Received: 19 October 2023 | Accepted: 23 May 2024

DOI: 10.1111/arcm.13003

ORIGINAL ARTICLE

Ceramic archaeometric studies in the Amazon and Caribbean regions: A review

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Abstract

Archaeometry had a slow start in the study of Amazonian and Caribbean ceramics, practiced almost exclusively by professionals outside of the archaeology discipline, primarily geologists, physicists and chemists, but is now slowly gaining track among archaeologists. In this paper, we summarize the archaeometric research done in the last thirty years in ceramics from the Amazon and Caribbean regions, emphasizing its main questions, aims and future developments for archaeometry in Latin America. Archaeometric studies are a growing field of research and improve understanding of past networks, technological knowledge and cultural traditions.

KEYWORDS

Amazonia, archaeometry, Caribbean, Guianas, INAA, petrography, TL, XRF

INTRODUCTION

Archaeometric studies in archaeological ceramic materials apply techniques from physical, chemical, biological and Earth sciences, and engineering (Wells, 2014) to solve questions on how past communities produced, used and exchanged these items. Although this approach has been active since the 1950s in Europe and North America, it was only in the late 1980s and, more actively since the 2000s, that archaeometric studies have been conducted in the Amazon and Caribbean regions, becoming a rapidly growing field of research commonly used by current archaeologists working in the area. Archaeological ceramics from Amazonia and the Caribbean display common technological and stylistic traits. Large ceramic and cultural complexes have been ascribed to the movement of peoples speaking the main linguistic stocks that nowadays exist in the region, such as Arawak, Tupi and Karib (Brochado, 1984; Lathrap, 1970; Neves, 2011; Neves et al., 2014). Arawak and Karib speakers inhabit both the Caribbean and the Amazon rainforest, with Tupi speakers exclusively living in South America (also outside of Amazonia). Despite the relevance of this area and its ceramic materials in understanding major

migration and interaction processes, little interest has been given to archaeometric approaches and their contribution to the archaeological discipline. This paper intends to fill that void by reviewing the history of ceramic archaeometric studies in the area. First, it addresses the development of archaeometric research, explaining how it went from complementary analyses conducted by specialists from other fields that confirm or contested ceramic typologies to exciting current research performed by archaeologists themselves. The second part of the paper will present the main topics and research questions in the field, divided by thematic groups that highlight the leading lines of inquiry in current ceramic archaeometric studies. Finally, we will suggest further developments in the study area, emphasizing new research avenues that have recently been explored and the subjects that need some attention in the future.

The bibliographic revision of archaeometric studies on Amazonian or Caribbean ceramics here presented only considers published articles and/or book chapters in English, Portuguese, French or Spanish. Master's thesis and PhD dissertations, conference presentations, posters and gray literature have not been included, given their restricted access and distribution. Each reviewed paper and/or chapter was analyzed considering their authors' origins and affiliated institutions, the techniques and methodology applied for ceramic analysis and the laboratories where such analyses were conducted, the number of analyzed samples, as well as the research questions and theoretical framework used for their interpretation. Based on these data, in the following pages we will discuss the birth, development and current relevance of archaeometric research in the study area, which includes the Amazonian regions of Brazil, Bolivia, Colombia, Ecuador, French Guiana, Guiana, Surinam and Venezuela, and the Caribbean islands (Cuba, Dominican Republic, Haiti, Puerto Rico, Jamaica—the Greater Antilles; and the 24 island states of the Lesser Antilles) (Figure 1). We will then consider the main questions addressed in archaeometric studies in this region, subdividing the reviewed literature into thematic groups that consider the provenance, technology, chronology or function of ceramic materials. This division follows the main objectives proposed by the authors of each study, allowing us to compare and discuss the principal research questions in which these types of analyses are used in the region of study. Taking into account the previous sections, finally we will consider future avenues of research for archaeometric ceramic studies in Amazonia and the Caribbean.

DEVELOPMENT OF ARCHAEOMETRIC STUDIES

Archaeometric studies on ceramic materials began in the Amazon and Caribbean about 35 years ago, particularly in Venezuela and the Caribbean islands. This type of research was partly motivated by the early definition of this cultural area as the Circum Caribbean *sensu* Steward (1948, p. 13), as a product of migrations, mainly from northern South America to the Caribbean islands in the formative period (Rodríguez Ramos, 2010, pp. 21–22). This early definition envisioned long-distance contacts and exchange networks that motivated comparative studies, mainly from ceramic materials, to establish population movements. Initial research regarding migrations mostly relied on stylistic patterns, but the emphasis on compositional and physical traits started in the 1980s, deriving in early archaeometric analysis of pottery materials. The switch to including analytical methods in ceramic studies was also made possible by significant investment in laboratory equipment and international interdisciplinary collaborations promoting early archaeometric research in the region. Some of the first examples came from the Venezuelan Institute for Scientific Research (IVIC by its Spanish initials), where an Anthropology Laboratory was funded by J.M. Cruxent and the Sociology and Anthropology Schools of the Central University of Venezuela (Meneses & Gordones, 2009, p. 65). The IVIC team performed some of the early studies on provenance of ceramic materials using thermoluminescence (TL) and radioisotope X-ray fluorescence (XRF) (Labreque et al., 1988, 1990). While XRF analyses have proven accurate in characterizing the chemical composition and probable origin

