the northern Lesser Antilles (Allsworth-Jones, 2008; Conolley, 2022; Ostapkowicz, 2015; Ostapkowicz et al., 2012; Siegel et al., 2023). This view is consistent with current thinking regarding a connected Caribbean (Curet and Hauser, 2011; Hofman and van Duijvenbode, 2011; Keegan et al., 2013; Mol, 2014; Siegel, 2011). Distinctive pottery styles and settlement layouts along with imagery in other classes of artifacts identified across the region may represent unique expressions of identity maintained by interconnected cosmopolitan chiefly polities of the late precolonial West Indian world (Siegel et al., 2023).

Interconnections between Jamaica and other islands of the Greater Antilles were anticipated decades ago by Froelich Rainey (1940), albeit not in explicitly social or political terms. In summarizing Jamaican collections known at the time, Rainey noted similarities (interconnectedness) and differences (unique expressions of identity) between what we now call White Marl assemblages in Jamaica and what Rainey called Shell Culture (post-Saladoid) assemblages in Puerto Rico.

Shifting interpretations of the site are important to understand when considering its role in local and regional interactions. Based on (1) Rouse's reclassification of Meillacoid to Meillacan Ostionoid, (2) Rainey's (1940: 148) explicit linkage of the White Marl pottery style to Shell Culture assemblages in Puerto Rico, and (3) the most recent excavations in the site, it appears that the White Marl settlement may have been a significant node in local, regional, and interregional interactions in the context of the late prehistoric political dynamics of the Greater Antillean complex chiefdoms (e.g., Oliver, 1998, 2005, 2009; Roosevelt, 1999; Siegel, 1991, 1999, 2004, 2010a; Wilson, 1990). Our study builds on

Table 1
Tributaries to the Rio Cobre, area of drainage in Cretaceous inliers, and percentage of rock types.

Tributary	Inlier	Rock types	Area drained (km^2)	Percent	
Murmering Brook	Central	Basalts through andesites and associated sedimentary rocks of Santonian age	6.6	5	
Rio Magno, etc.	Benbow	Rhyolites and basalts and associated sedimentary rocks of early Cretaceous age	19.1	27	
Rio Doro and Rio Pedro	Above Rocks	Early Maastrichtian basalts and andesites and associated sedimentary rocks	28.5	21	68
		Granodiorite	64.6	47	
Total			136.6	100	

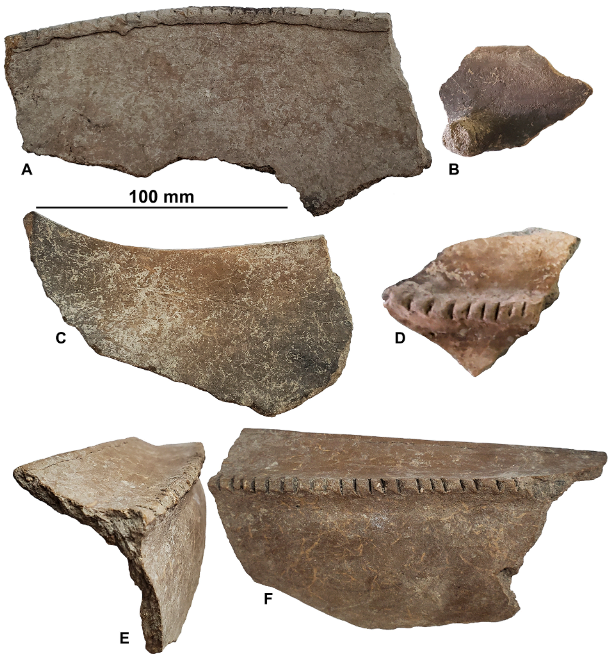


Fig. 4. Examples of White Marl pottery analyzed in this study: (A) WMS 123 (Pottery Group 1). Excavation Unit J-1, Level 3. Open bowl with horizontal, parallel notches on the flat lip of the rim, 240 mm diameter, 7.37 mm thick. (B) WMS 16 (Pottery Group 1 [outlier]). Excavation Unit U2.12 NE, Level 9. Very slightly restricted bowl with applique peg lug (handle?), 140 mm diameter, 6 mm thick. (C) WMS 68 (Pottery Group 3). Excavation Unit K1, Level 7. Restricted carinated bowl, 260 mm diameter, 5.68 mm thick. (D) WMS 3 (Pottery Group 3). Excavation Unit U2, Layer 3, NE quad. Body sherd with vertically incised/punctated applique strip 9.06 mm thick. (E, F) WMS 100 (Pottery Group 2). Excavation Unit K1, Level 4. Profile and front views of restricted carinated bowl with vertically notched applique strip along the carina, 490 mm diameter, 5.76 mm thick.

recent investigations into the geographic implications of Greater Antillean pottery compositional patterns (Casale et al., 2022, 2023; James-Williamson et al., 2022; Keegan et al., 2022; Kracht et al., 2022).

3. Geological context of the White Marl site

Jamaica constitutes the northeastern tip of the Nicaragua Rise, a massive shallow-water area extending from Jamaica westwards to Honduras and Nicaragua (Lewis and Draper, 1990; Mitchell, 2020). The island is characterized by a series of Cretaceous tectonic terranes, Paleogene rift deposits, and late Paleogene to Neogene shallow- and deep-water limestones (Mitchell, 2013a, 2020; Robinson, 1994; Robinson and Mitchell, 1999) (Fig. 2b). Four Cretaceous terranes have been identified from east to west: the NE Blue Mountains (NEBMT), SE Blue Mountains (SEBMT), Western Blue Mountains (WBMT), and Western Jamaica (WJT) terranes (Mitchell, 2020). The oldest rocks on the island exist in a series of Cretaceous inliers, although some early Paleocene rocks are also present. The inliers are surrounded by younger rocks. These inliers contain metamorphic and igneous rocks and associated volcaniclastic sediments that show characteristic variations in elemental composition related to the terrane from which they originated (Hastie, 2007; Hastie et al., 2008, 2009, 2010a, 2012, 2015; Mitchell, 2020; Mitchell et al., 2022; West et al., 2014). Rifting in the Paleocene to early Eocene (Mann and Burke, 1990) resulted in the deposition of a series of shallow-water and deep-water clastic rocks, derived from the surrounding Cretaceous rocks, and distinctive igneous rocks including dacites (JTA: Jamaican Type Adakites) and high-Nb basalt lavas also with distinctive elemental compositions (Boothe et al., 2022; Hastie et al., 2010b, 2010c, 2011, 2015). The late Paleocene to Eocene saw a transition from clastic to carbonate deposition and back to impure carbonates, passing from impure limestones (Paleocene–Middle Eocene Yellow Limestone Group) to pure carbonates (Eocene–Miocene White Limestone Group), and subsequently to shallow-water impure limestones (mid Miocene–Pleistocene Coastal Group) (James-Williamson and Mitchell, 2012; Mitchell, 2004, 2013a; Robinson and Mitchell, 1999).

The Cretaceous inliers and rift deposits are drained by a series of streams and rivers that form a distinctive network of river catchments around the island, some of which have cut gorges through the White Limestone, and deposit their sediments in a series of alluvial plains along the coastal zone of the island (Fig. 2b). The igneous, metamorphic, and volcaniclastic rocks in the inliers and rift deposits undergo intense weathering under the hot humid climate of Jamaica, resulting in the leaching of mobile elements from the weathered sediments. Sediments find their way into streams through bank erosion and landslide processes and are transported along the river systems, accumulating on floodplains and eventually deposited on alluvial fans and deltas adjacent to the coastline. During transport, sorting separates coarse-grained material (sands, pebbles, and boulders) from fine-grained deposits (clays and silts) and the alluvial fans and deltas are composed of alternating beds of coarser-grained clastics and clays.

Each river catchment drains only a limited suite of rock types; therefore, alluvial deposits associated with specific rivers are likely to show unique geochemical profiles linked to their source rocks (Fig. 1a). These alluvial materials contain the raw materials for pottery manufacture; it is expected that pottery produced within specific drainage basins is likely to register distinctive elemental compositions related to the source rocks from which the sediments originated (Fig. 1b).

The White Marl site is located within the catchment of the Rio Cobre, one of several large river systems in Jamaica draining rocks belonging to parts of the WBMT (Above Rocks Inlier) and WJT (Benbow and Central Inliers) (Fig. 2c). Numerous geological studies have addressed the igneous rocks in these inliers (Hastie et al., 2008, 2010a, 2010b, 2010c, 2012, 2015; Jackson, 1987; Jackson and Scott, 1997; Jackson and Smith, 1978, 1979; Jackson et al., 1980, 1989, 1998).

4. Field and laboratory methods

4.1. Pottery sampling

The White Marl collection is large and divided between two major curation facilities: (1) UWI, Mona Archaeology Laboratory and (2) JNHT. The rescue archaeological fieldwork conducted since 2016 in connection with the proposed Mandela Highway expansion is the most well-controlled and best documented of all the field projects that have been carried out in the site. We focused on artifacts from these recent excavations when selecting samples to analyze. Seventy-five pottery sherds were collected from the JNHT and UWI repositories (Table S1).

Excavation units from domestic and ritual areas of the site were selected to sample pottery. Domestic areas were defined by the presence of post molds, hearth features, and substantial amounts of subsistence remains. Ritual areas were defined by burials with funerary offerings. Domestic and ritual areas were identified in consultation with project field directors Zachary Beier and Selvenious Walters. All pottery from each selected excavation unit was laid out on lab tables and examined for vessel forms, surface treatments, and secondary shape features. For the most part, rims were selected from the full range of vessel forms/wares and decorated and undecorated vessels. Sherds of sufficient size (approximately 7x7 cm in area) were selected so that (1) vessel form could be identified, (2) diameters could be determined for circular-shaped vessels, and (3) enough material was available for the various analyses to be performed. In addition, several griddle fragments were selected. Each sherd was weighed and vessel wall thicknesses measured 2 cm below the lip. Munsell colors were recorded for each vessel and such unique characteristics as the presence of interior/exterior soot/smudging. Using a 10x hand lens, Simon Mitchell examined the cross section of a fresh break of each sherd for the approximate percentage and angularity of sand grains, the general makeup of the matrix, and inclusions. Sherds were photographed in at least two perspectives: profile and straight on (Fig. 4e, f). A circular rock saw was used to slice an edge of each sample to make a thin section for petrographic analysis. Using pliers, additional samples from each sherd were snapped for neutron activation analysis (NAA), X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), and inductively coupled plasma mass spectrometry (ICPMS). Initial processing was carried out in the UWI, Mona geology lab.

4.2. Raw material sampling

Within the framework of the source-to-sink model, it is our expectation that there will be concordance between the geochemical profiles of the Above Rocks Inlier rocks and the clays derived from them. According to the provenance postulate discussed earlier, the chemical compositions of the clays from the Rio Cobre watershed should be distinctively similar, in contrast to clays collected from watersheds associated with different inliers and distinctively different geochemical profiles. Exposed alluvial sedimentary deposits within an approximate 10 km radius of White Marl were surveyed for intact clay and sand deposits (Figs. 2d, 5). Most of these deposits were found in river banks or floodplain terraces along the Rio Cobre. The face of each exposed deposit was troweled back approximately 10 cm to remove contaminants (Rice 2015: 254) and multiple samples were collected. Sand samples were also collected from sand bars. Twenty-two clay or sand samples were collected.

Clay and sand samples were formed into approximate 3 cm^3 briquettes and fired to 600 °C. Firing was carried out in the kilns at the International Centre for Environmental and Nuclear Sciences (ICENS) UWI, Mona. Clay minerals, such as illite, do not undergo thermal decomposition below temperatures of 800 °C (Araújo et al., 2004). As with pottery samples, raw material thin sections were made in the UWI, Mona geology lab.

4.3. Elemental analyses

Neutron activation analysis was carried out at the Missouri University Research Reactor Center (MURR), measuring the distributions of 33 elements (Glascock, 1992; Glascock and Neff, 2003). Principal component analysis (PCA) was used to identify patterns relating to compositional groups (Glascock, 1992; Glascock and Neff, 2003; Neff, 2000, 2002). To date, MURR has analyzed nearly 2200 samples of pottery and clay from the Caribbean using NAA. Geographically, these studies range from Cuba, Jamaica, Puerto Rico, the Virgin Islands, the Lesser Antilles, and Trinidad. Aside from two preliminary studies on Puerto Rico (Siegel et al., 2008) and Jamaica (James-Williamson et al., 2022), the current project is the first in the Greater Antilles applying NAA to prehistoric pottery. As such, this will broaden the coverage of the NAA database in the Caribbean enhancing our ability to make cross-regional comparisons

Fig. 5. One of the sampled clay deposits downriver from the White Marl site. Photograph by Peter E. Siegel.

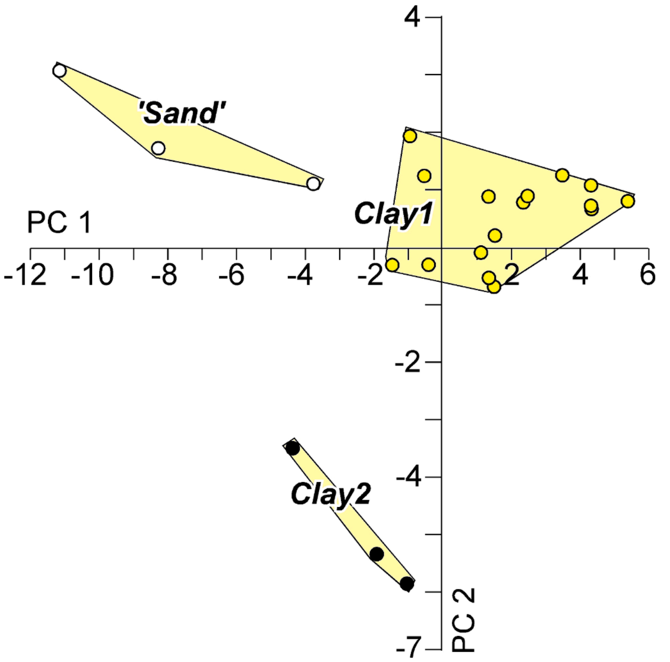


Fig. 6. Plots of the first two principal components for alluvial samples based on INAA data. Three distinct fields were identified: 'Sand', Clay1, and Clay2.

in elemental distributions and ultimately allowing for empirically based assessments of the circulation of pottery, raw clays, and tempering materials. Other relevant elemental and compositional studies have been conducted in Hispaniola and The Bahamas (Casale et al., 2022; Conrad et al., 2008; Keegan et al., 2022; Kracht et al., 2022), Jamaica (Hauser et al., 2008), the Cayman Islands (Petras and MacDonald, 2024), Puerto Rico (Carini 1991; Casale et al. 2023), Anguilla and St. Croix (Crock et al., 2008), St. Kitts (Ahlman et al., 2008), St. Lucia (Isendoorn et al., 2008), the French West Indies (Kelly et al., 2008), and Carriacou (Fitzpatrick et al., 2008). Lozada-Mendieta and Villagran (2024) provide a comprehensive regional overview of archaeometric studies in the Amazon and Caribbean.

