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The Ychsma ceramic provenance from Armatambo, 1250 – 1532 CE (Lima, Peru). A local or imported production?

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A B S T R A C T

The Ychsma society was one of the most important civilizations developed between 900 and 1532 CE in Lima, the present Peruvian capital, situated on the central coast of Peru. The Ychsma territory included the lower basin of the Rímac and Lurín valleys in the current city of Lima (Peru). Around 1470 CE, the Ychsma region was conquered and placed under the control of the Inca Empire, which ruled the region until the Spanish conquest in 1532 CE. Despite this, the Inca rule allowed local elites to maintain their position and control of the population. The archaeological site of Armatambo was an important administrative center of the Ychsma society. This site was actively occupied during the Middle Ychsma (1250–1350 CE) and Late Ychsma (1350–1532 CE) phases, and as the capital of the Sullco Curacazgo controlled a large part of the lower Rímac valley. During excavations at this site, many materials associated with ceramic production were found. One aspect crucial to the study of ceramic materials is the reconstruction of ceramic production and distribution networks, which allows us to obtain information linked to the social and economic interaction between communities. To determine the local or non-local origin of the materials found at Armatambo, 61 samples were analyzed using ICP-MS, Petrography, and SEM. The results were compared with archaeological and geological data from the Rímac valley to determine whether or not production there was local or non-local and to identify possible sources of raw materials.

1. Introduction

The pre-Hispanic history of the city of Lima, the Peruvian capital of the central coast, is extensive. There is evidence of long-standing occupation, ranging from the earliest hunter-gatherer societies to the presence of the Inca state (Moore 1996; Pozorski and Pozorski 2008). Among the social and cultural manifestations developed in this region, it is important to mention the Ychsma society, which developed between 900 and 1532 CE in the central coast (Fig. 1). Its territory included the lower basin of the Rímac and Lurín valleys (Díaz 2004; 2008). The Ychsma culture spans the Late Intermediate (900–1470 CE) and the Late Horizon (1470–1532 CE) chronological periods.

The earliest references to this society comes from ethnohistoric sources recorded in documents written by Spanish colonial rulers in the 16th century onwards. These documents contain numerous claims to the colonial authorities, the main aim of which was to regain ownership of agricultural land. Through the study of this historical information, it has been possible to identify the Ychsma ethnic group that developed in the Lima region before the arrival of the Incas (Rostworowski 1978). According to this historical evidence, this society was organised by *curacazgos*, which dominated large areas of the two lower valleys. A *curacazgo* was a portion of territory representing a political unity of lesser rank into the Ychsma Chiefdom. Along these lines, Armatambo is considered the capital of that *curacazgo* named Sullco, Sulco or Surco, and it is also referred to as the "Señorio de Sullco". There were six *curacazgos* in the Rimac valley and one in the Lurin valley, including Pachacamac in Lurin, the most important center of the cacicazgo or "Lordship" (Eeckhout, 2004a, b). Some of the most important sites in the Rímac valley are Armatambo, Mateo Salado, Pedreros, Mangomarca and Catalina Huanca. In the Lurín valley it is important to note the sanctuary of Pachacamac and the site of Pampa de Flores.

Historical and archaeological references to the Ychsma society are further supported by material evidence, such as architecture, tombs and ceramics. Since the first archaeological investigations were carried out on the central coast, Late Period ceramics have had different names, such as "Huancho" (Iriarte 1960), "Puerto Viejo" (Bonavia 1959) or

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other names based on decorative characteristics. In 1990, the first important definition and classification of this pottery was made by Bazán del Campo (1990), who referred to it as the Ychsma style based on the ethnohistoric findings of Rostworowski (1978). Del Campo classified ceramics into three phases corresponding to their various chronological periods, which were completed by Vallejo (2004): Early, Middle and Late Ychsma Phases, with a subdivision of each of them into two subphases, called A and B. In this way, he established the basis for future work on this topic (Fig. 2). The latter classification is based on technical and formal differences. Thus, it is observed that in the first phase some decorative canons of the previous periods are preserved, such as the elaboration of globular vessels or double-bodied bottles with decorative designs in a wide range of colors. In the intermediate phase, the Ychsma style was consolidated, with simpler ceramics in terms of decoration and finish. However, in the last phase, a greater variety of techniques and forms can be identified, with the influence of foreign styles, such as the so called Chimú-Inca or Inca provincial styles. This classification has been made mainly with ceramic material from Armatambo, considered the capital of the "Señorío de Sullco" (Díaz 2004; Eeckhout, 2004a, b; Rostworowski 2009).

The main objective of this study is to characterize the ceramic material found at the Armatambo site (dating from the Middle Ychsma to Recent Ychsma) by means of ICP-MS, SEM and petrography in order to determine the provenance of the raw materials. In this way, it will be possible to formulate hypotheses about the distribution networks during the Late Intermediate and Late Horizon periods. This will allow us to better understand the socio-economic processes of this society during this period. An important fact is that during the different seasons of archaeological excavations in our study area, no kilns for pottery firing were found, probably due to the use of open pit firing that had not left clear traces.