FIGURE 1 Map showing the study area reviewed for this current paper on archaeometric analysis of ceramics from archaeological contexts.

of certain ceramic materials, TL has remained in use in the region mostly as a dating method. An early interest in paste recipes and technology questions on pottery materials can also be traced back to the 1990s in the Guianas (Rostain, 1990), though consisting only of macroscopic photographs and detailed descriptions of the paste with a magnifying glass. Although macroscopic analyses were the first technique used in this region to characterize tempers and pottery composition, it would take years for the development and publication of more sophisticated and microscopic archaeometric studies.

Despite the early interest in ceramic technology and composition, publications of archaeometric research in the Caribbean during the 1990s were scarce. The field only truly developed right after the turn of the 21st century, with multiple examples of the application of key techniques widely used in archaeometric research today, such as instrumental neutron activation analysis (INAA). In the first decade of the 21st century, most archaeometric research in our study area came from the Caribbean and the Brazilian Amazon, with a single remaining example located in the Colombian Amazon (Costa et al., 2011).

Brazil has concentrated most of the archaeometric studies on Amazonian ceramics, with an exponential growth of published works in the 2000s. However, the field of archaeometry in the country began in the 1990s (Appoloni & Ikeoka, 2023). In 2007, the city of São Paulo hosted the first Latin American Symposium of Physical and Chemical Methods in Archaeology, Art and Conservation (Simpósio Latino-Americano de Métodos Físicos e Químicos em Arqueologia, Arte e Conservação), which today counts eight editions hosted in other Latin

American cities. The Brazilian School of Archaeometry and Sciences Applied to Heritage (Escola Brasileira de Arqueometria e Ciências Aplicadas ao Patrimônio) was founded in 2012 and organizes biannual meetings. Also, since the 2000s, the National Congress of the Society for Brazilian Archaeology (SAB by its initials in Portuguese) has included several symposia dealing with archaeometry and characterization of archaeological materials. A revision article published in 2018 summarizes the research of the Laboratory of Applied Nuclear Physics (Laboratório de Física Nuclear Aplicada from the University of Londrina) using several methods for the characterization of archaeological ceramics, rock art and paintings (Appoloni, 2018). Another revision article was published in 2020, summarizing the work of the Group of Archaeometric Studies of the Institute of Energetic and Nuclear Research (Grupo de Estudos Arqueométricos do Instituto de Pesquisas Energéticas e Nucleares—IPEN) with archaeological ceramics from different regions in Brazil, including Amazonia (Munita et al., 2020). In 2023, a special volume of the scientific journal of SAB was dedicated to archaeometry in Brazil. In this special volume, the editors summarize the current development of the field in the country, highlighting the contributions of archaeometry in the study and preservation of Brazilian cultural heritage (Appoloni & Ikeoka, 2023).

The late development of archaeometric studies in Amazonia, outside of Brazil, can be explained by multiple factors, including limited research due to civil unrest and armed conflict in the region; and the fact that the research communities and facilities in other Amazonian countries, such as Colombia or Peru, are located mainly in the Andean area and not in the Equatorial lowlands. The last decade has witnessed a significant development of archaeometric studies in ceramic materials in the region, with a particular interest in petrography and XRF in pottery from the Guianas, Ecuador, the Peruvian Amazon and the Venezuelan Orinoco. This trend also coincides with the increased visibility of archaeometric analyses in international congresses in the Americas (such as the Society for American Archaeology—SAA), in the Caribbean (The International Association of Caribbean Archaeology—IACA) or the broader Amazon area (Encuentro Internacional de Arqueología Amazónica—EIAA).

The history of archaeometric studies in Caribbean and Amazonian ceramics can therefore be divided into two phases: the first phase, with a slow start in the 1990s, where research mostly focused on paste characterization; and the second phase, in the 2000s, where research questions broadened and analytical methods expanded. Of the 56 reviewed published papers and chapters, almost half (41%) were produced in the Antilles—mostly in Cuba, Dominican Republic, Puerto Rico and Saint Croix—closely followed by Brazil (32%) (Figure 2). Only a tenth of the research studies reviewed were conducted in the Guianas, followed by Venezuela (7%). The other Amazonian countries in our sample, such as Colombia, Ecuador and Peru, are

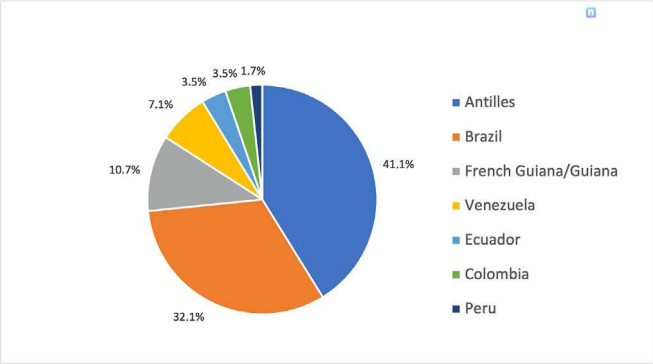

FIGURE 2 Pie chart, with percentage represented by the published research studies reviewed per region/country.

collectively responsible for the remaining 9%. No works were identified from Bolivia, Guiana, or Surinam.