Subsamples of pottery and raw clay samples were characterized for geochemistry by the Federal Institute for Geosciences and Natural Resources (BGR, Hannover, Germany). ICPMS was used to measure additional trace elements for the multielement plots and XRF to measure major element distributions. A PANalytical Zetium spectrometer was used for XRF analysis of powdered samples. To determine loss on ignition (LOI), 1 g of sample material was heated to 1030 °C for 10 minutes including a ramp at 700 °C. After XRF measurements, Li metaborate melt beads were crushed, ground to < 64 μm grain size, and the powders dissolved with suprapure diluted nitric acid. The solutions were analyzed for rare earth elements (La to Lu), Y, Th, and U with a Thermo Fisher Scientific iCAP TQ tandem ICP-MS (ICP-MS/MS) with Li-matrix matched calibration solutions and blanks. Y, La, Ce, Pr, Ho, Th, and U were measured in single quadrupole mode, whereas all other elements were measured in kinetic energy discrimination (KED) mode with He as collision gas to reduce common interferences.

4.4. Mineralogical analyses

Pottery and raw clay subsamples at BGR were analyzed for their mineralogical composition using XRD, especially for the identification of clays. BGR's mineralogical analysis was qualitative (presence/absence). XRD patterns were recorded using a Panalytical X'Pert PRO MPD Θ-Θ diffractometer (Cu-Kα radiation generated at 40 kV and 40 mA), equipped with a variable divergence slit (20 mm irradiated length), primary and secondary soller, Scientific X́Celerator detector (active length 0.59°), and a sample changer (sample diameter 28 mm). Additionally, polished thin sections were investigated for their texture and mineralogical composition under transmitted and reflected light using a ZEISS Axioplan polarized light microscope.

Petrographic analysis of pottery and sediment samples was also undertaken at Montclair State University Department of Earth & Environmental Studies (MSUEAES). Thin sections were viewed under a petrographic microscope to identify mineral inclusions and rock fragments that are silt size or larger (>2 μm) (Degryse and Braekmans, 2014: 193; Stoltman, 2015: 8–11). Petrographic analysis of sherds potentially allows for the identification of ceramic fabric groups, which in turn may be linked to specific resources used for inclusions in pottery production. A ZEISS Axioskop 40 petrographic microscope was used to point count thin sections on a 1-mm grid. Between 300 and 500 points were counted for each slide, depending on the amount of material available in a given thin section.

4.5. Statistical analyses and graphical techniques

Univariate, bivariate, and multivariate analyses are typically used to address elemental concentrations in rocks, sediments, and pottery samples (Glascock, 1992; Glascock and Neff, 2003; Neff, 2002). While multivariate analyses often develop clusters or fields, which can be illustrated on scatterplots with reduced dimensions (e.g., principal component analysis), visualization of the resulting plots is often difficult. We therefore used a range of multivariate analyses to understand variation and clusters and multielement diagrams to compare rocks, alluvial sediments, and pottery.

Principal component analysis was used to reorganize the original input variables into a new set of variables or principal components that included progressively smaller contributions to the variance. The original concentrations for each element within the analyzed dataset were standardized using z-scores: $z = (x - \mu)/\sigma$, where z is the standardized score, x is the raw data value, μ is the population mean, and σ is the population standard deviation. Z-scores allow us to compute the probability of a score falling within a standard normal distribution and to compare scores from different samples with different means and standard deviations (Warne, 2021).

The use of z-scores standardizes concentrations of elements contributing to the PCA. A broken-stick model was used to determine the number of components with statistical significance, although some PCA groups were only distinguished with lower variance eigenvectors (Peres-Neto et al., 2003). Datasets were illustrated as plots of samples on the first few components. The contributions of each element to the eigenvector were used to identify distinct clusters or fields within a given dataset.

The compositional variations of the igneous rocks can broadly be illustrated using multielement diagrams normalized to mid-ocean ridge basalt (N-MORB). Data were normalized to N-MORB as this has previously been used to interpret most Jamaican igneous rocks (Hastie et al., 2012, 2015; Mitchell, 2020). These diagrams have dozens of trace elements on the abscissa with more incompatible elements on the left passing to more compatible elements on the right. The diagrams show progressive enrichment in the more incompatible elements passing from IAT to CA to Shoshonitic to JTA/HNB (Hastie et al., 2012, 2015; Mitchell, 2020). Multielement plots reflect processes that occur during partial melting, producing magmas to crystallization of igneous rocks and are routinely used to infer the tectonic environment in the formation of igneous rocks. Jamaica is characterized by a wide variety of igneous and metamorphic rocks produced in different tectonic environments and these characteristics are likely to be retained in alluvial sediments derived from their weathering. Pottery made from the alluvial sediments is also liable to retain the signature of the alluvial sediments from which it originated.

Univariate analyses are used to illustrate variability in elements between different groupings identified from PCA, multielement diagrams, and elements with similar chemical characteristics. These diagrams illustrate changes in elemental composition between the igneous rocks, alluvial sediments, and pottery groups. Bivariate element (element against element) and bivariate ratio (element verses ratio of two elements) plots are used to illustrate variability in samples and they complement the principal component plots. Bivariate plots provide a visually simple way to illustrate differences between identified igneous, alluvial sediment, and pottery groupings.

5. Results, data integration, and interpretations

We first characterize the Rio Cobre drainage in terms of the relative percentages of the sedimentary inputs from the three relevant inliers followed by elemental and petrographic analyses of the sediment and pottery samples.

5.1. Cretaceous inlier areas drained by the Rio Cobre

The Rio Cobre drains a large catchment in the parish of St Catherine (Fig. 2c). The geology of the area consists of an older suite of igneous and sedimentary rocks exposed in the Central, Benbow, and Above Rocks Cretaceous Inliers, rocks of the Yellow Limestone and White Limestone groups, and superficial deposits (alluvium and bauxite deposits). The Cretaceous rocks are represented by igneous (both extrusive and intrusive) and associated sedimentary rocks derived from similar sources; limestones are also present but are generally subordinate to the other rock types. The Yellow Limestone consists of quartz-rich sandstones and impure limestones, but is poorly represented spatially within the drainage basin. The White Limestone is represented by pure limestones, dolomitic limestones, and dolostones. The alluvium is represented by conglomerates, sands, and clays derived from the Cretaceous (and locally Paleocene) inliers. Bauxite deposits are largely restricted to enclosed depressions in the White Limestone and do not contribute significantly to alluvial material. The contribution of alluvium to the Rio Cobre is therefore going to be dictated by erosion in the three inliers, as well as remobilization of alluvium in floodplains, which will likely have a similar composition to the inliers.

The Rio Cobre includes three major tributaries, the Rio Doro, Rio Magno, and Rio Pedro, each of which rises in a different inlier, or different parts of the same inlier (Fig. 2c). The Rio Cobre rises as the Murmuring Brook in the eastern part of the Central Inlier and flows into Lluidas Vale where it deposits extensive alluvial deposits. It then sinks at the eastern margin of the vale to rise in St Thomas-in-the-East where it flows towards Bog Walk Gorge. Tributaries to the Rio Cobre include the Rio Magno in the northern part of St Thomas-in-the-East (ephemeral and dry during dry season) that drains the southern flanks of the Benbow Inlier and the Rio Doro and Rio Pedro, both of which drain extensive areas of the Above Rocks Inlier. The various inliers provide differential amounts of source materials that make up the Rio Cobre drainage basin (Table 1). The main contribution of sedimentary material to the basin is derived from the Above Rocks Inlier, occupying about two-thirds of the Cretaceous – Paleogene source area.

5.2. Geochemistry of igneous rocks in the Rio Cobre drainage basin

The Western Blue Mountains and Western Jamaica terranes contain a suite of igneous rocks that show progressive geochemical changes as the island arc developed and different parts of that evolution are preserved in the rocks of the Benbow, Central, and Above Rocks Inliers that are present in the drainage basin. The Benbow Inlier is characterized by island-arc tholeiites (IAT) and primitive calc-alkaline lavas (CA), the eastern Central Inlier by primitive calc-alkaline lavas, and the Above Rocks Inlier by CA lavas and granodiorite. Background fields were produced for multielement diagrams illustrating the elemental compositions of rocks found in the Benbow, eastern Central, and Above Rocks Inliers drained by the Rio Cobre (data from Hastie, 2007; Hastie et al., 2009, 2012, 2015). These fields show the Benbow, eastern Central, and the lavas and granodiorite of the Above Rocks Inliers and are compared to the alluvial sediment samples collected from the Rio Cobre near the White Marl site (Supplementary Data and Analyses Files).

5.3. Characterization of alluvial sediments in the Rio Cobre

A PCA on the NAA data for the alluvial sediments from the Rio Cobre distinguishes three separate sediment groupings (Fig. 6**,** Table S2). The broken-stick model suggests that the first two components are significant. The first principal component has negative loadings for Na, K, Ba, Sr, and Rb, and to a lesser extent Ca and Hf, and positive loadings with most other elements, and is largely reflecting the significance of alkali (Na, K, and Rb) and alkaline earth (Ca, Ba, and Sr) elements (Supplementary Data and Analyses Files). The second principal component has a more complex relationship, with negative loadings for Ta, Cr, Ti, Hf, Th, V, and Al, and positive loadings for many rare earth elements (REEs) (La, Lu, Nd, Sm, Yb, Tb, Ce, Eu, and Dy) together with Mn, Na, Ca, Ba, Sr, Rb, and Co, but mostly negative with others. The three sediment groupings are called Clay1, Clay2, and 'Sand' (which was collected as 'sand') in the further analyses below. Petrographically, Clay1 and Clay2 are indistinguishable (Table 2). XRD data indicate illite and smectite clays are not present, which means that alkali elements (Na, K) were removed from the system during the breakdown of minerals into clays by weathering (Table 3).

5.4. Comparison of alluvial sediments and igneous rocks from the Rio Cobre drainage basin

Using multielement diagrams, the three alluvial sediment groups (Clay1, Clay2, and 'Sand') will now be compared geochemically with the rocks from the three Cretaceous inliers that are drained by the Rio Cobre (Fig. 7). The multielement patterns and elemental concentrations of the alluvial deposits (NAA and ICPMS data [Tables S2, S3]) match very closely with the patterns and concentrations from the Above Rocks granodiorite and moderately well with the extrusive rocks of the Above Rocks Inlier (which have lower concentrations of Ta, Hf, and Zr). There is no match with the multielement patterns from the Central or Benbow Inliers, which are both depleted in the incompatible trace elements. These patterns demonstrate that neither the Central Inlier (where alluvial sediments of the Rio Cobre are largely trapped in Lluidas Vale) nor the Benbow Inlier (where the Rio Magno is dry for much of the year) are significant sources of the clays and sands in the alluvium of the lower Rio Cobre. Based on the patterns documented in the multielement plots, the Above Rocks Inlier is the dominant source of alluvium in the lower course of the Rio Cobre.

The PCA (NAA data) identified three alluvial sediment types: Clay1, Clay2, and 'Sand' (Fig. 6). Using multielement diagrams based on NAA and ICPMS data, the sediment types are compared with the granodiorites and lavas/volcaniclastics (Fig. 8). All three sediment types show reasonable matches to both rock populations, although there are subtle differences; La shows greater concentrations than Ta in Clay 1, whereas they have similar concentrations in Clay 2. To link source to cultural sinks, we now compare the three alluvial sediment fields to pottery elemental compositions.

5.5. Comparison of pottery to alluvial sediment samples

A PCA was undertaken for the pottery samples using *z*-score normalized NAA data (Supplementary Data and Analyses File); three groups of pottery (PG1, PG2, PG3) and an outlier (PG1(O)) can be distinguished (Fig. 9). The broken-stick model indicates three significant principal components accounting for 64 % of the total variance. The first principal component accounts for 35.9 % of the variance, with positive loadings for most elements, but negative loadings for alkali and alkaline earth elements (Na, K, Ba, Rb) excluding Ca. The second principal

Table 2
Percentage distributions of sediment sample mineralogical components. The sediment type and Dott (1964) classification are shown for reference.

	Sample					
	RC1-3	**Wys2**	**ST1**	**RC1-4**	**ST3 sand**	**RC5 sand**
Type	Clay1	Clay1	Clay1	Clay2	'Sand'	'Sand'
mono quartz	1.9	18.6	2.6	1.4	34.0	22.7
poly quartz	0.0	1.4	0.0	0.0	5.7	8.6
feldspar	4.0	5.9	16.0	4.1	7.7	17.9
matrix	92.8	60.2	72.7	93.6	34.3	4.5
opaque	1.1	6.3	6.2	0.9	6.3	0.3
amphiboles	0.0	0.9	1.5	0.0	4.3	1.4
muscovite	0.3	1.8	1.0	0.0	2.0	0.3
volcanics	0.0	2.7	0.0	0.0	2.0	12.4
felsics	0.0	2.3	0.0	0.0	3.7	31.3
bioclast	0.0	0.0	0.0	0.0	0.0	0.7
Total	100	100	100	100	100	100
Dott Classification	Mudstone	Wacke	Wacke	Mudstone	Wacke	Arenite

Table 3
Qualitative XRD results for sediment samples.[a]

Sample	quartz	feldspar	vermiculite	kaolinite	calcite	amphibole	laumontite	hematite	musc./illite	smectite
RioCobre1	+	+	+	+	–	–	–			
RioCobre2	+	+	+	+	+	–				
RioCobre3	+	+	+	+	–	–				
RioCobre4	+	+	+	+	–	–	–	–		
RioCobre5	+	+	+	+	–					
RioCobre6	+	+	+	+	+	–	–	–		
RioCobre7	+	+	+	+	–	–	–	–		
RioCobre8	+	+	+	+	+					
Rosetown	+	+	–	–	–	–				
Callaloo	+	+	+	–	–	–				
Wisynco1	+	+	–	–	–	–	–	–		
Wisynco2	+	+	+	–	–	–	–	–		
Wisynco3	+	+	+	–	–	–	–	–		
Wisynco4	+	+	+	–	–	–	–			
CentralVillClay1	+	+	+	+	+	–	–	–		
Spanishtownclay1	+	+	+	+	–	–	–	–		
Spanishtownclay2	+	+	+	+	–	–	–	–		
Spanishtownclay3	+	+	+	+	–	–	–			
SpanishtownSand3	+	+	+	–	–	–	–	–		

[a] Note the absence of illite and smectite. + = abundant, – = detected, empty cell = undetected.

component accounts for 15.5 % of the variance and shows a complex pattern of negative and positive correlations with different elements. The third principal component accounts for 12.5 % of the variance and shows a positive correlation with many elements, but a negative correlation with V, Ti, Zr, Hf, Cr, and As. The scatterplot for PC2 vs. PC1 (Fig. 9A) clearly distinguishes PG1, PG2, and PG1(O), but PG3 is not distinct on this plot. The scatterplot for PC2 vs. PC3 (Fig. 9B) clearly distinguishes PG3 from PG1 and PG2.