2. Site and *geological background*

2.1. Armatambo site

This site is located on the left bank of the lower Rímac valley, at the base of the natural promontory called Morro Solar, located a few meters above sea level, in the present-day district of Chorrillos, south of Lima (Fig. 3). Armatambo was a large urban settlement composed of different monumental constructions and residential areas for the common people and their elites, which at its peak was home to a large population (Díaz 2008). This site was extensively excavated in numerous campaigns from 1998 to 2004, which made it possible to determine the different occupations of this important archaeological complex, from the Middle Ychsma (MY) to the Late Ychsma (LY), with a clear Inca presence at the site (Díaz 2004; Díaz and Vallejo 2002). Its location made it a privileged place to make contact with different Ychsma sites located in the Rímac and Lurín valleys, especially with the sanctuary of Pachacamac. Archaeological work carried out in 2002 identified some artefacts such as tools, remains of possible ceramic production, remains of cooking and possible combustion areas (Díaz and Vallejo, 2002). These findings could be associated with possible *in situ* ceramic production.

Although, there are few works that address the study of Ychsma ceramics, it is possible to identify-two main research lines. The first is oriented towards the classification of the Ychsma ceramic style based on macroscopic observations that have allowed for the typological classification of Ychsma ceramics (Díaz and Vallejo 2002; Falconí, 2008; Vallejo, 2004, 2009), this information has allowed us to identify which were the main forms found in the different archaeological sites in this region. However, a recurring aspect of these works is the very superficial description of the types of inclusions and the use of the colouring of the pastes as a diagnostic element to separate the types of pastes. The disadvantage of using this diagnostic method is that we worked with fragments of vessels of which we do not know the firing method. This information is important because no evidence of firing structures has

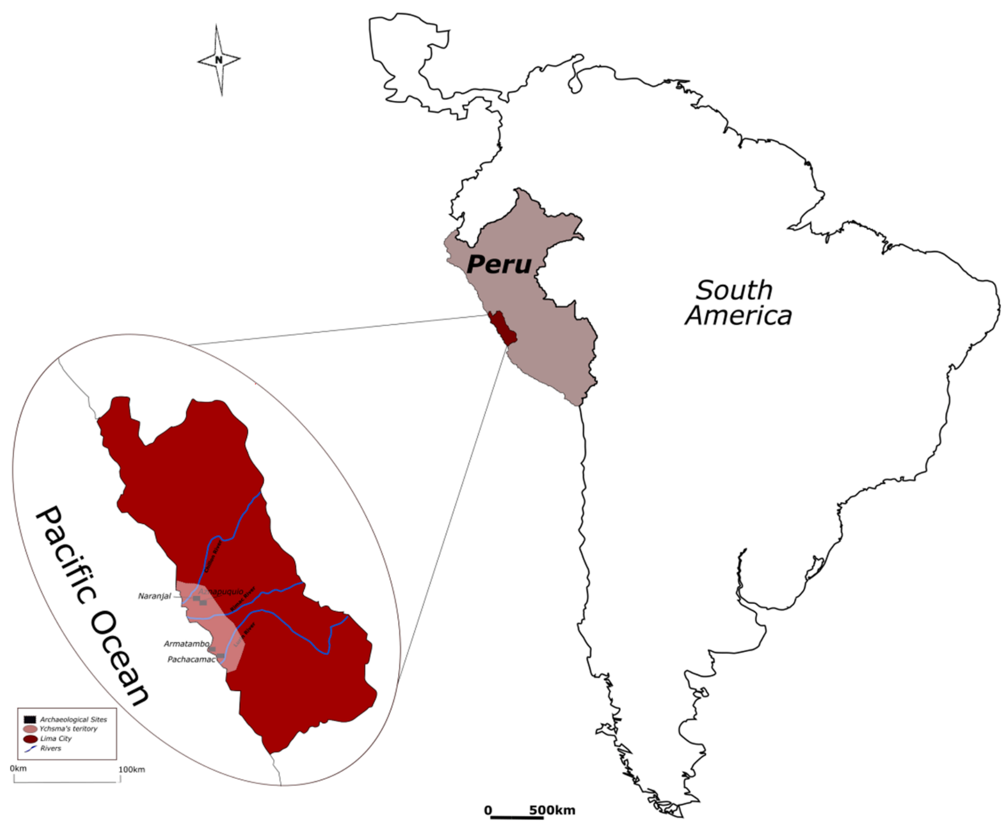

Fig. 1. Map of Lima city in its actual state in 2022 with location of archaeological sites of Armatambo, Pachacamac, A Naranjal and Aznapuquio.

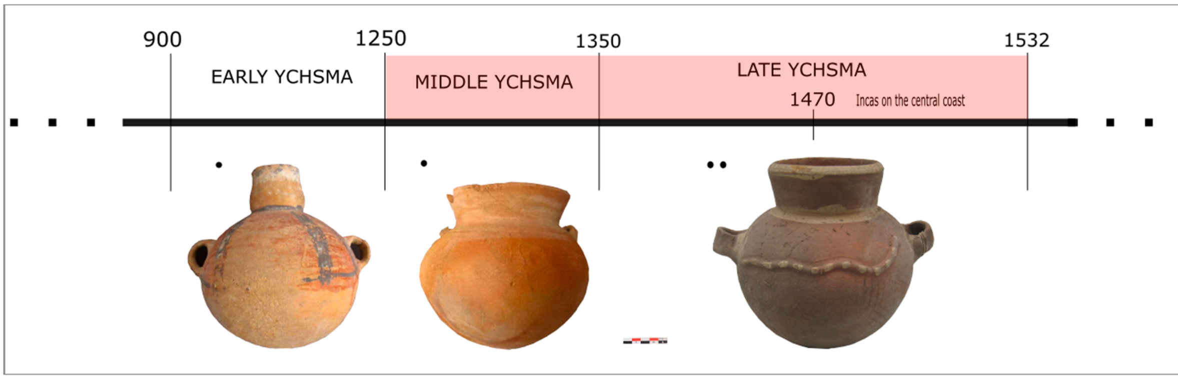

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Fig. 2. Chronological chart of the Ychsma society. It mainly shows the periods associated with the occupation of the Armatambo site, the Middle Ychsma (1250 – 1350 CE), and the Late Ychsma (1350 – 1532 CE). (Photo: Luisa Diaz Dante Casareto).