The disparities between countries are associated with the strength of their local research resources, particularly regarding their access to laboratories and equipment, and their scientific trajectory. In this sense, Brazil has the physical capacity to analyze archaeological ceramics locally and produce research in a more accessible and faster manner than the other countries, which, for the better part of their history, have relied on foreign laboratories to perform specialized analysis. This is the case for most of the specialized archaeometric analysis in the Antilles or in French Guiana, which have mostly relied in foreign laboratories in the USA, France and the Netherlands to conduct petrographic analysis, as well as INAA, XRF and TL studies (Table 1). Unlike the former, Colombia, Ecuador, Peru, Venezuela and Cuba have opted for a mixed model, establishing alliances between their local laboratories and foreign scientists in France, Hungary and the UK to apply specialized analytical techniques. Despite this more horizontal approach, the archaeometric research in much of the study region—except for Brazil—is still heavily reliant on US and European nations for access to instrumental analysis and funding. Even though transnational research teams could provide a more sustainable model for archaeometric studies to flourish in the area (Killick, 2015), it would not solve the dependency issue at hand. This inequality is also somehow related to the history of archeological research in Amazonia, with Brazil leading the field since the 1990s (Heckenberger et al., 1998, 1999, 2007, Heckenberger & Neves, 2009; Neves, 2000, 2005, 2008, 2011, Schaan, 2001, 2007), having today museums, universities and archaeology programs located in its Amazonian states.

MAIN TOPICS AND RESEARCH QUESTIONS

Archaeometric studies in ceramics from the Amazon and Caribbean have focused mainly on the characterization of ceramic pastes with two main goals: (1) providing information about ceramic composition technology and the manufacturing process; and (2) the identification of cultural contacts or trade in the past. Archaeometric studies have allowed archaeologists to explore the provenance of clays and tempers, and the techniques and methods followed by ancient potters, to identify cultural interactions (e.g., exchange networks) and/or landscape use. Studies dealing with the use of ceramics, in terms of food consumption or other purposes, as well as studies on the conservation state of certain ceramic materials, are still few. As seen in Figure 3, most of the ceramic archaeometric studies reviewed for this area have focused on technological questions, especially on paste composition and ceramic production. Even though this research is present in almost all countries—except for Venezuela—it is most common in the Antilles and Brazil. On the other hand, provenance studies are noticeably more numerous in Brazil, while studies focused on use, function or conservation of archaeological ceramic materials are rare and only present in the Antilles and the Guianas. In the following sections, we will summarize the works done in Amazonian and Caribbean ceramics according to the main goal of the studies, whether focusing on technology, provenance, or "other" (use/function or conservation).

Technology

Interest in reconstructing the production of ceramic materials has been part of archaeology since its beginnings, focusing on material identification and possible sources when macroscopically describing different fabrics and styles. These early studies relied on the use of the magnifying glass and ethnographic work to document and identify the type of clay, minerals and possible sources used archaeologically in a particular area (Rostain, 1990).

TABLE 1 Archaeometric studies per country discriminated by type of author, analytical technique and location of laboratory facilities.

Ceramic materials provenance	Authors	Analytical technique	Laboratory facilities
Cuba	Local	Petrography	Cuba
		X-ray radiography	France
		SEM-EDS	
		INAA	
		PIXE	
Dominican Republic	Mixed	Petrography	USA
		INAA	Netherlands
Puerto Rico	Local/foreign	INAA	USA
Jamaica	Foreign	Petrography	USA
		INAA	
Grenadines	Foreign	Petrography	USA
		INAA	
Martinique/St Croix	Foreign	Petrography	USA
		XRF	Netherlands
		INAA	
Nevis	Foreign	Petrography	USA
French Guiana/Guiana	Foreign	Macrotrace	Netherlands
		Petrography	France
		TL	
		Starch analysis	
Brazil	Local/foreign	Petrography	Brazil
		TL	Germany
		X-ray radiography	Brazil
		SEM-EDS	Brazil, Germany
		XRF	Brazil
		INAA	Brazil
		PIXE	Brazil
		XRD	Brazil, Germany
		ICP-MS	Brazil
		FTIR	Brazil
		Thermogravimetric analysis	Brazil
		EPR spectroscopy	Brazil
		ED-XRF	Brazil
		Computed radiography	Brazil
		Gamma ray densitometry	Brazil
		Synchrotron micro-XRF	Brazil
		Mössbauer spectroscopy	Brazil
		Synchrotron micro-CT	Germany
Venezuela	Local/mixed	Petrography	Venezuela
		SEM-EDS	Cuba
		XRF	Hungary