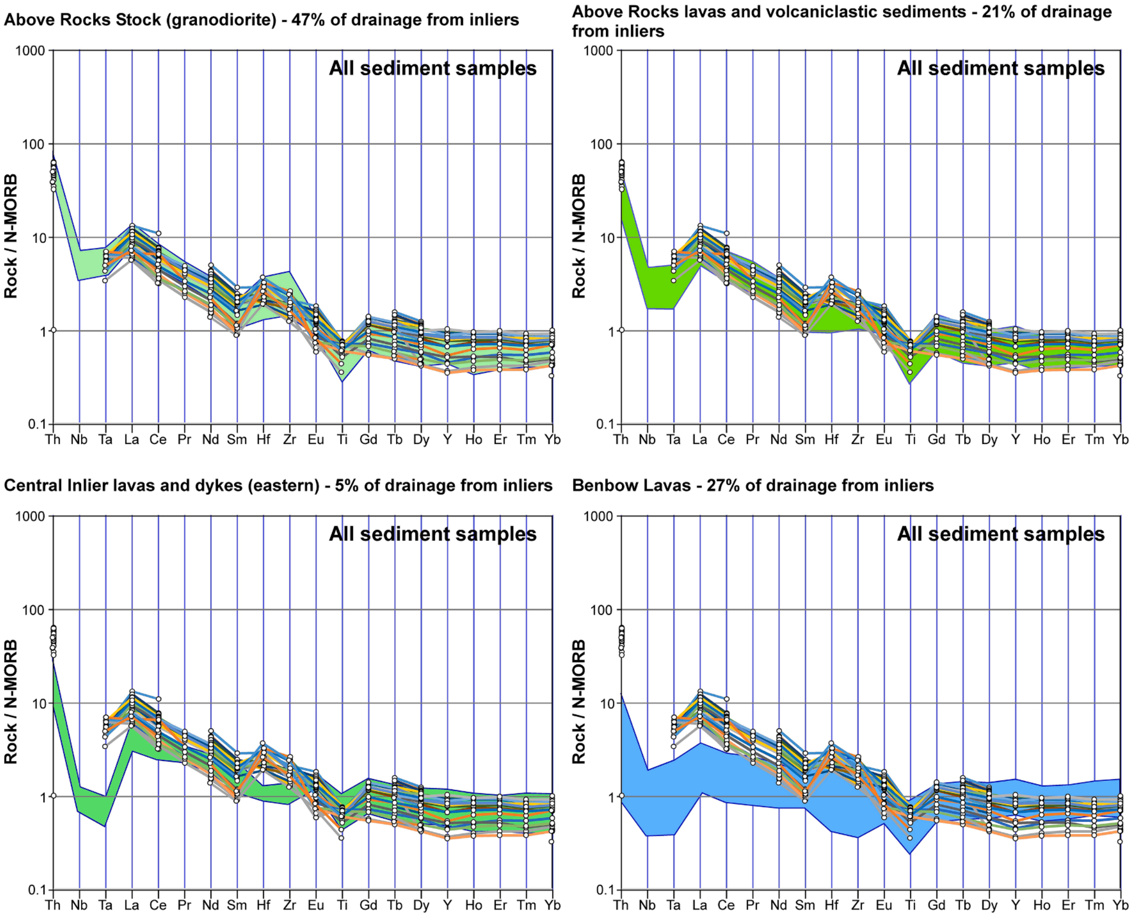
The pottery groups may now be compared with the alluvial sediment types from the Rio Cobre using multielement plots (NAA and ICPMS data) (Figs. 10–12; Tables S1, S3). In general, the three pottery groups show similar patterns to the alluvial sediments, although some elements are diluted. All three pottery groups display relatively similar multielement characteristics, which may not be unique to the Rio Cobre because rocks in the NW Central Inlier (drained by the Rio Minho) are also of late Maastrichtian to early Paleocene age (Mitchell, 2013b, 2020).

5.6. Other elements

Silicon (XRF data) is present both in quartz, alumina-silicates (feldspars), and Fe-Mg silicates (amphiboles, pyroxenes, and micas), which are also present in the Above Rocks granodiorite and the andesites/dacites and volcaniclastic rocks of the Above Rocks Inlier (Fig. 13; Table S4). Compared to the source rocks (granodiorites and andesites/dacites) the Rio Cobre sediments show a notable drop in Si concentration; only one sample is available for 'Sands'. This is most easily explained by stable silt- and sand-sized quartz grains (as well as some feldspar) separating from the clay fraction during transportation along the river system. The separation of quartz would also result in increased concentrations of other elements seen in the multielement plots.

In contrast to Si, Al (NAA data), which is present in the alumina-silicates, is more highly concentrated in the sediments (clays and sands) than in the rocks, resulting from the breakdown of unstable grains during weathering in soil profiles with the formation of clay minerals (alumina-silicates). The sands also show an increase in Al, possibly reflecting the presence of feldspars together with quartz, while other grains are broken down during transport.

Potassium (NAA data) occurs in K-feldspars, micas (biotite and muscovite), and clay minerals (such as illite) (Deer et al., 1992; Smith et al., 2019). In the Above Rocks granodiorite, K is present in K-feldspar and biotite and the granodiorite typically contains 0.5 to 1.2 wt% K_2O (although one sample has 2.2 wt%) (Fig. 13). In situ tropical weathering of the granodiorite progresses from the regolith to the soil profile leading to the breakdown of unstable minerals (e.g., mica and K-feldspar) and the production of clay minerals, whereas stable minerals (e.g., quartz) are retained in the soil profile unless there is extensive leaching. Qualitative XRD analysis of the sediment samples indicates that neither illite nor smectite are present, demonstrating that K is leached from the system during weathering under a hot humid climate (Table 3).


Above Rocks Stock (granodiorite) - 47% of drainage from inliers

Above Rocks lavas and volcaniclastic sediments - 21% of drainage from inliers

Central Inlier lavas and dykes (eastern) - 5% of drainage from inliers

Benbow Lavas - 27% of drainage from inliers

Fig. 7. Comparison of all sediment samples (dots and lines) from the Rio Cobre with multielement diagram fields from the Central Inlier (andesites and basalts), Benbow Inlier (andesites and basalts), and Above Rocks Inlier (andesites, basalts, and granodiorite); inlier data from Hastie (2007) and Hastie et al. (2009, 2013, 2015). The points show a good match with the Above Rocks Inlier, but poor matches with the Central and Benbow Inliers.

Physical weathering leads to the transport of material into river systems and subsequent transport along the drainage network; with greater residence times in floodplains the mobile elements are removed from sediments. River transport leads to the physical separation of bed load particles (sands consisting of such stable grains as quartz and heavy minerals and unweathered grains including feldspars, micas, and ferromagnesium minerals) and suspended load materials (clays and fine silts), resulting in distinctive depositional events on the floodplains. Physical transportation increases the K-concentration to 1 to 2.5 wt% in the clay sediment fraction. Even the 'sands' sampled in the Rio Cobre contain high concentrations of K, but they also contain relatively high proportions of clay material documented in thin sections.

Both Rb and Ba (NAA data) can substitute for K in the crystal structures of K-feldspar and biotite (Deer et al., 1992; Smith et al., 2019). Rb shows low concentrations in the granodiorite (typically < 10 ppm), but is significantly enriched (55–85 ppm) in the clays and sands of the lower Rio Cobre floodplain, where it is probably taken up in clay minerals (Fig. 13); both K and Rb are highly mobile during tropical weathering so their concentrations in the igneous rocks can be variable. Ba concentrations in the granodiorite and Rio Cobre sediments (clays and sands) are similar (Fig. 13); Ba is also a highly mobile element during tropical weathering.

Co can substitute for Fe and Mg in such minerals as pyroxene (e.g., augite), amphibole (e.g., hornblende), and olivine, as well as in sulphide minerals associated with hydrothermal mineralization (Deer et al., 1992; Smith et al., 2019). The Above Rocks granodiorite contains both pyroxene and hornblende. The granodiorite contains Co concentrations of 9–18 ppm, whereas the clays in the lower Rio Cobre are divided into two groups: Clay 2 with Co concentrations of 10–13 ppm, and Clay 1 with Co concentrations of 17–31 ppm; the first (Clay 2) similar to concentrations in the igneous rocks and the second (Clay 1) being enriched in Co.

In summary, there are changes from the elemental compositions of the rocks in the Above Rocks Inlier to the sediments (clays and sands) in the lower Rio Cobre. Yet the sediments retain similar multielement patterns to the Above Rocks igneous rocks, demonstrating their derivation from that inlier. Other elements show notable changes between the igneous source and the sedimentary sink: Si decreased in concentration, while Al, K, and Rb increased due to separation of the sand (quartz) from clay fractions during transport along the river system.

5.7. Petrographic analysis of pottery and sediment samples

The petrographic compositions of 23 pottery and 6 alluvial (clay/'sand') sediment samples were analyzed by point counting. For pottery thin sections, between 302 and 556 points/slide were counted, whereas for alluvial sediment (clay/'sand') thin sections, between 300 and 582 points/slide were counted (Table S5). We distinguished alluvial sediment groups and pottery groups identified in the analyses for convenience of cross reference.

The pottery thin sections are dominated by bulk composition and minor amounts of purposely added tempering materials and its mineralogical makeup may be characterized by percent monocrystalline quartz; percent polycrystalline quartz; and percent feldspars, mafics, and micas (FMM) (Stoltman 2015: 15). In the White Marl assemblage, the percent FMM includes feldspars, amphiboles, opaque phases,

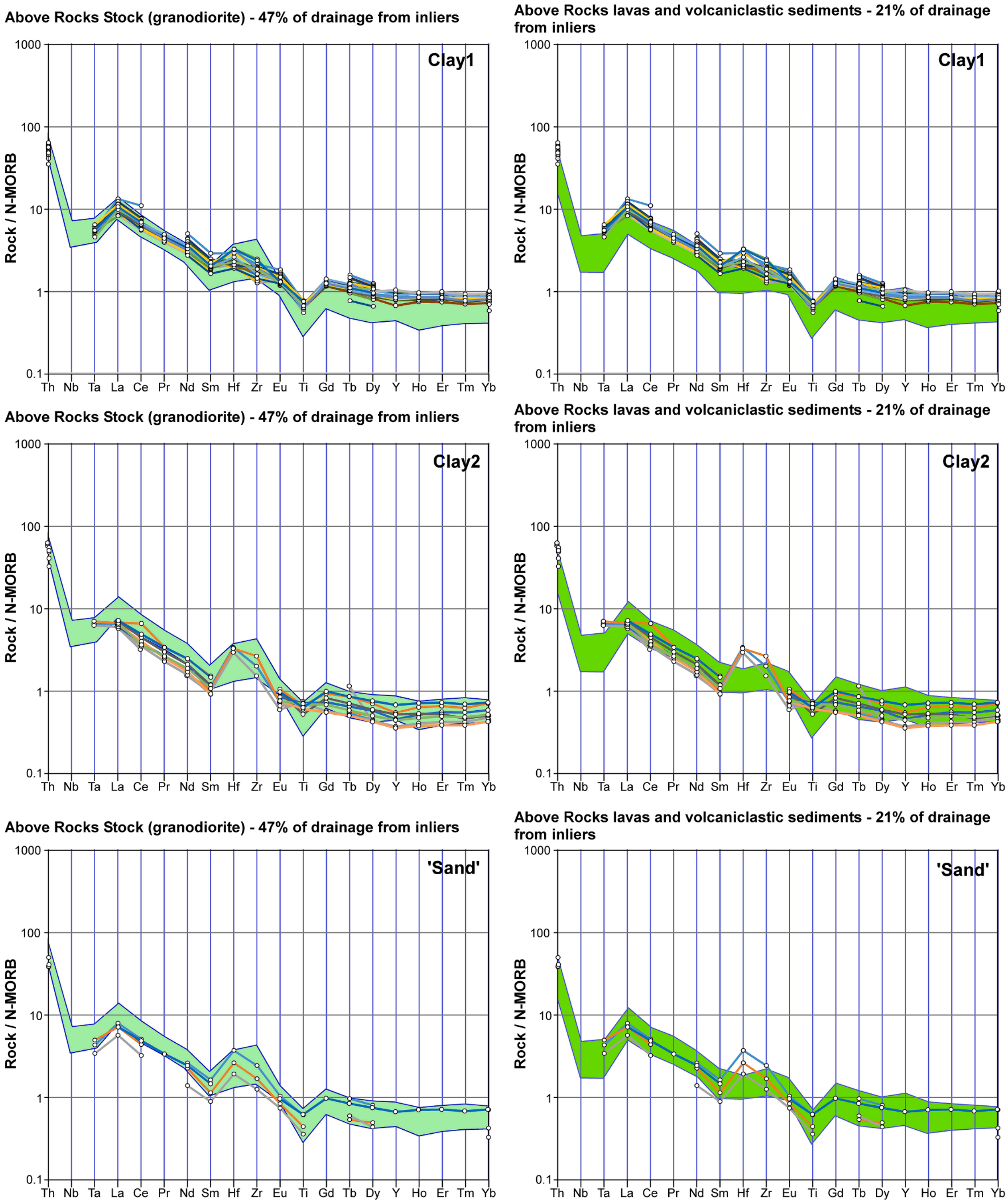


Fig. 8. Multielement diagrams comparing the three alluvial sediment types (Clay 1, Clay 2, and 'Sand') with the fields for the Above Rocks granodiorites and lavas/volcaniclastic sediments.

muscovite, and fragments of volcanic and felsic rocks.

The three pottery groups are consistent in matrix (including grog) to clast ratios (approximately 60 to 40) (Table 4). In the White Marl assemblage, grog appears to consist of clasts of clay or argillaceous fragments in the matrix rather than crushed pottery pieces added as temper material (Cuomo di Caprio and Vaughan, 1993; Herbert and Smith, 2010). The absence of crushed pottery as temper was confirmed through Simon Mitchell's examination of 153 sherd cross sections (including the 75 selected for the current study) using a 10x hand lens (see also Fig. 14). Bioclasts were present in only one sample (WMS3 in PG3) (Fig. 14B). The remarkable consistency of matrix to clasts ratios suggests that a pure clay (lacking clastic grains) was mixed with a temper consisting solely of clastic grains. Two of the sampled clays are pure with about 93 % matrix (i.e., clay and fine silt). This would suggest that a ratio of clay to temper of about 60 % to 40 % was used. We can compare this with dilution factors in the elemental concentrations for clays to pottery in Pottery Groups 1 and 2.

5.8. Alkali metals (Na, K, Rb, Cs) and alkaline earth metals (Ca, Sr, Ba) – NAA data – pottery vs. clays

Alkali metals (specifically Na and K) in igneous rocks are typically incorporated in K–feldspar, whereas K can also be incorporated into biotite and amphibole. The Above Rocks granodiorite contains both K-feldspar and biotite and these minerals are the likely sources of K and Na. Small proportions of Rb and Cs can be incorporated into K-feldspar

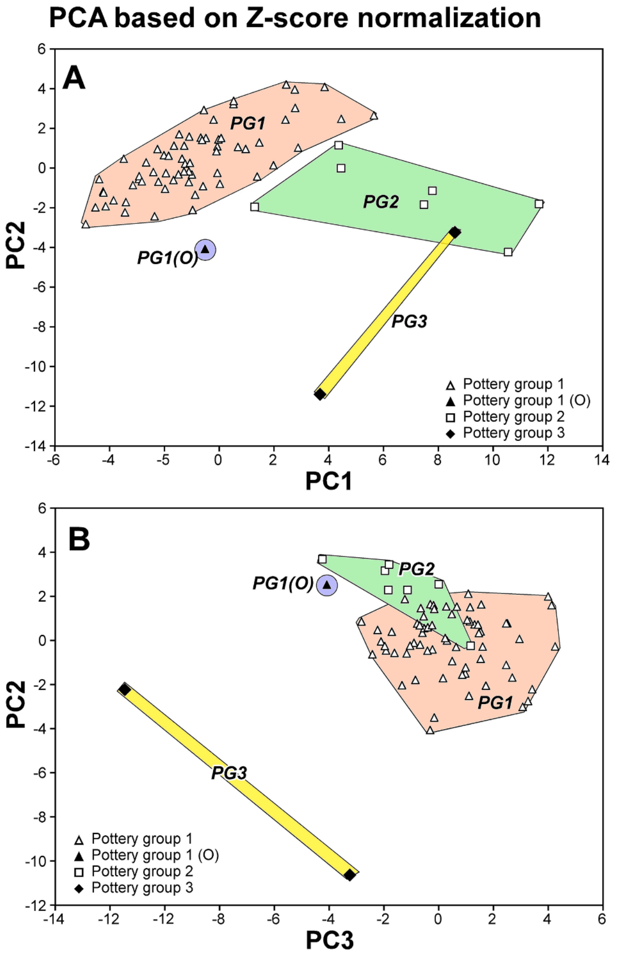


Fig. 9. Scatterplots for (A) PC2 versus PC1 and (B) PC3 versus PC2 using z-normalized INAA data. Plot A clearly distinguishes PG1, PG2, and PG1(O) whereas Plot B distinguishes PG3.