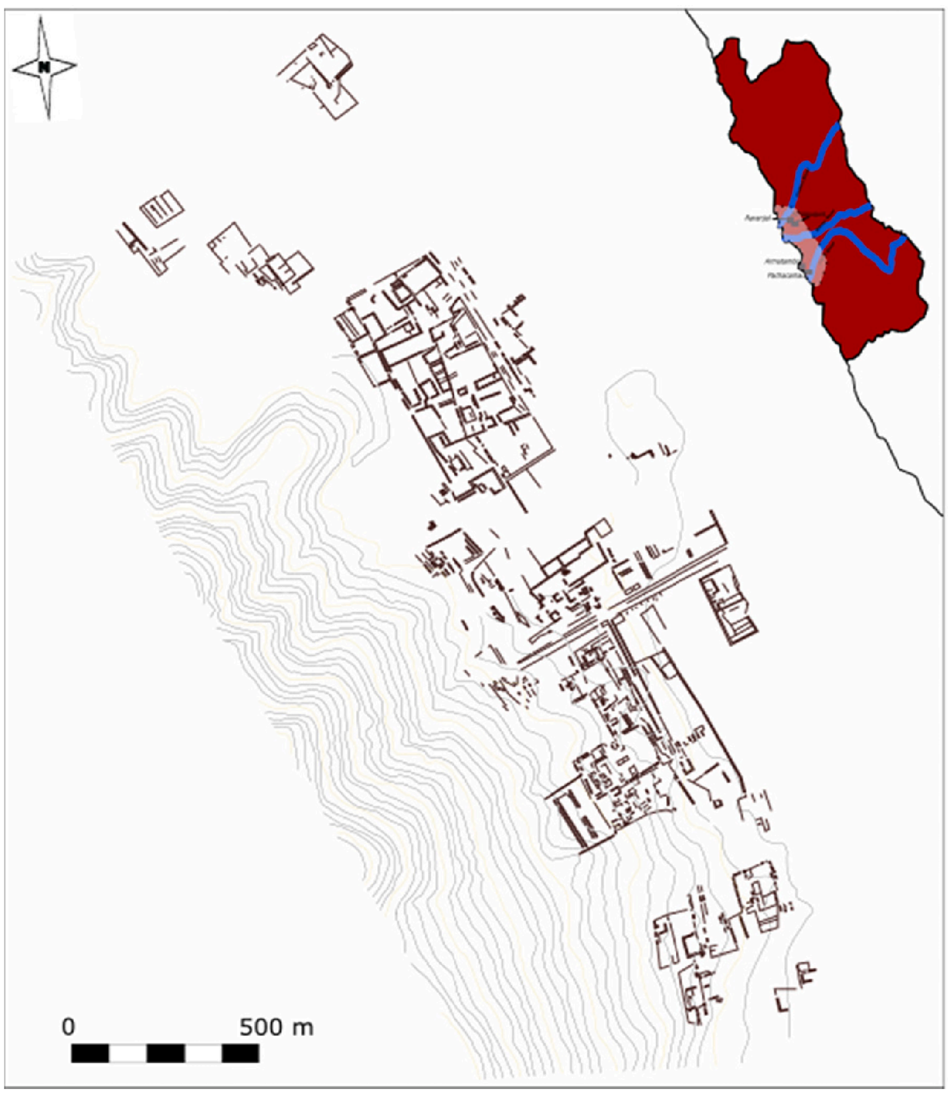

Fig. 3. Plan of the archaeological site of Armtambo made from a 1947 aerial photograph.

been found, but rather areas of burning that would be associated with open-fire firing. In this type of structure, the same vessel may have areas with different colorations as a result of greater or lesser exposure to air during firing. The second line applies chemical analysis techniques, such as LA-ICP-MS and NAA, seeking to identify possible areas of supply of raw materials used for the production of the ceramics. Among the latter ones, there are studies which have focused on the ceramics found at the sites of Pachacamac and Pueblo Viejo Pucara in the Lurín Valley, whose results allow researchers to propose that the material found in Pachacamac would come from adjacent areas to this archaeological site, such as the upper areas of the Lurín Valley and the lower areas of the Rímac Valley (Oré Menéndez, 2012; Makowski and Oré 2013).

2.2. Geological background

The central coast is topographically diverse, with coastal plains and alluvial fans that are interrupted by low hills, which progressively change to a more rugged relief. The knowledge of the geological characteristics of our study region is important and necessary to approach the study of the origin of the raw materials and the identification of the techno-petrographic groups. Thus, this area presents a lithostratigraphic sequence composed of four groups (Alemán et al. 2006):

(a) The Puente Piedra Group corresponds to the Terminal Jurassic and the base of the Lower Cretaceous. It is composed of volcanic sandstones, andesitic and basaltic lava flows, shales and limestones.
(b) The Morro Solar Group belongs to the Lower Cretaceous and is composed of silty clayey limestones, shales, evaporites and bioclastic limestones.
(c) The Lima Group is an intercalated marine sequence, characterized by the presence of micritic limestones and grey limestones (packstone and mudstone), covered by reddish and greenish siltstones.
(d) The Camas Group is Lower and Upper Cretaceous, associated with the coastal batholith composed of pyroclastic breccias, lavas, volcanic sandstones, gabbros and dolerites (León et al., 1999; León and De la Cruz, 2003; Aleman et al. 2006).