TABLE 1 (Continued)

Ceramic materials provenance	Authors	Analytical technique	Laboratory facilities
		TL	UK
		INAA	
Ecuador	Mixed	Petrography	Ecuador
			France
Colombia	Mixed	XRD	Colombia
		Petrography	Brazil
			UK
Peru	Local	SEM	Peru
		XRD	

Abbreviations: SEM-EDS, scanning electron microscopy by energy dispersive X-ray spectroscopy; INAA, instrumental neutron activation analysis; PIXE, particle-induced X-ray emission; XRF, X-ray fluorescence; TL, thermoluminescence; XRD, X-ray diffractometry; ICP-MS, inductively coupled plasma mass spectrometry; FTIR, Fourier transform infrared spectroscopy; EPR, electron paramagnetic resonance; ED-XRF, energy-dispersive XRF.

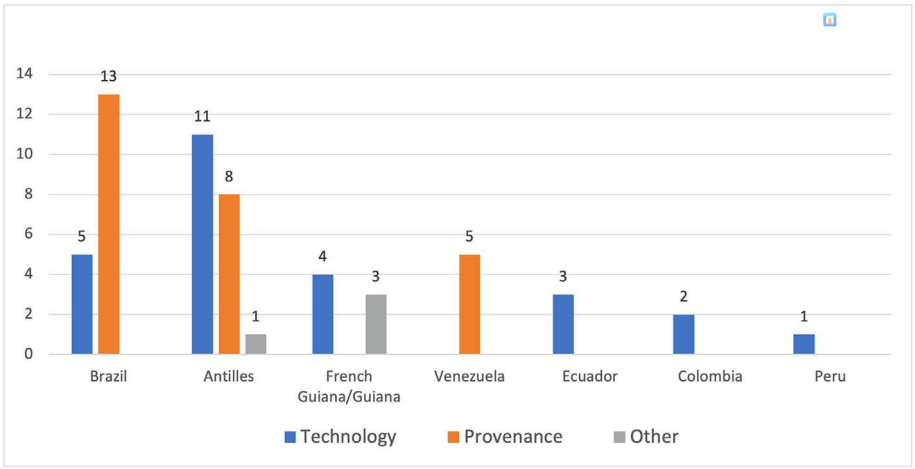

FIGURE 3 Number of archaeometric studies on ceramic materials in the study area by topic per country or region.

In the Caribbean, the use of archaeometric techniques to describe ceramic technology became a main topic in the 1990s through specialists, based in the USA, that initially came from other disciplines, such as physics or geology, and conducted the first studies on small data sets to confirm typologies or functional traits. A key early example is Donahue et al. (1990), who performed petrographic studies on ceramics from the Northern Lesser Antilles and published in a geoarchaeology journal. Another early example is Curet (1997) in Puerto Rico, published in an archaeological science journal, where the author explores the porosity, water absorption, density and firing temperature of ceramics from different periods to compare their changes through time.

In the early 2000s, several studies were published in a special volume dedicated to the chemical characterization of Caribbean ceramics from the pre-Hispanic and colonial periods. This publication shows an increasing trend of archaeometric studies in the area and of archaeologists who were conducting analysis themselves. These first studies of the second wave, mostly performed by academics in the USA, the Netherlands and the UK, were focused on technological

change and paste characterization using thin-section petrography (Hauser et al., 2008; Kelly et al., 2008). Later, research publications on the subject, between 2013 and 2021, follow this trend of technology studies, characterizing paste recipes and pottery production sequences (Pavia et al., 2013), as well as making some larger local and regional comparisons in terms of raw materials and paste composition (Lawrence et al., 2016, 2021). Other studies focus on exploring the existence of pottery manufacturing standardization in precolonial and colonial times (Ting et al., 2017, 2018) or even identifying types of recipes as chronological markers of key technological transformations during pre-Hispanic times (Fronteau & Van Den Bel, 2021).

In the Brazilian Amazon, Costa et al. (2004), in one of the earliest archaeometric studies, analyzed the composition of 51 pottery fragments from a Terra preta soil (also known as Anthropogenic Dark Earth soils—ADE) in the lower Amazon using ceramic petrography, X-ray diffractometry (XRD), scanning electron microscopy by energy dispersive X-ray spectroscopy (SEM-EDS), Fourier transform infrared spectroscopy (FTIR) and thermogravimetric analysis. Aluminum and iron phosphates were identified inside the pots and interpreted as either formed during food cooking or after discarding sherds with other waste material that led to ADE formation. In another study on pottery recovered from ADE sites in central Amazonia (upper Solimões) and the lower Amazon (Trombetas River, Caxiuanã Bay and northeast coast of Pará state), Costa et al. (2009) characterize the ceramic pastes using petrography, SEM-EDS, XRD and inductively coupled plasma mass spectrometry (ICP-MS). The authors also identify Al–Fe phosphates in the pottery fragments that may form after repeated cooking of food inside the pots. This work also provides one of the first petrographic descriptions of organic inclusions in Amazonian pottery, such as freshwater sponge spicules (cauíxi) and tree bark ashes (caraipé). Analyses in both studies led by Costa were performed in laboratory facilities in Brazil, starting a trend that characterizes Brazilian archaeometry until today.