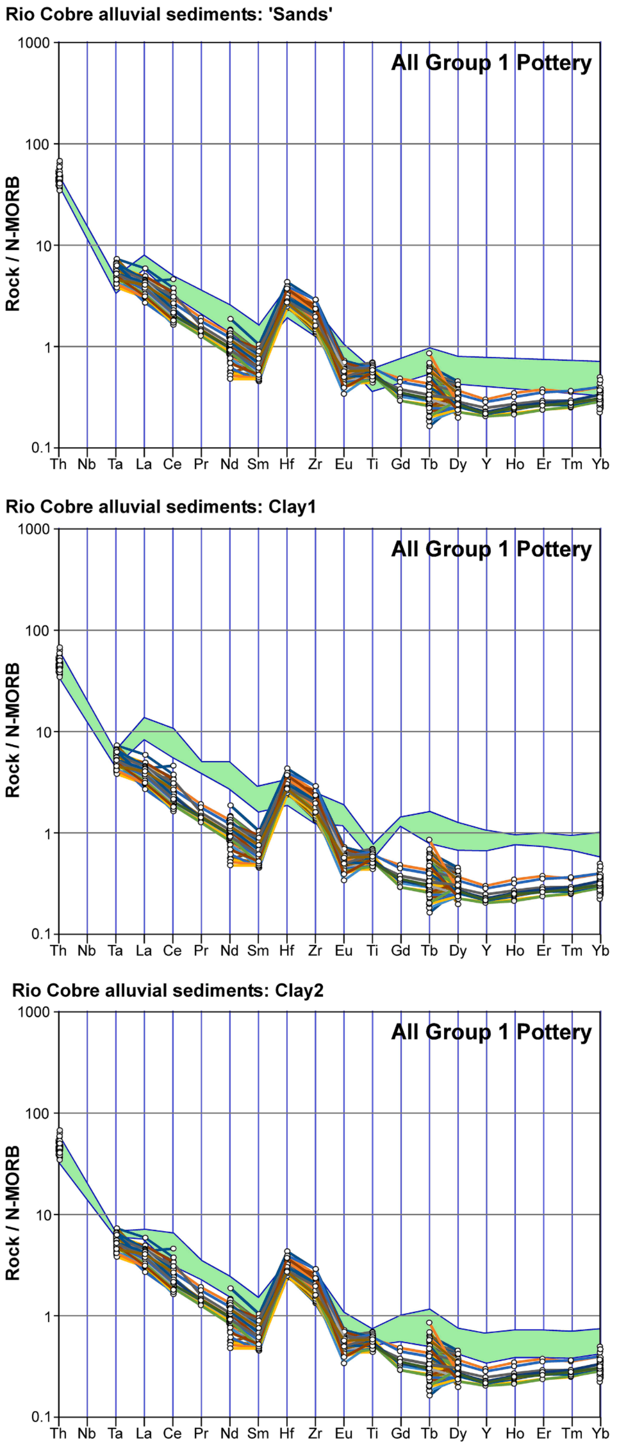


Fig. 10. Multielement plot for group 1 pottery (PG1) compared with fields for the three types of alluvial sediment from the Rio Cobre. The best match is with Type 2 clays, although some elements have lower concentrations (diluted) in comparison to the clay. The green fields represent the sediment compositions. White circles connected by lines represent individual pottery samples with their associated elemental concentrations. Incomplete lines represent different element suites analyzed by different laboratories.

as a substitute for K.

The alkaline earth metals (especially Ca) are typically found in plagioclase feldspar, amphiboles (such as hornblende), and clinopyroxene, which is the likely source of Ca in clays, although there could also be components from the weathering of limestones ($CaCO_3$). Sr and Ba can also substitute for Ca in plagioclase and Sr in calcite.

The behavior of the alkali metals and alkaline earth metals in the pottery groups shows a distinctive pattern (Fig. 15). Pottery Groups 1 and 2 generally show similar proportions of Na, K, Rb, and Cs, whereas PG3 (only two samples) has notably lower concentrations of these elements (other than Na in one sample). PG1 and PG2 have broadly similar concentrations of Ca, Sr, and Ba, while PG3 revealed significant variance (Fig. 15). One PG3 sample (WMS 3) is relatively high in Ca and Sr but low in Ba, whereas the other (WMS 68) is low in Ca, Sr, and Ba. Petrographic analysis of WMS 3 revealed marine bioclasts (Fig. 14B) and marine carbonate sand (calcite with high Sr content and seawater with high Na content) added as temper material could account for its distinctive elemental concentrations. Other than Ca, Sr, and Ba, PG3 is characterized by low concentrations of alkali and alkaline earth metals, contrasting markedly with PG1 and PG2 (Fig. 15).

In comparison to the clay samples, PG1 and PG2 sherds show a moderate to good agreement of concentrations of Na, Rb, and Sr, a less well-developed correlation of Ca concentrations, and poor correlation for K and Ba. Most of the clay samples have higher Ca concentrations than in the PG1 and PG2 samples (Fig. 15). PG1 and PG2 samples have higher concentrations of K and Ba than do the clay samples. Such differences between pottery and clay samples are most likely a result of introducing temper, which is either enriched (K, Ba) or depleted (Ca) in elements relative to the clays.

5.9. Distinctions between rocks, clays, and pottery groupings

A PCA of the combined NAA z-score normalized data for alluvial

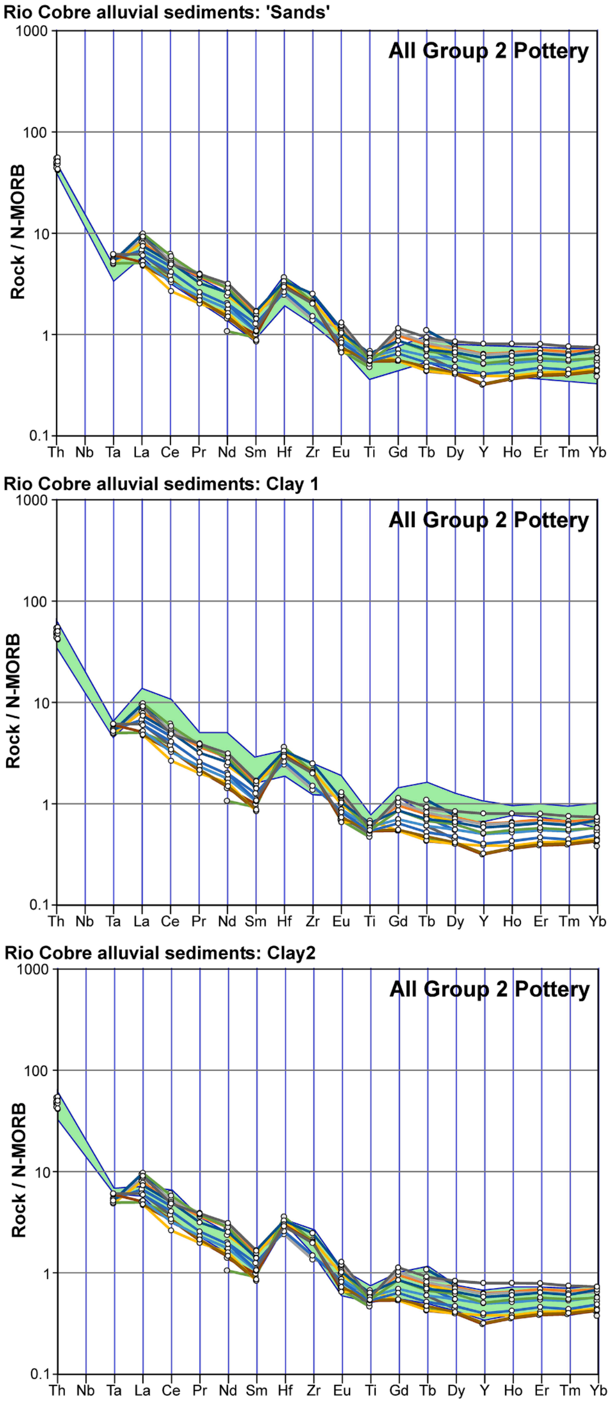


Fig. 11. Multielement plot for group 2 pottery (PG2) compared with fields for the three types of alluvial sediment from the Rio Cobre. The multielement plots show good agreement with either the ‘sands’ (unlikely) or Type 2 clay as the best match and most likely source.

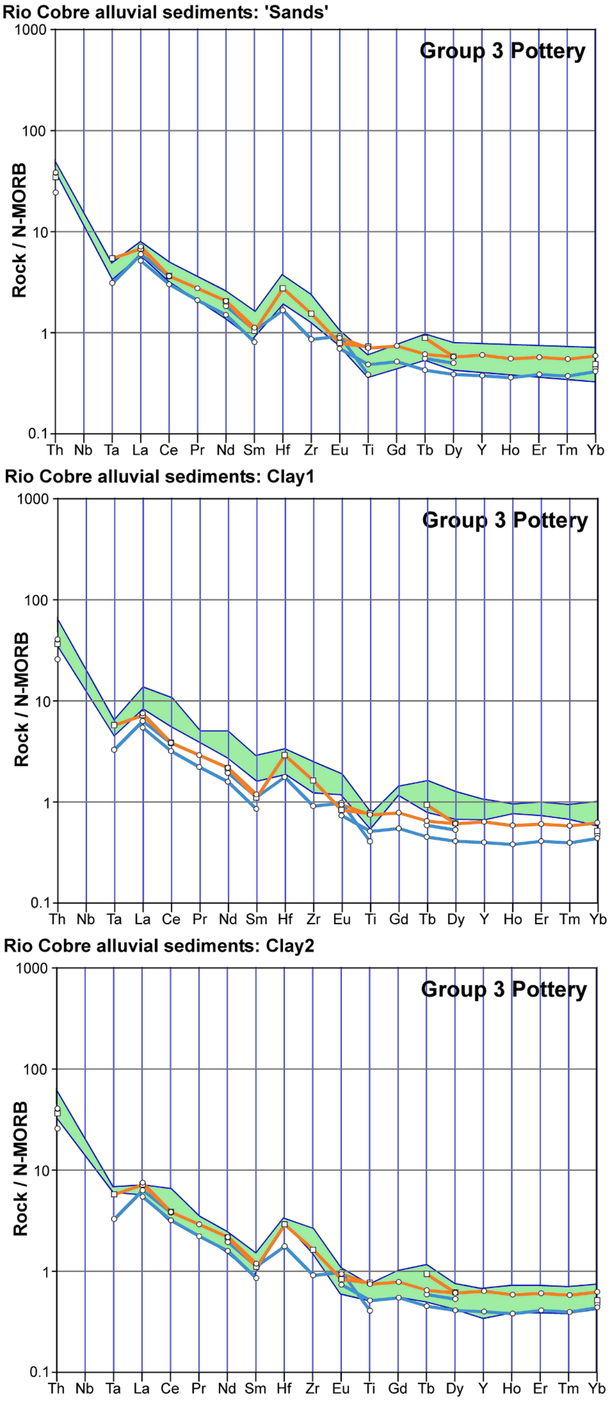


Fig. 12. Multielement plot for group 3 pottery (PG3) compared with fields for the three types of alluvial sediment from the Rio Cobre. There are moderately good matches, although the concentrations of Th and Ta are lower than those of the alluvial sediments.

sediments and pottery samples (Supplementary Data and Analyses File) reveals distinctions among the samples. The broken-stick model indicates two principal components accounting for nearly 69 % of the total variance; the third principal component distinguishes PG3 and is therefore also included in this discussion. The first component accounts for 58.8 % of the variance and shows positive loadings for most elements, but negative loadings for Hf and alkali and alkaline earth elements (minor Na, K, Ba, and Rb) excluding Ca. PC2 accounts for 10.1 % of the variance and shows a complex pattern of negative and positive correlations with different elements (Fig. 7). PC3 accounts for 6.9 % of the variance and shows a positive correlation with many elements, but a negative correlation with Ti, Ca, Ni, Cr, and As. A scatterplot of the scores for PC2 vs. PC1 (Fig. 16A) distinguishes the three sediment types (Clay1, Clay2 and ‘sands’), PG1 and PG2 (with slight overlap), and PG1 (outlier); PG3 is not distinguished on this plot. A scatterplot of the scores for PC3 vs. PC1 (Fig. 16B) clearly distinguish PG3 from PG1 and PG2 and the sediment samples. The principal component analysis of the *z*-score normalized pottery database shows that Pottery Groups 1, 2, and 3 and the sediment samples (Clay 1, Clay 2, and ‘sands’) can be distinguished.

Principal component analysis helps to identify clusters of points

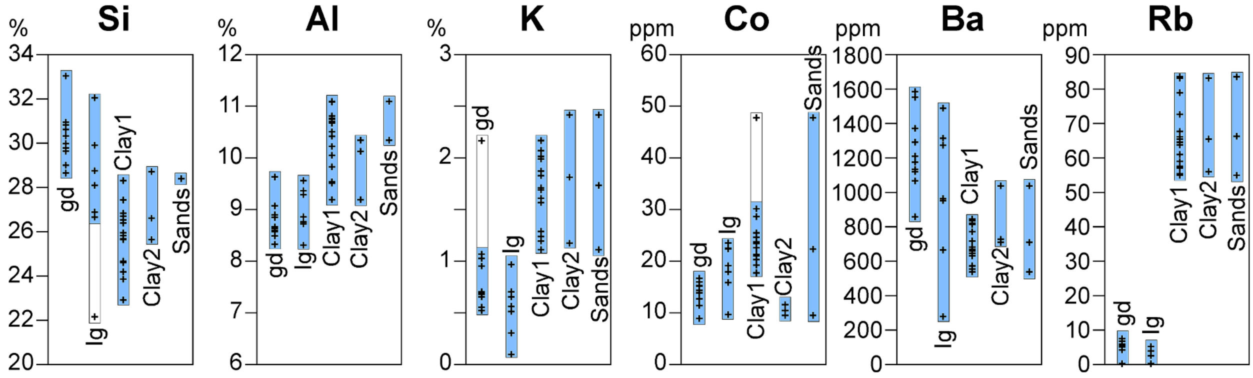


Fig. 13. Comparison of selected elements between rocks (granodiorites and andesites/dacites) of the Above Rocks Inlier with sediment types in the Rio Cobre. gd, granodiorite; lg, andesites and volcaniclastics. + represents individual samples and outliers are easily identified.