The type of deposits in this region are characterized by the presence of alluvial sediments, typical of an ejection cone such as that of the Rimac river. However, aeolian and marine deposits have also been identified. Another type of deposit corresponds to the colluvial type, which is defined as the accumulation of materials close to their site of origin and cover the palaeoforms. These deposits are formed by the detachment of soils from mountainous areas or streams due to the effects of gravel and in some cases by occasional precipitations. Some of these phenomena occurring on the central coast are mentioned by Villacorta (2018), which correspond to debris flows in different areas and in different periods. It is important to take into account this information regarding the types of geological deposits as they can be identified during the study of our thin section and can help us to define the petrographic groups.

3. Ceramic samples

In this study we analyzed 65 Armatambo samples from funerary contexts excavated in 2002 (Díaz and Vallejo 2002). The ceramic corpus is composed of 44 samples from the Middle Ychsma and 21 samples from the Late Ychsma[1] (table 1 in supplements), comprising rims, body parts and bases of different vessels (Fig. 4), of which a small number of samples present some kind of pictorial decoration based on three colors (white, black and brown). The rest of the samples present mainly as surface treatment, a simple smoothing. For our study, we have selected three types of vessels: pitchers, pots and jars, because these forms are the ones that appear recurrently in the archaeological records of the different excavations carried out in this region (Díaz and Vallejo 2004; Falconí, 2008; Vallejo, 2004, 2009; Oré Menéndez, 2012; Makowski and Oré 2013). This has allowed us a better comparison taking into account the main forms found in the archaeological record of Ychsma. It should be noted that not all samples went through the same analysis techniques, due to the size of the samples.

[1] In 2015, a fire consumed part of the deposits of the Universidad Nacional Mayor de San Marcos. There were ceramic collections from Armatambo. For this reason, we have a few samples of Later Ychsma.

4. Methodology

4.1. Petrographic analysis

As a first approach to determine the types of inclusions present in our samples, we made petrographic observations by means of a polarizing microscope (Leica Microsystems, Wetzlar, Germany) with 2.5 × to 20 × objectives, coupled to a Leica DM2500 camera. This system uses the Leica Application Suite v3 imaging processing software. Thin sections were prepared to a thickness of 30 μm and metallographically polished by mechanical methods. Plane polarized light (PPL) and cross polarised light (CPL) images were taken at different magnifications to identify the nature of the inclusions present in the ceramic pastes and to define the petrographic groups. To determine the percentage of inclusions, present in the samples, the comparative chart for visual estimation of percentages of minerals in rocks was used (Terry and Chilingar 1955).

The criterion taken to identify the petrographic groups was the identification of the nature of the inclusions, their size and their percentage. The identification of the types of inclusions was compared with the observation of the geological charts of the Lima region (Palacios et al. 1992): 25j (Lurín), 25i (Lima), 24j (Chosica) and 24i (Chancay), which allow us to determine the possible areas of supply of raw materials in pre-Hispanic times.

4.2. Scanning electron microscopy–energy dispersive X–ray spectroscopy (SEM-EDX)

Microscopic analyses were performed to determine, based on the chemical composition and morphology, the type of minerals and rocks present within the pastes. For this purpose, we used a JEOL-IT 500 scanning electron microscope in low vacuum mode (30 Pa), with EDS (Oxford Instruments UltimMax 100). Measurements were performed at an accelerating voltage of 20 kV, with the probe current from 10^{-10} to 5.10^{-9} A and a working distance of 10 mm. The micrographs were recorded in back-scattered electron mode (BSE). The results were processed using the program Oxford Instruments Aztec NanoAnalysis. Each EDS spectrum was registered with a total counts number of 400 000. This EDS analysis allowed quantification of only the major and minor elements (Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, K_2O, CaO, TiO_2, MnO and Fe_2O_3).

4.3. Inductively coupled plasma mass spectrometry (ICP-MS)

To study the provenance of our material, it was decided to use a highly sensitive multi-elemental approach such as ICP-MS. Therefore, we used the protocol proposed in Iñañez et al. (2020) to perform our analyses. The initial stage comprised of mechanically removing external and internal surfaces to avoid postdepositional contaminants, then grinding ~ 5 g of each ceramic in a planetary ball tungsten carbide cell mill before calcining at 900 °C for one hour in an electric furnace under oxidizing conditions. In a laboratory clean room (class 100) the samples were then prepared and analyzed by ICP-MS with a NexION 300 ICP/MS (PerkinElmer, Ontario, Canada). The alkaline fusion method was used to create solutions of 250 mg unknown samples, blanks, and certified materials for external calibration (Geological Survey of Japan: andesite JA2, granodiorite JG-1a, granite JG-2, and basalt JB-3) by mixing 500 mg $LiBO_2$ in Pt - Au crucibles with four drops of LiBr solution as a non-wetting agent and melting using propane melting equipment. The resulting solution was then diluted (1:200) with a mixture of 0.32 N HNO_3 and very dilute HF, as well as In (50 μg L^{-1}) and Bi (10 μg L^{-1}) standard solutions. Concentrations of analytes ^{27}Al, ^{31}P, ^{88}Sr, ^{120}Sn, $^{9}0Zr$, ^{93}Nb, ^{133}Cs, ^{137}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{142}Nd, ^{147}Sm, ^{153}Eu, ^{158}Gd, ^{159}Tb, ^{164}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{174}Tb, ^{175}Lu, ^{180}Hf, ^{181}Ta, $^{206+207+208}Pb$, ^{232}Th and ^{238}U (Internal standards: In and Bi) were

Fig. 4. Picture of ceramic fragments analysed by petrography and ICP-MS, composed of rims, bodies and bases of Ychsma vessels (credit: Dante Pareja).

analyzed in standard mode; while ^{23}Na, ^{24}Mg, ^{28}Si, ^{39}K, ^{44}Ca, ^{47}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{56}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu and ^{66}Zn (Internal standard: In) were analysed in collision mode with He as cell gas. Sample introduction and experimental conditions for ICP-MS data acquisition per sample were optimised to 20 scans, 1 read and 3 replicates, with an integration time of 1000 ms (for further details, see García de Madinabeitia et al. 2008; Sanchez-Garmendia et al. 2020).