In one of the most comprehensive works on the use of freshwater sponge spicules in precolonial Amazonian pottery, Natalio et al. (2015) performed an overarching study to determine the mechanical advantages of cauíxi in the ceramic paste. The study, carried out abroad, combines experimental tests, SEM, synchrotron phase-contrast enhanced micro-computed tomography (μ-CT), FTIR by attenuated total reflectance (FTIR-ATR) and determination of the mechanical properties of sponge spicules. Sponge spicules act as microscopic glass fibers that enhance the mechanical stability of ceramics, preventing shrinkage and crack propagation, especially when oriented using the coil-roll technique. A total of 16 archaeological potsherds from different sites in central Amazonia were analyzed, and the results indicated the use of highly oriented sponge spicules in the paste. Villagran et al. (2022) conducted the first comprehensive petrographic study of ceramics from southwestern Amazonia (Rondônia state) in a collective work with Brazilian students and researchers at the University of Sao Paulo. This study confirmed the high frequency of freshwater sponge spicules in the paste by analyzing 22 ceramic fragments from the Monte Castelo shell mound (including one fragment of a pot-stand). Spicules are oriented in the same way that Natalio et al. (2015) demonstrated to improve the stiffness and resistance of the ceramic paste. A constant recipe for Bacabal ceramics was identified in fragments dating from c. 4000 BP to 1000 BP. A comparison with sponge spicules from natural deposits near the site indicated that cauíxi could have already been present in the clay sources and intentionally added during paste preparation to maintain the preferred proportion of clay and cauíxi.

Ceramics from three shell mounds in coastal Amazonia (Maranhão state) were analyzed by Ikeoka et al. (2022) in Brazil using optical microscopy, energy-dispersive X-ray fluorescence (EDXRF), particle-induced X-ray emission (PIXE), Mösbauer spectroscopy, XRD and computed radiography. This work aimed to identify production processes, technology and the provenance of raw materials. Multivariate analyses showed the presence of two chemical groups, one including two sites and the second with one site. Both groups were interpreted as resulting from different clay sources, whose geographic location could be determined for one site. Other

types of tempers (quartz grains, grog and shell) were identified by computed radiography, indicating various production technologies.

In the Amazonian region outside of Brazil, the earliest study that uses petrographic analysis as a complementary technique to compare and further discuss ceramic typologies in the region is Arellano (1997), who studied 18 ceramic materials from different archaeological sites located to the east, in the mountainous transition and the lowland area of the Ecuadorian Amazon. This leading research was conducted locally, at the Archaeological Research Centre of the Universidad Católica de Quito. On the contrary, during the second wave of research on ceramic technology, the first archaeometric study conducted on materials from the Colombian Amazon border was performed by Costa et al. (2011) in Brazil, where they analyzed ceramics from ADE sites using petrography and XRD, and compared the results with previous studies conducted in other ADE sites in the Brazilian Amazon.

In the last decade, new research has been conducted in the Ecuadorian and Peruvian Amazon. Local archaeometric analysis, conducted by Mujica et al. (2021) at the BizaLab facilities in Perú, used XRD and SEM to study a small sample of pre-Hispanic ceramic artifacts from the Peruvian Amazon and compared them with their previously assigned typology and chronology. The Ecuadorean studies combined petrography, macro trace analysis and ethnoarchaeological research (Lara, 2019; Lara & Iliopoulos, 2020) to reconstruct the *chaîne opératoire* of different technological ceramic traditions. This same approach has been applied in the Guianas (Coutet, 2014, 2015; Gaspar, 2019) and the Dominican Republic (Casale et al., 2022), also as part of the French school influence in the region. The latter implies that some of the analyses in Ecuador, French Guiana and Dominican Republic—particularly petrographic and macro trace analysis—were also conducted outside of the region, back in France, by foreign members of their research team (Table 1).