Table 4
Summary of petrographic point count data for pottery groups.

Pottery Group	Statistics	Clasts (%)	Bioclasts (%)	Matrix + Grog (%)
1 (n = 19)[a]	Min	37.1	0	60.7
	Mean	38.2	0	61.8
	Max	39.3	0	62.9
	Standard deviation	0.64	0	0.64
2 (n = 1)	N/A	39.1	0	60.9
3 (n = 2)	Min	37.1	0	61.6
	Mean	37.8	1.9	62.2
	Max	38.4	3.9	62.9
	Standard deviation	0.94	2.75	0.94

[a] In total, 75 pottery sherds were selected for analysis (elemental, petrographic). A subsample of sherds was selected for petrographic point counting. Total sherds by pottery group: PG1, 66; PG2, 7; PG3, 2. Percentage of sherds point counted by pottery group: PG1, 29% (19/66); PG2, 14% (2/7); PG3, 100% (2/2). Pottery groups were defined by geochemical profiles.

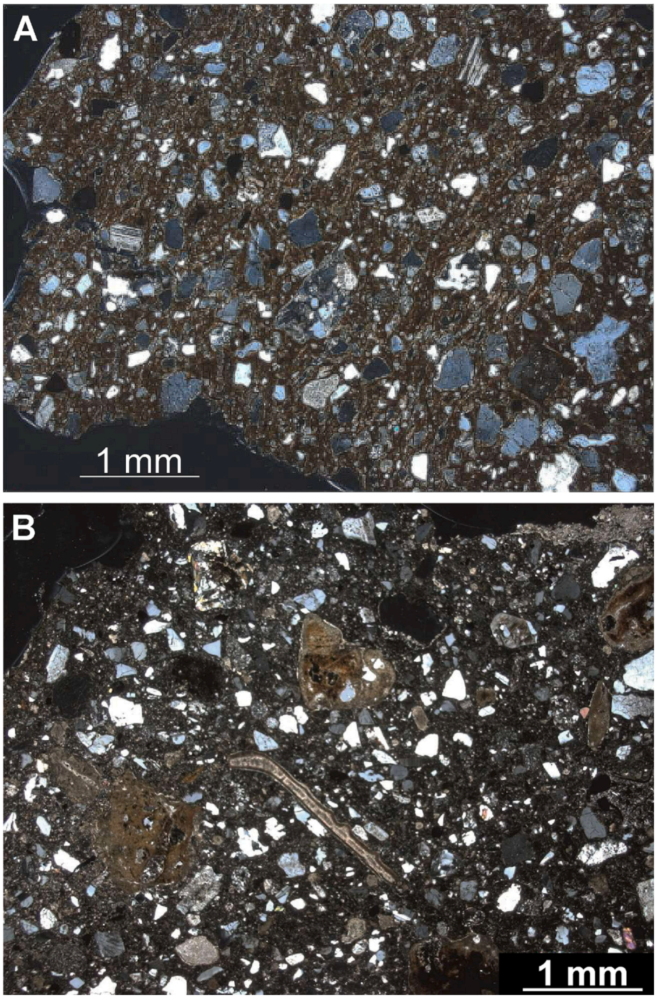


Fig. 14. Photomicrographs of pottery sherds in cross polarized light. A: WMS95 (Pottery Group 1). B: WMS3 (Pottery Group 3) with bioclast (mussel shell fragment) in middle.

however the resulting new variables represent a reorientation of axes in multidimensional space that are difficult to visualize. We present simple diagrams based on selected elemental concentrations and ratios to better illustrate the variation (Fig. 17). Pottery Groups 1, 2, and 3 can be distinguished on bivariate plots of Co vs. ratios of Ta/La, Ta/Ce, and La/Ce and K vs. Rb; pottery sample WMS 16 plots as a distinctive outlier in the plot of Co vs. La/Ce (Figs. 10, 11). These elements were used because they show diagnostic concentrations for the analyzed rocks, sediments, and pottery as detailed earlier. The sampled clays in the Rio Cobre fall into two groups, Clay1 and Clay2, and these are the probable source materials for Pottery Groups 2 and 1, respectively. WMS 16 represents an outlier that does not match either of the clay sources in the Rio Cobre, yet its high K and Rb values suggest an Above Rocks source area (either an unsampled clay source or a different basin draining the Above Rocks Inlier). PG3 is distinctive because of its low concentrations of K and Rb, and almost certainly originating in a different drainage basin than the Rio Cobre (see discussion to follow).

The geochemical patterns of most White Marl pottery and the Above Rocks Inlier granodiorites are closely related and the differences are attributed to the dilution effects of tempering materials added to the clays in pottery production (Neff et al., 2003). Since we can trace Pottery Groups 2 and 1 to Clay1 and Clay2 respectively, we can compare the pottery to the clay compositions (Table 5) and offer inferences into the composition of the pottery temper. To explain the pottery compositions, the temper material must have been rich in Na, K, Rb, Sr, Ba, and Si with elevated Th, Ca, Al, and As. Many of these elements are consistent with an alluvial sand temper consisting of quartz (Si), K-feldspar (K, Rb, Al, Si), and plagioclase feldspar (Na, Ba, Ca, Al, Si). Such a sand could be generated from weathering of the granodiorite in the Above Rocks Inlier, although none of the three ‘sands’ sampled in the Rio Cobre match these specifications. Mineralogically, all of the analyzed pottery samples had approximately 60 % matrix (clay) indicating that the recipe followed in the manufacture of White Marl pottery included 60 % clay

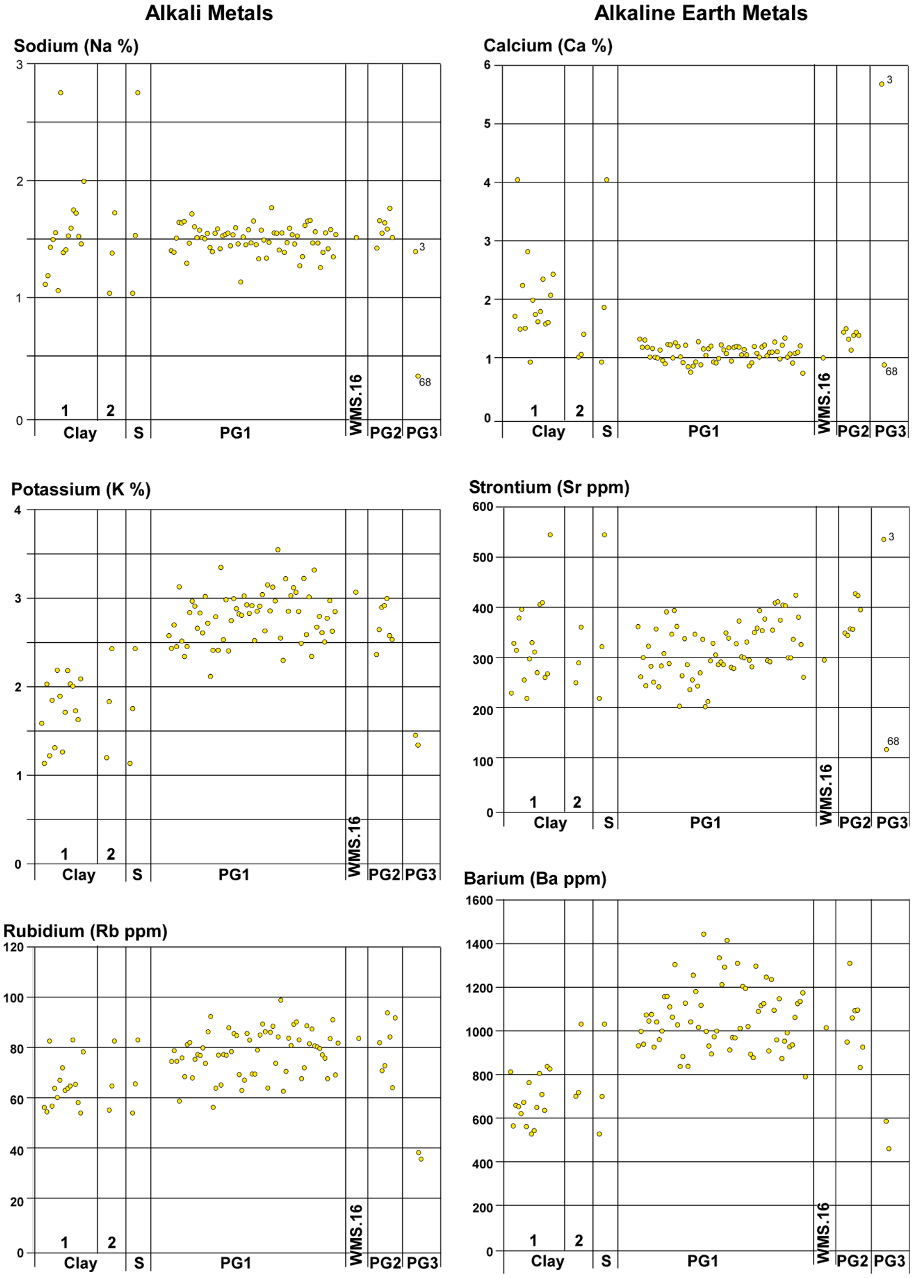


Fig. 15. Univariate plots comparing selected alkali metal and alkaline earth metal concentrations in sediments and pottery groups: Clay 1, Clay 2, Sand (S), PG1, PG2, WMS 16, and PG3.

and 40 % temper, a finding consistent with other petrographic studies of prehistoric pottery assemblages (e.g., Stoltman 2015).

6. Discussion

Results of the NAA, XRF, and ICPMS are consistent in revealing a relatively narrow range of variation in the elemental distributions of the 75 pottery and 22 sediment samples, indicating that most of the White Marl pottery was sourced from clays located close to the site. Out of 75 pottery samples, Samples 3 and 68 (Pottery Group 3) were geochemical and petrographic outliers. With low concentrations of K and Rb, Pottery Group 3 samples likely originated from a region outside of the Above Rocks Inlier catchment. Although there are some similarities in the multielement diagram to the Above Rocks Inlier, the low Th and Ta concentrations indicate a less evolved igneous source, most likely from the Maastrichtian volcaniclastics of the Central Inlier drained by the Rio Minho (Hastie, 2007).

Two hypotheses may be proposed to account for the presence of the outliers in the White Marl pottery assemblage:

Hypothesis 1. The two geochemical outliers out of 75 analyzed sherds represent an indeterminate number of vessels that were manufactured elsewhere and imported. Of course, people do not generally travel with or exchange sherds but whole pots. In his clay vessel-breaking experiments, Chase (1985) produced on average 15 sherds per pot. Fifteen sherds per pot is most likely an underestimate given the messiness of human behavior, village activities, trampling factors, and post-depositional processes (Baker, 1978; Brose, 1970: 46–49; DeBoer and Lathrap, 1979: 129: McPherron, 1967: 254–255; Rice, 2015: 261–264; Schiffer, 1978; Siegel and Roe, 1986; Stahl and Zeidler, 1990). Since the parameters of actual numbers of sherds in the White Marl site, pottery breakage patterns, and comminution factors are unknown we cannot provide estimates for the number of pots that may have been imported

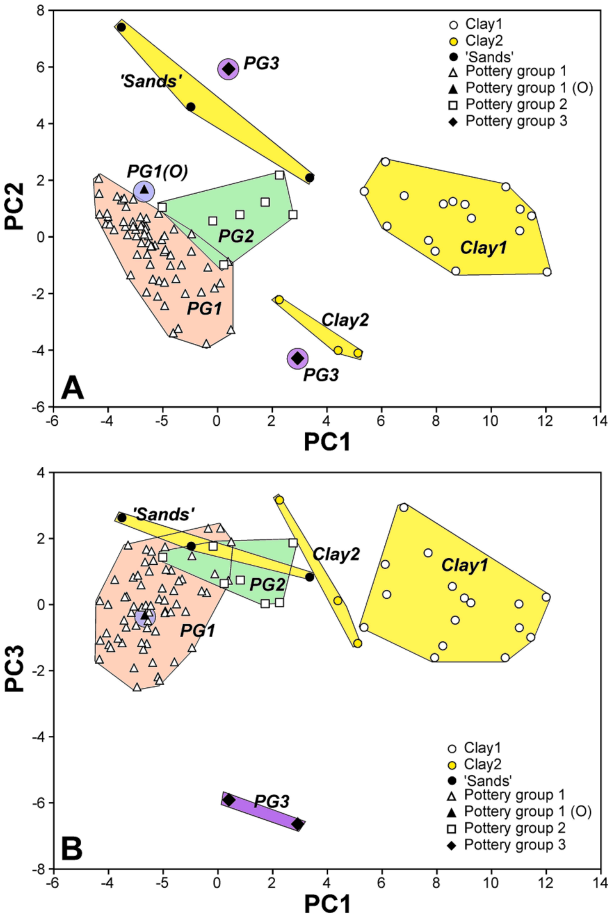


Fig. 16. Plots of principal components of the combined sediment and pottery samples based on INAA data: (A) PC2 against PC1, (B) PC3 against PC1. These PCA results separate the three sediment groups (Clay1, Clay2, 'Sand') and the pottery groups (PG1, PG1(O), PG2, PG3).

under this hypothesis. Further, at this stage of research we cannot assess what amount of pottery may have been exported from the village.

Hypothesis 2. The White Marl potters collected Rio Minho clays themselves through direct procurement. As the crow flies, the Rio Minho watershed is located approximately 40 km west of the White Marl site. If potters from White Marl collected the clay themselves it is unlikely they would have walked a straight line between two watersheds carrying heavy loads of clay. The canoe travel distance from White Marl down the Rio Cobre, along the south coast, to the mouth of the Rio Minho is 90 km (Fig. 2b).

Distance between clay sources and pottery-production areas has been shown to be an important variable, with an approximate catchment radius of 7–10 km accounting for about 90 % of ethnographically documented cases (Arnold 1980, 1985; Rice 2015: 130–133). For canoe-traveling cultures greater distances between clay deposits and production areas have been documented (e.g., Arnold, 1985: 50–57; DeBoer and Lathrap, 1979; Hogbin, 1951; Lauer, 1970, 1971, 1973; Reina and Hill, 1978). For six Shipibo-Conibo communities, DeBoer and Lathrap (1979: Table 4.1) recorded mean canoe distances between villages and clay deposits ranging from 1–20 km. Through a combination of travel and trade, some Shipibo potters obtained particularly desirable black clays from as far as 180 km (Arnold, 1985: 51; DeBoer and Lathrap, 1979: 115–116). In the northern region of the Peten, Guatemala, Reina and Hill (1978: 142, Map 5) documented potters traveling by canoe 10 km for 2.5 h to collect clay. Indigenous potters of the Huon Peninsula in Papua New Guinea were documented to travel by canoe from approximately 14–26 km to collect clays (Hogbin, 1951: xiv, 87–88). Amphlett potters of the Goodenough Islands in Polynesia traveled 4–24 km by canoe for their clays (Lauer, 1970: 389, 1973: 29, 45). The people of Papua New Guinea and the Goodenough Islands used sails with their canoes (Hogbin, 1951: 58, 77–79; Lauer, 1970: 383, 390, 393), a form of technology not documented for the Indigenous Caribbean.