5. Results

5.1. Petrographic

For this stage, we worked with 55 thin sections, which were analyzed by petrography. This allowed us to determine the presence of minerals and magmatic rocks present in the pastes. The presence-absence of these elements allowed us to suggest the presence of four groups (Fig. 5) and a petrographic subgroup. In the same way, four samples could not be classified. This makes us think that this classification may vary if we increase the number of samples from other sites of the central coast.

Group 1A. **(n: 30)** The pastes of this group present a reddish coloration that indicates firing in an oxidizing atmosphere. The type of clay used to produce the vessels of this group is of alluvial origin, because it presents a fine clay, with particles with a size smaller than 50 μm. However, the inclusions observed in the thin section present a subrounded shape with a very uniform distribution in the paste, with a homogeneous size, between 150 and 200 μm. The percentage of inclusions in this group varies between 35 % and 45 %.

The samples of this group present an elongated porosity, parallel to the walls of the vessels. In the case of some of these porosities, they are partially filled with secondary calcite recrystallization. The types of inclusions are mainly mineral and we have separated them into three categories. Predominant to dominant: quartz and plagioclase. Common to rare: micas (biotite and muscovite in lower percentage), amphibole and opaque inclusions corresponding to an iron mineral. Rare to scarce magmatic rocks and some sedimentary rocks (detrital rocks) were identified.

Group 1B. **(n: 3)** Individuals belonging to this subgroup have the same characteristics as group 1A, but some of them showed the presence of grog, used as a temper.

Group 2. **(n: 2)** The paste of the individuals of this group has a reddish coloration, with large inclusions visible to the naked eye. The clayey matrix is composed of inclusions with a continuous granulometry, the size of the inclusions is quite large and mainly with an angular shape, which is a characteristic of colluvial deposits. The distribution of inclusions is homogeneous; however, the size is very heterogeneous, with inclusions ranging from small < 50 μm to 2 mm. The