Provenance

After the early start of research on provenance using XRF (Labreque et al., 1988, 1990) and TL (Tarble & Vaz, 1986–1987) in ceramic items from Venezuelan archaeological sites, both techniques were replaced in archaeometric studies with a more precise method that will allow the identification of clay sources and materials circulation. In Venezuela and other Caribbean countries, several studies were outsourced to the USA, with a special interest in the application of the INAA technique and the promise of building a Caribbean ceramics database to identify the provenance of ceramic materials within a wider area (Ahlman et al., 2008; Conrad et al., 2008; Crock et al., 2008; Fitzpatrick et al., 2008; Isendoorn et al., 2008; Siegel et al., 2008). Because of the high costs of INAA (it demands a nuclear reactor), there is a special funding from the University of Missouri Research Reactor Facility (MURR) and the National Science Foundation with the US Department of Energy Office of Nuclear Energy, Science, and Technology, which benefits academics working in the Caribbean but based on US academic institutions (Descantes et al., 2008, p. 2). This previous condition makes it mandatory for Caribbean researchers to have a US-based team member or lead author to access this type of expensive and exclusive technique, deepening the dependency on analytical instruments and scientific research. Although usually described as non-destructive, samples are either drilled to extract a powder or a subsample is pulverized in a mortar. When a whole ceramic fragment is analyzed, INAA causes its contamination from radiation lasting for several years, even if the external appearance of the ceramic is maintained (Pollard et al., 2007).

Other key provenance studies at the beginning of the 21st century were conducted in Cuba at the Centre for Technological Applications and Nuclear Development (CEADEN by its initials in Spanish) where complementary INAA, XRF and petrographic studies were performed

in pre-colonial and post-contact ceramics from the island (Padilla et al., 2002, 2003, 2006), exhibiting comparable results. The Simon Bolivar University in Venezuela and the Institute of Isotope and Surface Chemistry in Budapest (Hungary) also collaborated in the analyses of Caribbean ceramics in the early 2000s by applying INAA, XRF, prompt gamma-ray activation analysis (PGAA) and petrographic studies on a small data set of pre-Hispanic ceramic figurines (Bohus et al., 2005, 2006), advancing our knowledge on clay sources, trade and exchange networks in the past.

Most recently, a study combining portable X-ray fluorescence (pXRF), thin-section petrography and SEM on over 60 beads and 13 ceramic stamps from the Middle Orinoco in Venezuela—an intermediate area between the Caribbean and the Amazon region (Lozada-Mendieta et al., 2022)—was published, proving that other less expensive techniques can have comparable results to identify provenance and circulation. Also, the study discussed the multiethnic identity of pottery communities in the area and the products of their contacts in terms of hybrid recipes and stylistic features, using petrography and pXRF to understand ways of making and negotiating identity in the past (also see Casale et al., 2022, for similar discussion on the transformation and preservation of technical traditions through time and space in Hispaniola). The beads and stamp study from the Middle Orinoco required the sample to be shipped to University College London (UCL) for processing and analysis, given the current situation of research facilities in Venezuela after the socio-political unrest of 2017, which affected the advance of local archaeometric studies, after being a pioneering country for this type of research.

Early archaeometric works dealing with ceramic provenance in the Brazilian Amazon compared ethnographic and archaeological pottery. As in the case of technological studies, an overwhelming proportion was done by Brazilian researchers in local laboratory facilities (this revision only encountered one study done in European facilities). Silva et al. (2004) published one of the first archaeometric studies of Amazonian ceramics focused on provenance. Using EDXRF and gamma-ray densitometry, the authors characterize the paste and pigments of two archaeological and two ethnographic pottery fragments from the Assurini of Xingu (Pará state). The results indicate different clay sources for the four analyzed samples and a possible continuity between the archaeological technology of Tupi ceramics and present-day Assurini. Munita et al. (2005) further expanded this work by analyzing 33 samples from two clay deposits and four Assurini pottery fragments by INAA and SEM. Analyses reveal chemical differences in the clay sources and a preference of Assurini potters for one specific clay source, which guarantees a better performance of the ceramic paste. Ethnographic pottery from Assurini and Xikrin peoples was studied by da Silva et al. (2006) using EDXRF, synchrotron micro-XRF and SEM-EDS to determine the most suitable method for provenance studies. Analyses of 30 pottery fragments (eight ethnographic from Amazonia and 22 archaeological Tupi pottery from southern Brazil) revealed that EDXRF was the most suitable technique to statistically group ceramic pastes for provenance analyses.

After these pioneering works, the method of INAA has been commonly used in the study of Amazonian pottery to group larger ceramic artifacts data sets according to the composition of the ceramic pastes. Hazenfratz et al. (2012) analyzed 80 pottery fragments from central Amazonia (Lagoa Grande and Osvaldo sites) for a preliminary comparison between the two sites. Analysis showed two compositional groups, mixing ceramics from both sites. This was interpreted as evidence for commercial or cultural exchange in the region, signaling sociocultural interactions between the sites. In another study, Hazenfratz et al. (2016) and Neves et al. (2019) expanded the number of samples from the same sites ($n = 200$) and focused on identifying exchange networks using INAA. Two compositional groups were again identified, mixing both sites and interpreted as complex multimodal means of social and cultural integration in Central Amazonia.