Ethnohistoric observations of Contact-period Indigenous canoe travel in the Greater Antilles are relevant: "even with hard paddling a canoe cannot make more than ten leagues [approximately 55 km] in a day and a night" off the coast of Jamaica (Colón, 1959: 276–277). "And that the island of Hispaniola, or the other island of Yamaye [Jamaica], was near mainland, ten days' journey by canoe, which would be 60 or 70 leagues [330–385 km]" (Columbus, 1989: 315), averaging 36 km in a day.

Bérard and his team have carried out a series of canoe experiments in the Lesser Antilles, including the construction of dugout canoes, to assess the challenges in navigating open ocean and coast lines (Bérard et al., 2016a, 2016b; Bérard and Biar, 2021; Billard et al., 2009). Given the currents and ocean swells along the south coast of Jamaica, the 80-km distance between the mouths of the Rio Cobre and Rio Minho is not easy to navigate today in a powerboat and would have been a formidable challenge in a dugout canoe. Without considering the specific conditions of the Jamaican south coast, Bérard (personal communication, 2024) suggested that canoeing the 80-km distance would take approximately 13–15 h of hard paddling, which most likely would have been accomplished over two to three days. Ethnographic, ethnohistoric, and experimental evidence for canoe travel combined with the documented availability of good-quality clays in close proximity to White Marl does not support Hypothesis 2, although it cannot be rejected at this stage of research.

In a general discussion of exploitable territories for resource extraction, Browman (1976: 469) observed that there is "one range where returns increase more rapidly than costs," what he called "the preferred territory of exploitation." Regarding distance traveled for collecting clays, the preferred territory of exploitation relates directly to our findings that 97 % of the White Marl pottery samples were produced from clays that originated in the Above Rocks Inlier, the source rocks for alluvial sediments in the Rio Cobre drainage. Our current follow-up investigation of 16 additional prehistoric sites across Jamaica should help refine the range of exploitation territories for pottery clays as well as intra-island trade networks.

While our sample size of 75 sherds is small, Samples 3 and 68 may be evidence for some pottery vessels being manufactured elsewhere and transported to White Marl (Hypothesis 1 discussed above). Pottery Samples 3 and 68, clearly distinguished in the principal component analyses, were not made from locally available clays. Although the pots represented by these samples may be considered non-local (Rio Minho watershed), they came from an area within a likely closely-knit interaction sphere, perhaps a satellite community to the large White Marl settlement. Pottery Sample 16 is another outlier from the majority of samples. Geochemically, this sample is characteristic of the Above Rocks Inlier but appears to have been produced from a clay deposit uniquely different than the other analyzed sherds. At this stage of research, we are building the basis to address intraregional localized exchange networks (Arnold, 1980), which are particularly relevant for small to moderately sized islands.

An earlier study using fewer elements than those in the current investigation analyzed the geochemistry of pottery from 10 sites in Jamaica and four clay samples (James-Williamson et al., 2022). In that study, both Rb and K were considered to be useful and separated White Marl pottery from other sites across the island. However, that investigation only included a single element from the multielement diagrams used here, and it is not possible to compare the ten sites in that study with the geochemistry of the different Jamaican igneous rocks and the alluvium derived from them.

The pottery sampled in the current White Marl study falls into two

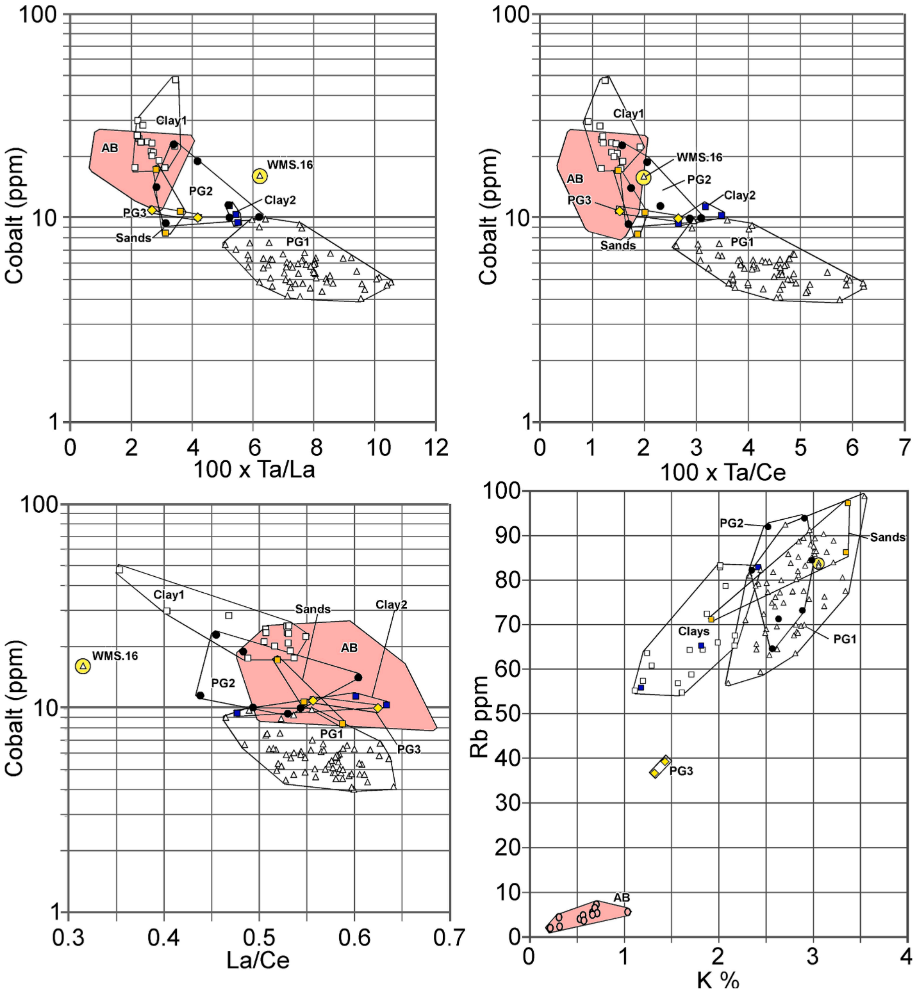


Fig. 17. Selected scatter diagrams that distinguish different fields for sediments, pottery groups, and Above Rocks Inlier (AB) rocks using un-normalized concentrations. Data for Above Rocks from Hastie (2007). Note that WMS 16 is a notable outlier from other pottery samples.

Table 5
Comparison of pottery groups to potential clay sources (100 x pottery group/clay source).[a.]

Elements	Th	Ta	La	Ce	Nd	Sm	Hf	Zr	Eu	Ti	Tb	Dy	Yb
Pottery 1/Low Nd clays	73.2	81.8	59.0	58.8	60.1	62.2	94.4	92.7	71.1	78.0	52.3	65.6	68.2
Pottery 2/High Nd clays	89.6	100.2	64.3	62.9	53.8	59.8	122.1	107.1	61.6	81.4	58.7	57.3	63.0
Temper	+	++	−	−	−	−	++ / +++	++	+ / −	+	−	−	−
Elements	**Na**	**K**	**Rb**	**Cs**	**Ca**	**Sr**	**Ba**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Zn**
Pottery 1/Low Nd clays	108.3	153.9	115.1	58.7	93.6	105.2	130.0	69.0	65.2	78.4	67.2	56.3	61.2
Pottery 2/High Nd clays	101.9	155.9	122.1	61.4	69.6	115.8	152.6	71.3	76.9	48.5	73.2	57.0	58.3
Temper	++	++++	+++	−	+ / −	+++	++++	+	− / +	+ / −	−	−	−
Elements	**Si**	**Al**	**U**	**As**	**Sb**	**Sc**							
Pottery 1/Low Nd clays	113.7	82.2	49.6	72.4	64.1	58.1							
Pottery 2/High Nd clays	125.3	86.5	51.7	71.7	69.4	62.8							
Temper	++++	+	−	+	−	−							

[a] Relative amounts of temper:
− lacking in temper.
+ present but less than in clays.
++ similar to clays.
+++ enriched.
++++ strongly enriched.

major groups (PG1, PG2), an outlier (WMS 16), and two specimens assigned to PG3. PG1 and PG2 share similar multielement patterns with the alluvial clays found in the Rio Cobre. The alluvial clays show identical multielement plots to the igneous rocks found in the Above Rocks Inlier. The two alluvial clay types are found in different locations along the Rio Cobre and may represent variable aged deposits, different climatic and weathering conditions, or differing residence times on the alluvial terraces of the river. The pottery samples and their source clays are characterized by high concentrations of K, Rb, and Ba, distinguishing them from non-White Marl pottery analyzed by James-Williamson et al. (2022). The outlier potsherd (WMS 16) also shows similar values for K, Rb, and Ba as PG1 and PG2, but differs in the very low La/Ce ratio. The high K, Rb, and Ba concentrations and its multielement plot suggest that WMS 16 was also sourced from the Rio Cobre (draining the Above Rocks Inlier), but the low La/Ce ratio points to a clay source that has yet to be sampled.

We have no basis at this time to estimate how much pottery was exported from White Marl and to what locations. The source-to-sink study of 75 pottery and 22 sediment samples demonstrates that the White Marl settlement was a major pottery production center using locally available clays. Based on two geochemical outliers, some vessels may have been imported to the village (Hypothesis 1), which we believe may relate to the social and political networks of one or more chiefly polities on the island. This hypothesis can only be tested with additional research. If JNHT's (2020) assertion is correct that White Marl was the seat of a paramount chiefdom then we should expect considerable amounts of materials, not only pottery, flowing to and from the village (de Montmollin, 1989; Johnson, 1977; Johnson and Earle, 1987; Renfrew, 1973).

A follow-up project to the White Marl pilot study is currently underway. Sixteen sites approximately contemporaneous with White Marl were carefully selected across Jamaica. Pottery has been selected from each of the sites and sediment samples collected from the environs of most of them. When the petrographic and geochemical data are available from these sites and the associated drainage basins we should have the basis to build a realistic and accurate geographic model for the social and political networks that we believe must have existed in Jamaica during the last centuries prior to the intrusion of Europeans in the Caribbean. We suggest too that systematically applying the source-to-sink concept to late prehistoric pottery assemblages in the other islands of the Greater Antilles, the Bahamas, and the northern Lesser Antilles will enable us to build robust evidence-based models for the interregional dynamics of complex chiefly polities that were extinguished with the arrival of Europeans.

CRediT authorship contribution statement

Peter E. Siegel: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Simon F. Mitchell:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Jeffrey R. Ferguson:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Vanessa Glaser:** Investigation, Formal analysis. **Alan R. Hastie:** Writing – review & editing, Validation, Investigation, Formal analysis. **Ulrich Schwarz Schampera:** Resources, Project administration. **Zachary J.M. Beier:** Supervision, Resources, Investigation, Conceptualization. **Simon Goldmann:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Formal analysis. **Stephan Kaufhold:** Writing – review & editing, Validation, Resources, Investigation, Formal analysis. **Dennis Kraemer:** Writing – review & editing, Validation, Resources, Investigation, Formal analysis. **Selvenious A. Walters:** Supervision, Resources. **Ann-Marie T.S. Howard-Brown:** Supervision, Resources. **Matthew L. Gorring:** Supervision, Resources. **Sherene A. James-Williamson:** Supervision, Resources. **Gregory A. Pope:** Supervision, Resources. **Kristian Ufer:** Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104899.

Data availability

All data used in this study are included in tables, figures, and supplementary materials with the paper.

References

Ahlman, T.M., Schroedl, G.F., McKeown, A.H., Speakman, R.J., Glascock, M.D., 2008. Ceramic production and exchange among enslaved Africans on St. Kitts, West Indies. J. Carib. Arch. Spec. Publ. 2, 109–122.

Allsworth-Jones, P., 2008. Pre-Columbian Jamaica. University of Alabama Press, Tuscaloosa.

Araújo, J.H., da Silva, N.F., Acchar, W., Gomes, U.U., 2004. Thermal decomposition of illite. Materials Res. 7, 359–361. https://doi.org/10.1590/S1516-14392004000200024.

Arnold, D.E., 1980. Localized exchange: an ethnoarchaeological perspective. In: Fry, R.E. (Ed.), Models and Methods in Regional Exchange. SAA Papers 1. Society for American Archaeology, Washington, DC, pp. 147–150.

Arnold, D.E., 1985. Ceramic Theory and Cultural Process. Cambridge University Press, Cambridge.

Baker, C.M., 1978. The size effect: an explanation of variability in surface artifact assemblage content. Am. Antiq. 43, 288–293.

Bérard, B., Biar, A., 2021. Indigenous navigation in the Caribbean Basin: A historical, ethnoarchaeological and experimental approach to the Caribbean-Guyanese Kanawa. Archaeonautica hal-03344356.

Bérard, B., Billard, J.-Y., L'Etang, T., Lallubie, G., Nicolizas, N., Ramstein, B., Slayton, E., 2016a. Technologie du fait maritime chez les Kalinago des Petites Antilles aux XVIe et XVIIe siècles. J. Société Américanistes 102–1, 129–160.

Bérard, B., Billard, J.-Y., L'Etang, T., Lallubie, G., Nicolizas, N., Ramstein, B., Slayton, E., 2016b. Approche expérimentale de la navigation précolombienne dans les Antilles. J. Société Américanistes 102–2, 171–204.

Billard, J.-Y., Bérard, B., Ramstein, B., 2009. Apport de l'hydrostatique à l'archéologie expérimentale: Etude d'une pirogue de haute mer (Kanawa). 19th Congrès Français de Mécanique, Marseille.

Boomert, A., 1987. Gifts of the Amazon: "green stone" pendants and beads as items of ceremonial exchange in Amazonia and the Caribbean. Antropológica 67, 33–54.

Boothe, T.J., Mitchell, S.F., Lentz, D.R., 2022. Mineralogy and geochemistry of Eocene plutons associated with iron skarn mineralization in the Wag Water Belt. Available online: 9 May 2022 Jamaica. Carib. J. Earth Sci. 54, 11–28. http://caribjes.com/CJESpdf/CJES54-2-Skarn-adakites.pdf.

Brose, D.S., 1970. The Summer Island Site: A Study of Prehistoric Cultural Ecology and Social Organization in the Northern Lake Michigan Area. Studies in Anthropology 1. Case Western Reserve University Press, Cleveland.

Browman, D.L., 1976. Demographic correlations of the Wari conquest of Junin. Am. Antiq. 41, 465–477.

Carini, S.P., 1991. Compositional Analysis of West Indian Saladoid Ceramics and Their Relevance to Puerto Rican Prehistory. University of Connecticut, Storrs. PhD dissertation.

Casale, S., van Dessel, K., Hoogland, M.L.P., Degryse, P., Hofman, C.L., 2022. Technological persistence in ceramic production in the southeastern Hispaniola. The case study of El Cabo (600–1502 CE). J. Anth. Arch. 65. https://doi.org/10.1016/j.jaa.2021.101387.