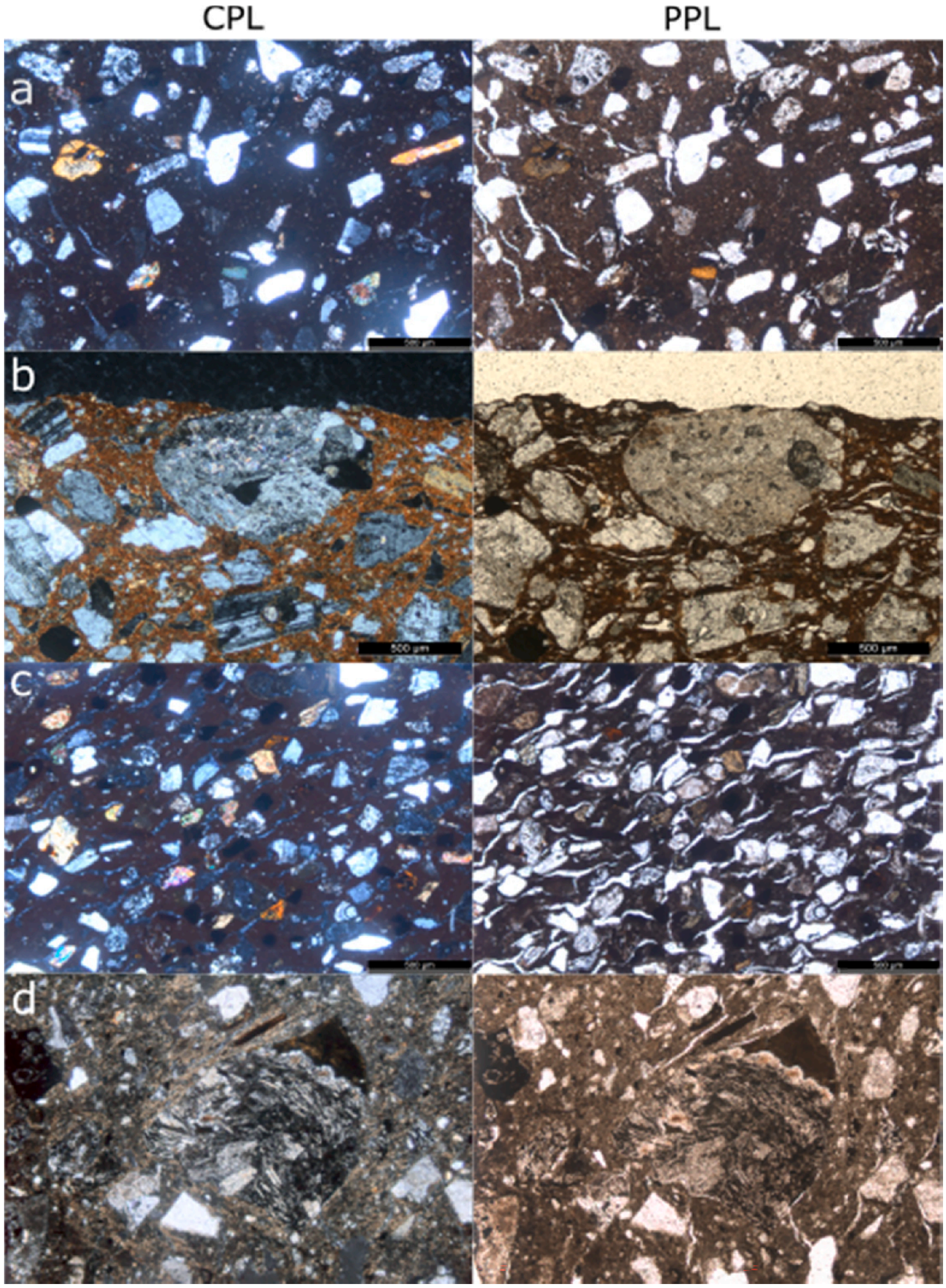

Fig. 5. Plate of the 4 identified groups differentiated by nature of minerals and rocks, size, percentage and distribution. On the left in cross-polarized light (CPP) and on the right in plane polarized light (PPL). a) group 1 (BDX22506); b) group 2 (BDX22456); c) group 3 (BDX22487); d) group 4(BDX22441).

percentage of inclusions in this group varies between 35 % and 40 %. The porosity of this group is elongated and its orientation is very irregular.

The inclusions are mainly composed of rocks of different sizes, which can be separated into three main categories: predominant to dominant: magmatic rocks, granites and granodiorites; frequent to rare: minerals, mainly quartz and plagioclase; gradually: micas, amphibole and iron minerals.

Group 3**. (n: 2)** The paste of this group is reddish, fine clayey matrix (<50 μm), with subrounded inclusions, the clay type comes from alluvial deposits. The distribution of the inclusions is uniform and their size is homogeneous, between 150 μm and 200 μm. The percentage of inclusions in the paste is 40 % to 50 %. The inclusions are mainly composed of minerals: predominant to dominant: amphibole and iron minerals are observed; dominant to frequent: quartz and plagioclase; slight to rare: magmatic rocks and sedimentary rocks.

Group 4**. (n: 14)** The pastes of this group vary from dark gray to more reddish colored pastes. The shape of the inclusions varies from sub-angular (rocks) to sub-rounded (minerals). The distribution of inclusions is uniform but the size of the inclusions is quite broad, with inclusions mostly in the range of 150–250 μm, however inclusions of 1 mm are also found. The percentage of inclusions varies from 40 % to 50 %.

The inclusions are composed of different types of materials between minerals and rocks and we have separated them into two categories: predominant to dominant: minerals, quartz, plagioclase, mica, amphibole and Fe-Ti oxide; dominant to frequent: magmatic rocks such as granites and diorites and sedimentary rocks such as flint.

5.2. Scanning electron microscopy–energy dispersive X–ray spectroscopy (SEM-EDX)

It was decided to perform a SEM-EDX spot analysis on 6 thin sections to identify, from the chemical composition, the types of inclusions present in the pastes. This is due to the impossibility to identify, by petrographic observations, the types of minerals and rocks present in the pastes. The selection of the samples was done randomly, based on the presence of inclusions that were analyzed by SEM-EDX to determine their nature. Thus, those analyses allowed us to determine the presence of biotite (Bt), quartz (Qtz), feldspar (Fs) and volcanic and plutonic rocks (RMP) within the sample (Fig. 6).

5.3. ICP-Ms

For this analysis, 65 samples were considered, of which 4 were withdrawn from the statistical study for showing anomalous chemical data without the possibility of repetition due to sampling size constraints. Therefore, the investigation continued with 61 samples (Table 2, supplementary materials). Calculating the compositional variation matrix (CVM) allows for identifying the variability of the chemical concentration of the elements (Fig. 7). In the CVM, the τ.i corresponds to the calculation value of the logarithmic variation of each element within the data set, and the vt represents the total variation. Therefore, in the study of the compositional data, the total variation value (vt) serves as an indicator of the monogenic or polygenic character of the sample (Buxeda and Kilikoglou, 2003). In this case, the variability of the 61 analyzed ceramics shows a mean relative value of vt (1.63) this corresponds to the high contribution of the following compounds: P_2O_5, Co, CaO, Zn, Cu, Cs, Cr (Fig. 7A). These elements removed from a new calculation of the compositional variation matrix analysis (Fig. 7B), as are considered elements that were highly affected by post-depositional alterations, e.g. P_2O_5 in habitational or burial contexts, or by the sample preparation processes, e.g. this is the case for Co which is a binder in tungsten alloys (Lemoine and Picon, 1982; Buxeda 1999, Boulanger et al., 2013; Sanchez-Garmendia et al. 2020).

Furthermore, in the case of CaO, it is removed from the statistical evaluation due to the presence of secondary calcite filling empty spaces and vacuoles observed in thin sections under the petrographic microscope (Fig. 8). The presence of secondary calcite can generate a wrong interpretation of the results, providing a higher value on CaO than the one that may correspond to the ceramic. Therefore, removing this compound from a statistical review is highly advisable. Considering the impact on the statistical data treatment provided by the previous elements, a new relatively low vt value of 0.67 is calculated, suggesting a low heterogeneity in the compositional dataset.