Nunes et al. (2013), working in a nearby settlement in central Amazonia (Hatahara site), analyzed 124 archaeological ceramics and six clay samples from natural deposits by INAA. The goal was to identify chemical groups in the ceramic phases identified at the site, both from Arawak and Tupi-speaking peoples. The authors conclude that ceramics were manufactured locally and demonstrate the occurrence of four ceramics groups that mix material from the three archaeological phases at the site (Paredão and Manacapuru—Arawak associated; and Guarita—Tupi associated). Using INAA, coupled with TL and electron paramagnetic resonance (EPR) spectroscopy, Baria et al. (2015) analyzed 70 pottery fragments from the Guarita phase (Tupi associated) at the São Paulo II archaeological site in central Amazonia. The compositional characterization of the ceramic paste revealed three chemical groups explained either as different cultural influences in the preparation of the pastes, as changes in land use, in the organization of ceramic production or in the availability of raw materials.

On the equatorial coast of Brazil (Maranhão state), Ikeoka et al. (2018) used EDXRF, PIXE, XRF and computed radiography to analyze 63 pottery sherds from three shell mounds (Sambaqui do Bacanga, Sambaqui Panaquatira and Rabo do Porco sites). The authors identified two chemical groups in ceramic samples from different sites and stratigraphic positions. This is interpreted as evidence of two clay sources used in pre-colonial pottery that vary in Ca, Zn and Rb content. The first archaeometric study in southwestern Amazonia was conducted by Carvalho et al. (2019), with ceramics from the Bacabal phase of Monte Castelo shell mound (Rondônia state). Using INAA, TL dating and EPR spectroscopy, the authors analyzed 84 pottery sherds and identified three chemical groups. Each group has a different chronology and is interpreted as different clay sources used in the Bacabal settlement at the site. Finally, in the middle Solimões River (central Amazonia), six pottery fragments from the Conjunto Villas Boas and São João sites were characterized by Oliveira et al. (2020) using optical microscopy, FTIR, EDXRF, XRD and SEM-EDX. To determine if pottery from both sites was related, authors compared ceramics with different paintings (red and white), paste and slip compositions, concluding that clay sources used in the preparation of pottery from Conjunto Vilas e São João are indeed different.

Significant research has been conducted in recent years in the Lower Amazon and the Upper Madeira River. In the former area, a study on Koriabo pottery, common in both the Lower Amazon and the Caribbean, has analyzed five samples using XRD for mineral characterization of the paste (Jaimes-Betancourt & Souza, 2021). The samples represent the paste variation in a ceramic collection from the Maicuru River (Pará state) stored at the BASA museum of the University of Bonn (analyses were done at the same university). The results indicate that Koriabo ceramics from the Maicuru River are homogeneous and locally produced. Most ceramics correspond to two pastes with a similar mineralogy. Only a flat body fragment with a zoomorphic decoration has a different paste, with a wider diversity of minerals, indicating that it was probably imported from another region.

Finally, in southwestern Amazonia, around the Upper Madeira River, Costa et al. (2021, 2023) performed an integrative study of ceramic technology and landscape used by pre-Colonial indigenous peoples in the 11th to 14th centuries AD analyzing ceramics from seven archaeological sites: Ilha de Santo Antônio, Ilha Dionísio, Do Brejo, Teotônio, Ilha das Cobras, Coração and Ilha do Japó (southwestern Amazonia). The authors successfully combine stylistic and techno-functional analyses with the chemical characterization of the ceramic pastes by INAA and EDXRF in 118 ceramic fragments. The results signal different cultural choices in clay sources and tempers by the makers of polychrome (Tupi associated) and Santo Antônio ceramics (Arawak and Tupi associated), on the one hand, and Dionísio ceramics, on the other hand. This interdisciplinary approach brought novel information about the interaction of indigenous peoples, the sharing of technological knowledge and the effective use of a riverine landscape for pottery production and circulation.

Other studies

The use of archaeometric techniques to answer other questions aside from technology and provenance on ceramic materials from archaeological sites has also been noted on some of the reviewed research papers featured here. One of the main examples from the Caribbean region is related to the use of archaeometric techniques such as XRF, XRD and SEM-EDX for conservation purposes in ceramic materials pertaining to museum collections (Mendoza, 2019). Other examples combine petrographic studies to characterize paste recipes and manufacturing technology with the analysis of starch grains in the walls of ceramic vessels to understand their use and function in culinary contexts in the past (Van Den Bel et al., 2014). Also, a single example of thermoluminescence application to date ceramics was found on ceramics from an archaeological context in French Guiana (Roque & Vartanian, 2015). Finally, in the Colombian Amazon region, a recent study from the middle Caquetá/Japurá river on pre-colonial ceramics materials from an anthropogenic soil context, included a geoarchaeological and petrographic analysis of pottery materials and their association with phytoliths and archaeobotanical data (Arroyo-Kalin et al., 2019). These latter applications show the broad range of research questions in which archaeometric studies can provide information, such as on conservation, use and function of ceramic vessels from archaeological sites or from museum collections.