Casale, S., López Belando, A., Shelley, D., Narganes, Y., Hernández, I., Degryse, P., 2023. Sharing ceramic manufacturing processes: a technological and petrographic study on ceramic production and exchange between Hispaniola and Puerto Rico (350–1200 CE). J. Island Coastal Arch. https://doi.org/10.1080/15564894.2023.2220284.

Cau Ontiveros, M.Á., Tsantini, E., Fantuzzi, L., Ramon, J., 2019. Archaeometric characterization of Late Antique pottery from the rural site of Ses Païsses de Cala d'Hort (Eivissa, Balearic Islands, Spain). Arch. Anthropol. Sci. 11, 627–649.

Chase, P.G., 1985. Whole vessels and sherds: an experimental investigation of their quantitative relationship. J. Field Arch. 12, 213–218.

Colón, F., 1959. The Life of the Admiral Christopher Columbus by his Son. Keen, B., transl. Rutgers University Press, New Brunswick, Ferdinand.

Columbus, C. 1989. The *Diario* of Christopher Columbus's First Voyage to America, 1492–1493. Dunn, O., Kelley, Jr., J.E., transl. University of Oklahoma Press, Norman.

Conolley, I.C., 2022. Definition of Montego Bay style pottery and its implications for Jamaican Meillacan Ostionoids. J. Carib. Arch. 22, 1–15.

Conrad, G.W., Beeker, C.D., Foster, J.W., Descantes, C., Glascock, M.D., 2008. Compositional analysis of ceramics from La Aleta, Dominican Republic: implications for site function and organization. J. Carib. Arch. Spec. Publ. 2, 57–68.

Crock, J.G., Petersen, J.B., 2004. Inter-island exchange, settlement hierarchy, and a Taíno-related chiefdom on the Anguilla Bank, northern Lesser Antilles. In: Delpuech, A., Hofman, C.L. (Eds.), Late Ceramic Age Societies in the Eastern Caribbean. Archaeopress, Oxford, pp. 139–158.

Crock, J.G., Morse, B.F., Petersen, J.B., Descantes, C., Glascock, M.D., 2008. Preliminary interpretations of ceramic compositional analysis from Late Ceramic Age sites in Anguilla and the Salt River site in St. Croix. J. Carib. Arch. Spec. Publ. 2, 45–55.

Cuomo di Caprio, N., Vaughan, S., 1993. An experimental study in distinguishing grog (Chamotte) from argillaceous inclusions in ceramic thin sections. Archaeomaterials 7, 21–40.

Curet, L.A., Hauser, M.W. (Eds.), 2011. Islands at the Crossroads: Migration, Seafaring, and Interaction in the Caribbean. University of Alabama Press, Tuscaloosa.

Curet, L.A., Stringer, L.M. (Eds.), 2010. Tibes: People, Power, and Ritual at the Center of the Cosmos. University of Alabama Press, Tuscaloosa.

DeBoer, W.R., Lathrap, D.W., 1979. The making and breaking of Shipibo-Conibo ceramics. In: Kramer, C. (Ed.), Ethnoarchaeolooy: Implications of Ethnography for Archaeology. Columbia University Press, New York, pp. 102–138.

Deer, W.A., Howie, R.A., Zussman, J., 1992. An Introduction to the Rock Forming Minerals, 2nd ed. Longman Scientific & Technical, London.

Degryse, P., Braekmans, D., 2014. Elemental and isotopic analysis of ancient ceramics and glass. Ref. Mod. Earth Sys. Envir. Sci. 14, 191–207.

de Montmollin, O., 1989. The Archaeology of Political Structure: Settlement Analysis in a Classic Maya Polity. Cambridge University Press, Cambridge.

Dott, R.H., 1964. Wacke, greywacke and matrix—what approach to immature sandstone classification? J. Sed. Petrol. 34, 625–632.

Earle, T., 1997. How Chiefs Come to Power: The Political Economy in Prehistory. Stanford University Press, Stanford.

Elliott, S., Maezumi, S.Y., Robinson, M., Burn, M., Gosling, W.D., Mickleburgh, H.L., Walters, S., Beier, Z.J.M., 2022. The legacy of 1300 years of land use in Jamaica. J. Island Coastal Arch. https://doi.org/10.1080/15564894.2022.2078448.

Fitzpatrick, S.M., Carstensen, J.A., Marsaglia, K.M., Descantes, C., Glascock, M.D., Kappers, M., 2008. Preliminary petrographic and chemical analyses of prehistoric ceramics from Carriacou, West Indies. J. Carib. Arch. Spec. Publ. 2, 59–82.

Fowler, K.D., Middleton, E., Fayek, M., 2019. The human element: discerning the effects of potter's behavior on the chemical composition of ceramics. Arch. Anthropol. Sci. 11, 171–198.

Glascock, M.D., 1992. Characterization of archaeological ceramics at MURR by neutron activation analysis and multivariate statistics. In: Neff, H. (Ed.), Chemical Characterization of Ceramic Pastes in Archaeology. Prehistory Press, Madison, Wisconsin, pp. 11–26.

Glascock, M.D., Neff, H., 2003. Neutron activation analysis and provenance research in archaeology. Measure. Sci. Tech. 14, 1516–1526.

Glascock, M.D., Braswell, G.E., Cobean, R.H., 1998. A systematic approach to obsidian source characterization. In: Shackley, M.S. (Ed.), Archaeological Obsidian Studies: Method and Theory. Plenum, New York, pp. 15–66.

Gomes, D.M.C., Costa, A.F., Munita, C.S., da Cunha, J.P.L. 2023. Archaeological evidence of the development of a regional society in Santarém (AD 1000–1600), Lower Amazon: a path to understanding social complexity. J. World Prehis. doi.org/10.1007/s10963-023-09177-3.

Hastie, A.R., 2007. The Tectonomagmatic Evolution of the Caribbean Plate: Insights from Igneous Rocks on Jamaica. Cardiff University, Cardiff, UK. PhD dissertation.

Hastie, A.R., Kerr, A.C., Mitchell, S.F., Millar, I.L. 2009. Geochemistry and tectonomagmatic significance of Lower Cretaceous island arc lavas from the Devil's Racecourse Formation, eastern Jamaica. In: James, K.H., Lorente, M.A., Pindell, J.L. (eds.), The Origin and Evolution of the Caribbean Plate. Geol. Soc. London Spec. Publ. SP328, 339–410.

Hastie, A.R., Kerr, A.C., Mitchell, S.F., Millar, I., 2008. The geochemistry of Cretaceous oceanic plateau lavas in eastern Jamaica: implications for the evolution of the Caribbean plate. Lithos 101, 323–343.

Hastie, A.R., Ramsook, R., Mitchell, S.F., Kerr, A.C., Millar, I., Mark, D.F., 2010a. Geochemistry of compositionally-distinct Late Cretaceous back-arc basin lavas from Jamaica: implications for the tectonomagmatic evolution of the Caribbean plate. J. Geol. 118, 655–676.

Hastie, A.R., Kerr, A.C., McDonald, I., Mitchell, S.F., Pearce, J.A., Wolstencroft, M., Millar, I.L., 2010b. Do Cenozoic analogues support a plate tectonic origin for Earth's earliest continental crust? Geol. 38, 495–498.

Hastie, A.R., Kerr, A.C., Mitchell, S.F., Pearce, J.A., McDonald, I., Millar, I., Barfod, D., Mark, D.F., 2010c. Geochemistry and petrogenesis of rhyodacite lavas in eastern Jamaica: a new adakite subgroup analogous to early Archaean continental crust? Chem. Geol. 276, 344–359.

Hastie, A.R., Mitchell, S.F., Kerr, A.C., Minifie, M.J., Millar, I.L., 2011. Geochemistry of rare high-Nb basalt lavas: Are they derived from a mantle wedge metasomatised by slab melts? Geochim. Cosmochim. Acta 75, 5049–5072. https://doi.org/10.1016/j.gca.2011.06.018.

Hastie, A.R., Mitchell, S.F., Treloara, P., Kerr, A.C., Neill, I., Barfod, D.N., 2012. Geochemical components in a Cretaceous island arc: The Th/La-(Ce/Ce*) Nd diagram and implications for subduction initiation in the inter-American region. Lithos 162–163, 57–69. https://doi.org/10.1016/j.lithos.2012.12.001.

Hastie, A.R., Fitton, J.G., Mitchell, S.F., Neill, I., Nowell, G.M., Millar, I.L., 2015. Can fractional crystallization, mixing and assimilation processes be responsible for Jamaican-type adakites? Implications for generating Eoarchaean continental crust. J. Petrol. 56, 1251–1284.

Hauser, M.W., Descantes, C., Glascock, M.D., 2008. Locating enslaved craft production: chemical analysis of eighteenth century Jamaican pottery. J. Carib. Arch. Spec. Publ. 2, 123–148.

Helms, M.W., 1988. Ulysses' Sail: An Ethnographic Odyssey of Power, Knowledge, and Geographical Distance. Princeton University Press, Princeton.

Herbert, J.M., Smith, M.S., 2010. Identifying Grog in Archaeological Pottery. Reconstructive/Experimental Archaeology, Gastonia, North Carolina.

Hermann, A., Molle, G., Maury, R., Liorzou, C., McAlister, A., 2019. Geochemical sourcing of volcanic materials imported into Teti'aroa Atoll shows multiple long-distance interactions in the Windward Society Islands. French Polynesia. Arch. Oceania 54, 184–199.

Hirth, K.G., 1996. Political economy and archaeology: perspectives on exchange and production. J. Arch. Res. 4, 203–239.

Hofman, C.L., Hoogland, M.L.P., van Gijn, A.L. (Eds.), 2008. Crossing the Borders: New Methods and Techniques in the Study of Archaeological Materials from the Caribbean. University of Alabama Press, Tuscaloosa.

Hofman, C.L., van Duijvenbode, A. (Eds.), 2011. Communities in Contact: Essays in Archaeology, Ethnohistory and Ethnography of the Amerindian Circum-Caribbean. Sidestone Press, Leiden.

Hofman, C.L., Bright, A.J., Boomert, A., Knippenberg, S., 2007. Islands rhythms: the web of social relationships and interaction networks in the Lesser Antillean archipelago between 400 B.C. and A.D. 1492. Lat. Am. Antiq. 18, 243–268.

Hogbin, H.I., 1951. Transformation Scene: The Changing Culture of a New Guinea Village. Routledge & Kegan Paul, London.

Howard, R.R., 1950. The Archaeology of Jamaica and its Position in Relation to Circum-Caribbean Culture. Yale University, New Haven. PhD dissertation.

Howard, R.R., 1956. The archaeology of Jamaica: a preliminary survey. Am. Antiq. 22, 45–59.

Howard, R.R., 1965. New perspectives on Jamaican archaeology. Am. Antiq. 31, 250–255.

Isendoorn, A.J.D., Hofman, C.L., Booden, M., 2008. Back to the source: provenance of clays and temper materials of pre-Columbian Caribbean ceramics. J. Carib. Arch. Spec. Publ. 2, 15–23.

Jackson, T.A., Smith, T.E. 1978. Metasomatism in the Tertiary volcanics of the Wagwater Belt, Jamaica, W.I. In: Mac Gillavry, H.J., Beets, D.J. (eds.), Geologie en Mijnbouw. Spec. Issue 8th Carib. Geol. Conf., Willemstad 57, 213–220.

Jackson, T.A., Smith, T.E., 1979. The petrochemistry of some mafic volcanics, Jamaica, West Indies. Trans. Lat. Am. Geol. Conf. 4, 387–396.

Jackson, T.A., Rodrigues, K., Smith, T.E., 1980. The composition and tectonic importance of Cretaceous pillow lavas near Whitehall. St. Thomas. J. Geol. Soc. Jamaica 19, 40–45.

Jackson, T.A. 1987. The petrology of Jamaican Cretaceous and Tertiary volcanic rocks and their tectonic significance. In: Ahmad, R. (ed.), Proceedings of a Workshop on the Status of Jamaican Geology, 1987, Geological Society of Jamaica, Kingston, pp. 107–119.

Jackson, T.A., Smith, T.E., Isaacs, M.C., 1989. The significance of geochemical variations in Cretaceous volcanic and plutonic rocks of intermediate and felsic composition from Jamaica. J. Geol. Soc. Jamaica 26, 33–42.

Jackson, T.A., Scott, P.W., 1997. A welded tuff boulder from within the Wagwater Belt. Jamaica. J. Geol. Soc. Jamaica. 32, 25–28.

Jackson, T.A., Draper, G., Robinson, E., Fleugeman, R.H., 1998. Field guide to the geology of eastern Jamaica. In: Donovan, S.K. (Ed.), Fifteenth Caribbean Geological Conference Articles Field Guides & Abstracts. Contributions to Geology UWI Mona 3, pp. 10–21.

Jamaica National Heritage Trust, 2016. Preliminary Archaeology Evaluation Report, White Marl. St. Catherine, Jamaica National Heritage Trust, Kingston.

Jamaica National Heritage Trust, 2018a. Brief and Specification Archaeological Evaluation Project (Phase 2), White Marl Mandela Highway Development. St. Catherine, Jamaica National Heritage Trust, Kingston.

Jamaica National Heritage Trust, 2018b. Archaeological Evaluation, White Marl. St. Catherine, Jamaica National Heritage Trust, Kingston.

Jamaica National Heritage Trust, 2020. Brief and Specification Archaeological Evaluation Project Phase 3, White Marl Mandela Highway Development. St. Catherine, Jamaica National Heritage Trust, Kingston.

James-Williamson, S.A., Mitchell, S.F., 2012. Revised lithostratigraphy of the Coastal Group of south-eastern St. Thomas. Jamaica. Carib. J. Earth Sci. 44, 9–17.

James-Williamson, S.A., Mitchell, S.F., Allsworth-Jones, P., Dolphy, J.E., Voutchkov, M., Lalor, G.C., 2022. Provenance of clays in pre-Columbian ceramics in Jamaica: a preliminary assessment. J. Carib. Arch. 22, 1–22.

Johnson, G.A., 1977. Aspects of regional analysis in archaeology. Ann. Rev. Anth. 6, 479–508.

Johnson, A.W., Earle, T., 1987. The Evolution of Human Societies: From Foraging Group to Agrarian State. Stanford University Press, Stanford.

Keegan, W.F., Hofman, C.L., Rodríguez Ramos, R. (Eds.), 2013. The Oxford Handbook of Caribbean Archaeology. Oxford University Press, New York.

Keegan, W.F., Bloch, L.C., Kracht, E.C., Pateman, M.P., 2022. The distribution of nonlocal pottery in Lucayan archaeological sites, Bahama Archipelago. J. Carib. Arch. 22, 1–16.

Kelly, K.G., Hauser, M.W., Descantes, C., Glascock, M.D., 2008. Compositional analysis of French colonial ceramics: implications for understanding trade and exchange. J. Carib. Arch. Spec. Publ. 2, 85–107.

King, R.H., 1987. Provenance of clay material used in the manufacture of archaeological pottery from Cyprus. Applied Clay Sci. 2, 199–213.

Kirch, P.V., 1984. The Evolution of the Polynesian Chiefdoms. Cambridge University Press, Cambridge.

Kracht, E.C., Bloch, L.C., Keegan, W.F., 2022. Production of Greater Antillean pottery and its exchange to the Lucayan Islands: a compositional study. J. Arch. Sci. Rep. 43. https://doi.org/10.1016/j.jasrep.2022.103469.