According to ICP-MS results (18.45 % Al_2O_3, 67.40 % SiO_2, 2.43 % MgO, 3.60 % CaO, 0.71 % TiO_2 and 5.47 % Fe_2O_3), it is evident that the set of Armatambo ceramics is not calcareous and contains a relatively high amount of silica (Table 4, supplementary materials). With these results, it was decided to perform a statistical treatment on the 61 samples retained from the ICP-MS analysis (Table 2, supplementary materials). A cluster analysis was performed using R software and the multivariate statistical approach developed in the ArchFlow package (R Core Team, 2014; Calparsoro, 2019 and references therein), which uses the squared Euclidean distance and the centroid algorithm after centered log-ratio transformation of the analytes retained after the matrix variation calculation to identify and plot chemical similarities among samples on the subcomposition (Al_2O_3, Rb, Sr, Pb, Sn, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Th, U, Na_2O, MgO, SiO_2, K_2O, TiO_2, V, MnO, Fe_2O_3). Therefore, Fig. 9 summarizes the multivariate statistical approach, showing 6 clusters, where the clusters on the left side of the dendrogram are formed by a single individual. However, a compact cluster formed by most of the individuals in the study is in the center and a cluster formed by 4 individuals is on the right side of the graph.

In addition, at the extremes of the hierarchical clustering, some individuals show slight chemical differences from the main group, including Fe_2O_3, TiO, Al2O_3, MgO and Zr: BDX22456 and BDX22480 (7.48 % Fe_2O_3 and 0.87 % TiO) and BDX22487, BDX22440 (an average of 9.59 % Fe_2O_3, 1.44 % TiO and 199.14 ppm Zr).

To further explore geochemical variability within clusters and to better understand resource and production strategies, and given the importance of using rare earth elements (REEs) in the study of raw material provenance for archaeological ceramics, normalization of our chemical data was performed using *N*-MORB (Bea 2015). The elements used for basaltic normalization were La, Ce, Pr, Nd, Sm, Eu, Gd, Td, Dy, Ho, Er, Tm, Yb, and Lu (Table 3, supplementary materials). Furthermore, we use these data taking into account that our study area is volcanic (Alemán et al. 2006). Thus, it is possible to identify 5 clusters (Fig. 10), which form from right to left by: a cluster of one individual (BDX22440), the second cluster, G3, is formed by two individuals (BDX22487and BDX22495), the third cluster formed by most of the individuals of GP1 and GP2, the fourth cluster formed by one individual, and the last cluster formed by two individuals. The samples at the extremes of the graph are BDX22440, BDX22456, BDX22475, BDX22480, BDX22487, and BDX22495. These individuals differ from the rest by having higher values than the rest in some elements (Fe_2O_3, TiO, Al_2O_3, MgO, and Zr), as shown in Table 4 (in Supplementary Materials).

6. Discussion

The first stage of our observations of the thin sections consisted of identifying the types of non-plastic inclusions within our ceramic pastes, for which we performed petrographic and SEM-EDS observations and analysis. We were able to identify the presence of micas (biotite), feldspars and plagioclase, as well as plutonic and volcanic rocks. These types of non-plastic inclusions vary in percentage in the different petrographic groups.

The petrographic results show the presence of four groups and one

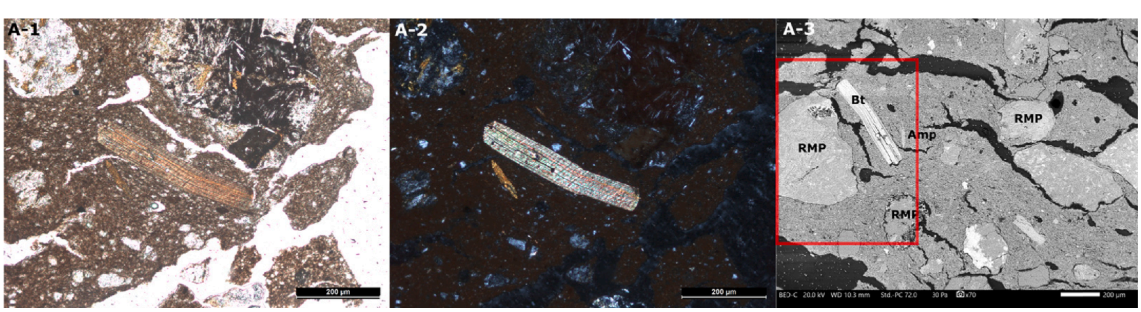

Fig. 6. Observations of the thin section under the polarizing microscope and analyzed in SEM-EDS. A1: plane polarized light (PPL) image. A2: cross polarized light (CPL) image, A3: BSE-SEM image showing the different inclusions identified. In the red frame of image A3 is outlined the area corresponding to the thin section observed in images A1 and A2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