FINAL THOUGHTS AND FUTURE DEVELOPMENTS

Archaeometry had a late start in the study of Caribbean and Amazonian ceramics, but it is increasingly gaining prominence in local archaeological research. Although the first wave and early second wave of studies, from the 1990s and early 2000s, respectively, were mainly conducted by researchers outside of archaeology, an increasing number of archaeologists, in the last ten years, are investing in these methods, revitalizing the scope of interpretations and advancing in the field by introducing new analytical techniques in their studies beyond the predominant petrography and INAA. However, the main disparity revealed by this revision has to do with the local versus non-local laboratories and researchers working with ceramics from the Brazilian Amazon and the Caribbean, respectively, which are certainly historical products of science development in each region.

In the Caribbean, most studies were done by foreign researchers in laboratories abroad, with little or no contribution to the transfer of knowledge and training of local scientists. On the opposite side of this trend, archaeometric research in the Brazilian Amazon—and the first one in the Colombian Amazon —has always been done by Brazilian researchers in local facilities. This attests to the long-lasting effort of Brazilian scientists to strengthen local research networks and consolidate national research institutions. Studies have also been carried out locally in the Amazon region outside of Brazil, without full dependence on foreign collaborations (e.g., Peru, Ecuador, Colombia and Venezuela).

Except for Cuba, most Caribbean archaeometry has been exported. Caribbean ceramic archaeometric studies are still heavily dependent on foreign collaborations, and there is a need to develop a local/regional school and facilities that can carry on the research work and ensure its continuity. Caribbean archaeometry is gradually decolonizing, with the development of local and regional scientific collaborations, which can hopefully increase in the near future.

In Brazil, a new generation of graduate students is being trained in archaeometric methods, such as ceramic petrography, XRF, FTIR, INAA and microtomography (e.g., A. Costa, K. Brandão, M. Alves and T. Kater). The Brazilian School of Archaeometry and the two well-established laboratories of archaeometric studies (at IPEN and the University of Londrina)

prove this field's consolidation in the country. The Laboratory of Microarchaeology at the University of São Paulo regularly offers graduate courses in ceramic petrography and complementary techniques (FTIR, XRF) and is currently researching Amazonian ceramics through collaboration with local and international researchers in Colombia and Germany. This has been a crucial step forward in consolidating the field. Now, archaeologists are being trained in archaeometric methods and doing the analyses themselves, without dependence on specialists from other disciplines. The main contribution to this is revealed in the quality of the interpretations, providing information of the historical trajectories of material culture and the complex interplay of peoples and nature, going beyond descriptive compositions or confirmation of ceramic typologies.

Thinking about new horizons for archaeometric studies in the region, we can safely state that nowadays there is a growing amount of archaeometric data on ceramics from the main linguistic and cultural traditions of Amazonia and the Caribbean. Data on Tupi ceramics are predominant, followed by Karib and Arawak, with only isolated studies dealing with complex ceramic styles such as Koriabo, Marajó and ceramics from the equatorial shell mounds (both coastal and riverine). However, the diversity and intricacy of Amazonian and Caribbean ceramics demand that more archaeometric studies be incorporated into current research. Ceramic archaeometric studies are still being done in isolation, generally trying to prove by quantitative methods the differences observed in macroscopic technological and stylistic analyses. More studies must be done to equate previous results with new findings and new ways of applying and interpreting archaeometric data. This is certainly attested by the few studies dealing with ceramics use and the overwhelming predominance of provenance and technological analyses in our study region.

Questions dealing with the identification of inter-regional and long-lasting persistent traits, the interpretation of hybrid ceramic styles, the definition of cultural areas, regional networks, patterns of interaction and cultural frontiers (see Lima et al., 2016, for a revision of the current state of Amazonian ceramics) would greatly benefit from the use of archaeometric analysis. Analytical methods, coupled with traditional macroscopic studies, will certainly provide a greater level of certainty in our understanding of the technology, circulations and socio-cultural dynamics of the pre-colonial indigenous peoples and their material culture from the Amazon and Caribbean.

From this revision it becomes clear that, among the positive aspects of archaeometry in the Amazon and Caribbean, there is a diversity of methods that have been applied and continue to expand, used in complementary ways to confirm or contest more complex questions on the production and circulation of ancient ceramic materials and the social groups behind them. Likewise, the current existence of established local laboratories and an increasing number of trained archaeologists in archaeometric techniques is the product of a slow but steady rise of the discipline in the region and its recent consolidation. As a downside, there is still a dependency that some countries have on foreign collaborations, due to the costs and limited access of certain type of instrumental analysis. Also, the research questions have been rather limited and there is a need to go beyond provenance studies and composition, for instance, into data about techniques, practices, and more complex anthropological questions on identity and functionality of this type of material culture. We envision that the future of ceramic archaeometry in the region will involve a larger diversity of methods and improved interpretations thanks to the development and consolidation of local research teams that will strengthen inter-continental alliances.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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How to cite this article: 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