Lauer, P.K., 1970. Sailing with the Amphlett Islanders. J. Polynesian Soc. 79 (4), 381–398.

Lauer, P.K., 1971. Changing patterns of pottery trade to the Trobriand Islands. World Arch. 3 (2), 197–209.

Lauer, P.K., 1973. The technology of pottery manufacture on Goodenough Island and in the Amphlett Group, S. E. Papua. Anthropology Museum University of Queensland Occasional Papers 2, 25–60.

Lewis, J.F., Draper, G., 1990. Geological and tectonic evolution of the northern Caribbean Margin. In: Dengo, G., Case, J.E. (Eds.), The Caribbean Region. Geological Society of America, Boulder, The Geology and North America, pp. 77–140.

Lozada-Mendieta, N., Villagran, X.S., 2024. Ceramic archaeometric studies in the Amazon and Caribbean regions: a review. Archaeometry 1–17. https://doi.org/10.1111/arcm.13003.

Malinowski, B., 1961 [1922]. Argonauts of the Western Pacific. E.P. Dutton, New York.

Mann, P., Burke, K., 1990. Transverse intra-arc rifting: Palaeogene Wagwater Belt. Jamaica. Marine and Petroleum Geol. 7, 410–427.

Martinsen, O.J., Sømme, T.O., Thurmond, J.B., Helland-Hansen, W., Lunt, I. 2010. Source-to-sink systems on passive margins: theory and practice with an example from the Norwegian continental margin. In: Vining, B.A., Pickering, S.C. (eds.), Petroleum Geology: From Mature Basins to New Frontiers – Proceedings of the 7th Petroleum Geology Conference. Geological Society, London, pp. 913–920.

McPherron, A., 1967. The Juntunen Site and the Late Woodland Prehistory of the Upper Great Lakes Area. Anthropological Papers 30. Museum of Anthropology. University of Michigan, Ann Arbor.

Meade, R.H., 1982. Sources, sinks, and storage of river sediment in the Atlantic Drainage of the United States. J. Geol. 90, 235–252.

Mickleburgh, H.L., Laffoon, J.E., Pagán Jiménez, J.R., Mol, A.A.A., Walters, S., Beier, Z.J. M., Hofman, C.L., 2018. Precolonial/early colonial human burials from the site of White Marl, Jamaica: new findings from recent rescue excavations. Intl. J. Osteoarch. 2018, 1–7. https://doi.org/10.1002/oa.2707.

Mitchell, S.F. 2004. Lithostratigraphy and palaeogeography of the White Limestone Group. In: Donovan, S.K. (ed.), The Mid-Cainozoic White Limestone Group of Jamaica. Cainozoic Res. 3, 5–29.

Mitchell, S.F., 2013a. Stratigraphy of the White Limestone of Jamaica. Bull. Soc. Géol. France 184 (1–2), 111–118.

Mitchell, S.F., 2013b. Lithostratigraphy of the Central Inlier. Jamaica. Carib. J. Earth Sci. 46, 31–42.

Mitchell, S.F., 2015. Geology of the parish of St Catherine (1:50,000 scale). Geological Map. Department of Geography and Geology. The University of the West Indies, Mona, Kingston, Jamaica.

Mitchell, S.F. 2020. Cretaceous geology and tectonic assembly of Jamaica. In Davison, I., Hull, J.N.F., Pindell, J. (eds.), The Basins, Orogens and Evolution of the Southern Gulf of Mexico and Northern Caribbean. Geological Society of London SP504, pp. 507–547. doi: 10.1144/SP504-2019-210).

Mitchell, S.F., Kerr, A.C., Hastie, A.R., 2022. Chronology and geochemistry of the Caribbean Large Igneous Province in Jamaica. Results in Geochem. https://www.sciencedirect.com/sdfe/reader/pii/S2666277922000016/pdf.

Mol, A.A.A., 2014. The Connected Caribbean: A Socio-Material Network Approach to Patterns of Homogeneity and Diversity in the Pre-Colonial Period. Sidestone Press, Leiden.

Neff, H., 2000. Neutron activation analysis for provenance determination in archaeology. In: Ciliberto, E., Spotto, G. (Eds.), Modern Analytical Methods in Art and Archaeology. John Wiley, New York, pp. 81–134.

Neff, H., 2002. Quantitative techniques for analyzing ceramic compositional data. In: Glowacki, D.M., Neff, H. (Eds.), Ceramic Production and Circulation in the Greater Southwest: Source Determination by INAA and Complementary Mineralogical Investigations. Cotsen Institute of Archaeology Monograph 44. University of California, Los Angeles, pp. 15–37.

Neff, H., 2012. Comment: chemical and mineralogical approaches to ceramic provenance determination. Archaeometry 54, 244–249.

Neff, H., Bove, F.J., 1999. Mapping ceramic compositional variation and prehistoric interaction in Pacific Coastal Guatemala. J. Arch. Sci. 26, 1037–1051.

Neff, H., Cogswell, J.W., Ross Jr., L.M., 2003. Supplementing bulk chemistry in archaeological ceramic provenance investigations. In: van Zelst, L. (Ed.), Patterns and Process: A Festschrift in Honor of Dr. Edward V, Sayre, Smithsonian Center for Materials Research and Education, Suitland, Maryland, pp. 201–224.

Neff, H., Blomster, J., Glascock, M.D., Bishop, R.L., Blackman, M.J., Coe, M.D., Cowgill, G.L., Diehl, R.A., Houston, S., Joyce, A.A., Lipo, C.P., Stark, B.L., Winter, M., 2006. Methodological issues in the provenance investigation of Early Formative Mesoamerican Ceramics. Lat. Am. Antiq. 17, 54–76.

Oliver, J.R., 1998. El centro ceremonial de Caguana, Puerto Rico: simbolismo iconográfico, cosmovisión y el poderío caciquil Taíno de Boriquén. BAR Intl Ser. 727. British Archaeological Reports, Oxford.

Oliver, J.R., 2005. The proto-Taíno monumental cemís of Caguana: a political-religious 'manifesto. In: Siegel, P.E. (Ed.), Ancient Borinquen: Archaeology and Ethnohistory of Native Puerto Rico. University of Alabama Press, Tuscaloosa, pp. 230–284.

Oliver, J.R., 2009. Caciques and Cemí Idols: The Web Spun by Taíno Rulers between Hispaniola and Puerto Rico. University of Alabama Press, Tuscaloosa.

Ostapkowicz, J., 2015. The sculptural legacy of the Jamaican Taíno, part 1: the Carpenter's Mountain carvings. Jamaica J. 35 (3), 52–59.

Ostapkowicz, J., Bronk Ramsey, C., Brock, F., Higham, T., Wiedenhoeft, A.C., Ribechini, E., Lucejko, J.J., Wilson, S., 2012. Chronologies in wood and resin: AMS ^{14}C dating of pre-Hispanic Caribbean wood sculpture. J. Arch. Sci. 39, 2238–2251.

Peres-Neto, P.R., Jackson, D.A., Somers, K.M., 2003. Giving meaningful interpretation to ordination axes: assessing loading significance in principal component analysis. Ecol. 84, 2347–2363.

Petras, E.M., MacDonald, B.L. 2024. Neutron activation analysis reveals Jamaican origin of Afro-Caribbean ware excavated from the Cayman Islands. Intl. J. Historical Arch. doi: 10.1007/s10761-024-00752-8.

Rainey, F.G. 1940. Porto Rican Archaeology. Scientific Survey of Porto Rico and the Virgin Islands. Vol. XVIII, Pt 1. The New York Academy of Sciences, New York.

Ramdial, L., 2017. Major Infrastructure Development Programme (MIDP). Mandela Highway Improvement Project. Report on file, National Works Agency, Kingston, Jamaica https://www.nwa.gov.jm/major-projects.

Redmount, C.A., Morgenstein, M.E., 1996. Major and trace element analysis of modern Egyptian pottery. J. Arch. Sci. 23, 741–762.

Reina, R.E., Hill II., R.M., 1978. The Traditional Pottery of Guatemala. University of Texas Press, Austin.

Renfrew, C., 1973. Monuments, mobilization and social organization in Neolithic Wessex. In: Renfrew, C. (Ed.), The Explanation of Culture Change; Models in Prehistory. University of Pittsburgh Press, Pittsburgh, pp. 539–558.

Rice, P.M., 2015. Pottery Analysis: A Source Book, 2nd ed. University of Chicago Press, Chicago.

Robinson, E., 1994. Jamaica. In: Donovan, S.K., Jackson, T.A. (Eds.), Caribbean Geology an Introduction. University of the West Indies, Kingston, Jamaica, pp. 111–127.

Robinson, E., Mitchell, S.F. 1999. Upper Cretaceous to Oligocene stratigraphy in Jamaica. In: Mitchell, S.F. (ed.), Contributions to Geology, UWI, Mona 4, 1–47.

Roosevelt, A.C., 1999. The development of prehistoric complex societies: Amazonia, a tropical forest. In: Bacus, E.A., Lucero, L.J. (eds.), Complex Polities in the Ancient World. Arch. Papers Am. Anth. Assoc. 9, 13–33.

Rouse, I., 1992. The Tainos: Rise and Decline of the People Who Greeted Columbus. Yale University Press, New Haven.

Schiffer, M.B., 1978. Methodological issues in ethnoarchaeology. In: Gould, R.A. (Ed.), Explorations in Ethnoarchaeology. University of New Mexico Press, Albuquerque, pp. 229–247.

Shev, G., Thomas, R., Beier, Z., 2022. Zooarchaeological and isotopic findings from White Marl, Jamaica: insights on Indigenous human-animal interactions and evidence for the management of Jamaican hutias. J. Carib. Arch. 22, 1–30.

Siegel, P.E., 1991. Political evolution in the Caribbean. Proc. Intl. Congr. Carib. Arch. 13 (1), 232–250.

Siegel, P.E., 1999. Contested places and places of contest: the evolution of social power and ceremonial space in prehistoric Puerto Rico. Lat. Am. Antiq. 10, 209–238.

Siegel, P.E., 2004. What happened after AD 600 on Puerto Rico? Corporate groups, population restructuring, and post-Saladoid social changes. In: Delpuech, A., Hofman, C.L. (Eds.), Late Ceramic Age Societies in the Eastern Caribbean. Archaeopress, Oxford, pp. 87–100.

Siegel, P.E., 2010a. Continuity and change in the evolution of religion and political organization on pre-Columbian Puerto Rico. J. Anth. Arch. 29, 302–326.

Siegel, P.E., 2010b. Crossing the Caribbean Sea and tracking intellectual history: a discussion. J. Carib. Arch. Spec. Publ. 3, 156–170.

Siegel, P.E., 2011. Competitive polities and territorial expansion in the Caribbean. In: Curet, L.A., Hauser, M.W. (Eds.), Islands at the Crossroads: Migration, Seafaring, and Interaction in the Caribbean. University of Alabama Press, Tuscaloosa, pp. 193–218.

Siegel, P.E., Roe, P.G., 1986. Shipibo archaeo-ethnography: site formation processes and archaeological interpretation. World Arch. 18, 96–115.

Siegel, P.E., Descantes, C., Ferguson, J.R., Glascock, M.D., 2008. Pre-Columbian pottery in the West Indies: compositional change in context. J. Carib. Arch. Spec. Publ. 2, 25–44.

Siegel, P.E., Beier, Z.J.M., Nibonrix Kaiman, K., 2023. Archaeological history, memory, and heritage at the White Marl site, Central Village, St Catherine Parish. Jamaica. Public Arch. 22, 1–31. https://doi.org/10.1080/14655187.2023.2279414.

Silverberg, J., Vanderwal, R.L., Wing, E.S., 1972. The White Marl Site in Jamaica: Report of the 1964 Robert R. Howard Excavation, Environmental Archaeology Library, Florida Museum of Natural History, Gainesville.

Skagit Climate Science Consortium. n.d. The flow of sediment. www.skagitclimatescience.org/skagit-impacts/sediment/.

Smith, D.B., Solano, F., Woodruff, L.G., Cannon, W.F., Ellefsen, K.J. 2019. Geochemical and mineralogical maps, with interpretation, for soils of the conterminous United States. U.S.G.S. Sci. Investig. Rep. 2017-5118. doi: 10.3133/sir20175118.

Stahl, P.W., Zeidler, J.A., 1990. Differential bone-refuse accumulation in food-preparation and traffic areas on an early Ecuadorian house floor. Lat. Am. Antiq. 1, 150–169.

Stoltman, J.B., 2015. Ceramic Petrography and Hopewell Interaction. University of Alabama Press, Tuscaloosa.

Stoltman, J.B., Marcus, J., Flannery, K.V., Burton, J.H., Moyle, R.G., 2005. Petrographic evidence shows that pottery exchange between the Olmec and their neighbors was two-way. Proc. Natl. Acad. Sci. 102, 11213–11218.

Tschegg, C., Ntaflos, T., Hein, I., 2009. Integrated geological, petrologic and geochemical approach to establish source material and technology of Late Cypriot Bronze Age Plain White ware ceramics. J. Arch. Sci. 36, 1103–1114.

Wallis, N.J., Pluckhahn, T.J., Glascock, M.D. 2016. Sourcing interaction networks of the American Southwest: neutron activation analysis of Swift Creek Complicated Stamped pottery. Am. Antiq. 81, 717–736.

Walters, S., Topping, M., Senior, S., Howard-Brown, A.-H., Dobson-Wolfe, D. 2018. Archaeological Evaluation White Marl Zone B. Phase 1, St. Catherine. Jamaica National Heritage Trust, Kingston.

Walters, S., Topping, M., Senior, S., Howard-Brown, A.-H., Dobson-Wolfe, D. 2019a. Intrusive Archaeological Evaluation White Marl Zone B. Phase 2, St. Catherine. Jamaica National Heritage Trust, Kingston.

Walters, S., Topping, M., Senior, S., Dobson-Wolfe, D. 2019b. Intrusive Archaeological Evaluation White Marl Zone B. Phase 2, St. Catherine. Jamaica National Heritage Trust, Kingston.

Warne, R.T., 2021. Statistics for the Social Sciences: A General Linear Model Approach, 2nd ed. Cambridge University Press, New York.

Weigand, P.C., Harbottle, G., Sayre, E.V., 1977. Turquoise sources and source analysis: Mesoamerica and the southwestern U.S.A. In: Earle, T.K., Ericson, J.E. (Eds.), Exchange Systems in Prehistory. Academic Press, New York, pp. 15–34.

West Jr., D.P., Abbott Jr., R.N., Bandy, B.R., Kunk, M.J., 2014. Protolith provenance and thermotectonic history of metamorphic rocks in eastern Jamaica: Evolution of a transform plate boundary. Geol. Soc. Am. Bull. 126, 600–614.

Wilson, S.M., 1990. Hispaniola: Caribbean Chiefdoms in the Age of Columbus. University of Alabama Press, Tuscaloosa.

Wu, X., Ji, F., Zhang, X., Wang, F., Feng, F., Lu, Q., Zhao, S., Zhang, Y., Wang, C., Huang, F., Zhang, X., 2022. Geochemical evidence reveals a long-distance trade of white pottery in Neolithic China 5,000 years ago. J. Arch. Sci. Rep. 44 (103533), 1–10.