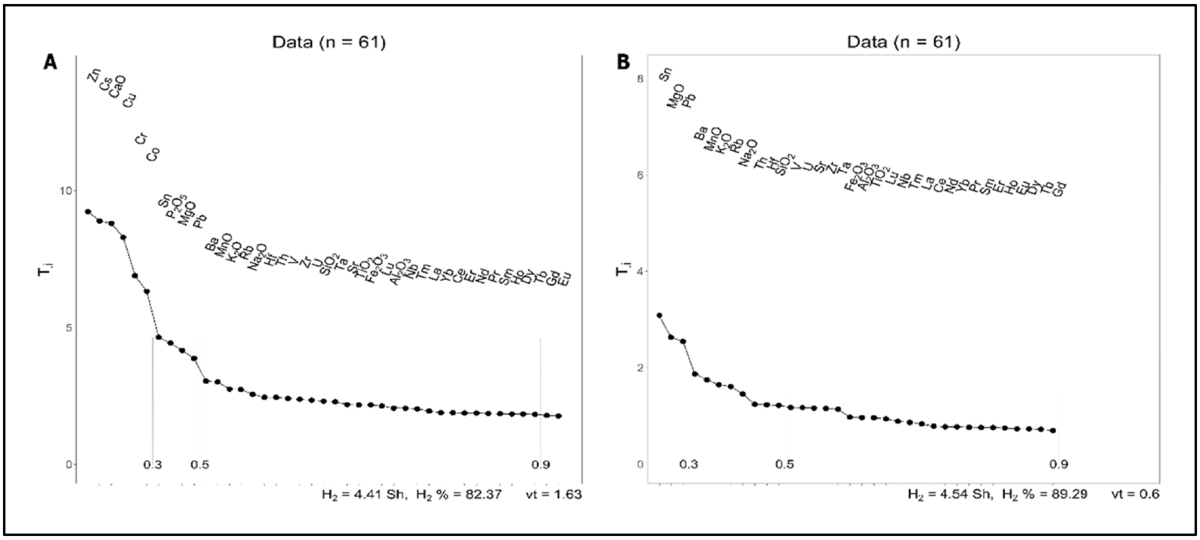

Fig. 7. Matrix variation graph of 61 samples. A) All the elements are used and vt 1.63 is obtained. B) Graph without CaO, P2O5, Zn, Cu, Cs, Cr, obtaining a vt 0.67.

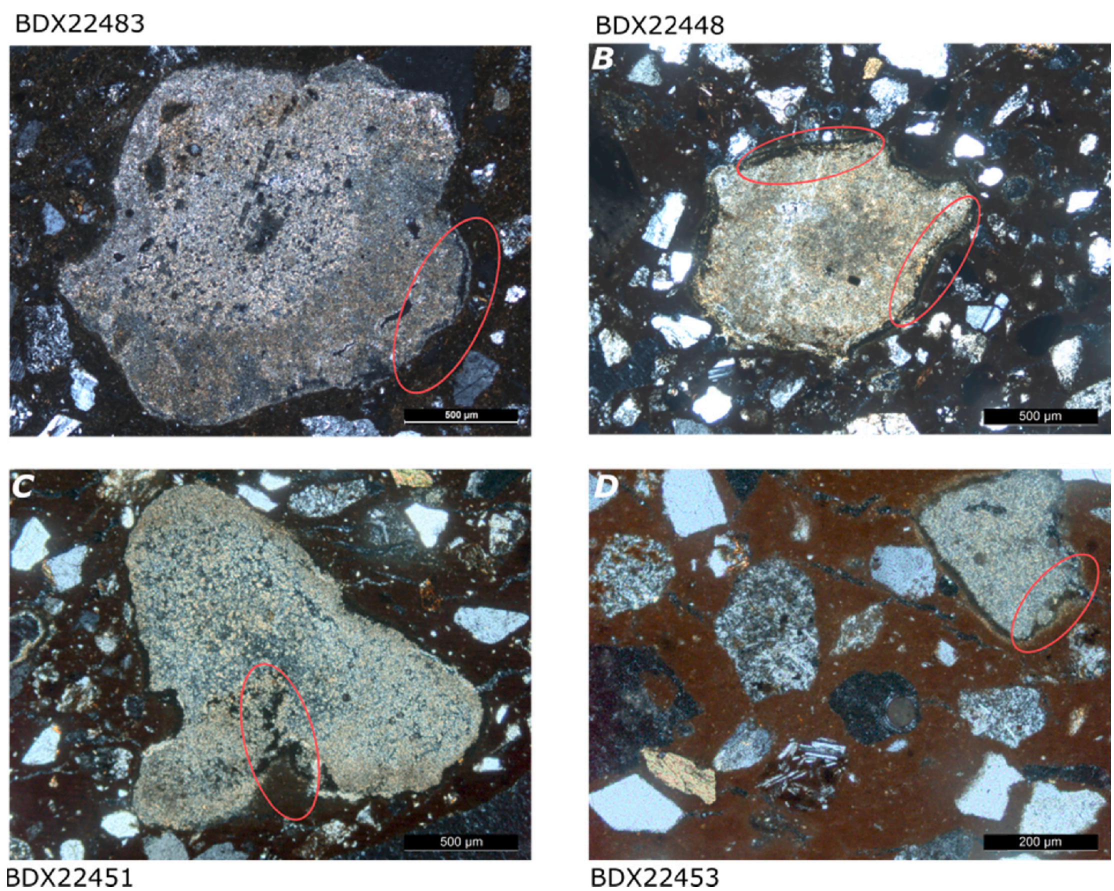

Fig. 8. Images showing the presence of secondary calcite that formed within the voids of the paste.

subgroup. The classification of these groups was made according to the types of inclusions, their size, distribution and percentage. Groups 1A, 1B, Group 3 and Group 4 (they can also be included, although they present some large inclusions), in general, present a homogeneous size of their inclusions (150–250 µm). The characteristics of the inclusions present in the pastes of these samples suggest that they are typical elements of raw materials from an alluvial deposit, in terms of their rounded or subrounded shape. This character indicates that these specimens have been heavily eroded as a consequence of having been transported a long distance. However, an additional element to consider is the technical aspect, which can be identified in the observations of the thin sections. Thus, we propose that the artisans would have crushed the clay lumps, sieving them, thus obtaining uniformity in the size of the non-plastic inclusions. This type of clay treatment practice is documented in different geographical areas such as India (Roux 2016) or the Andean area (Ramón, 1999, Druc 2011). Before using the clays, they go

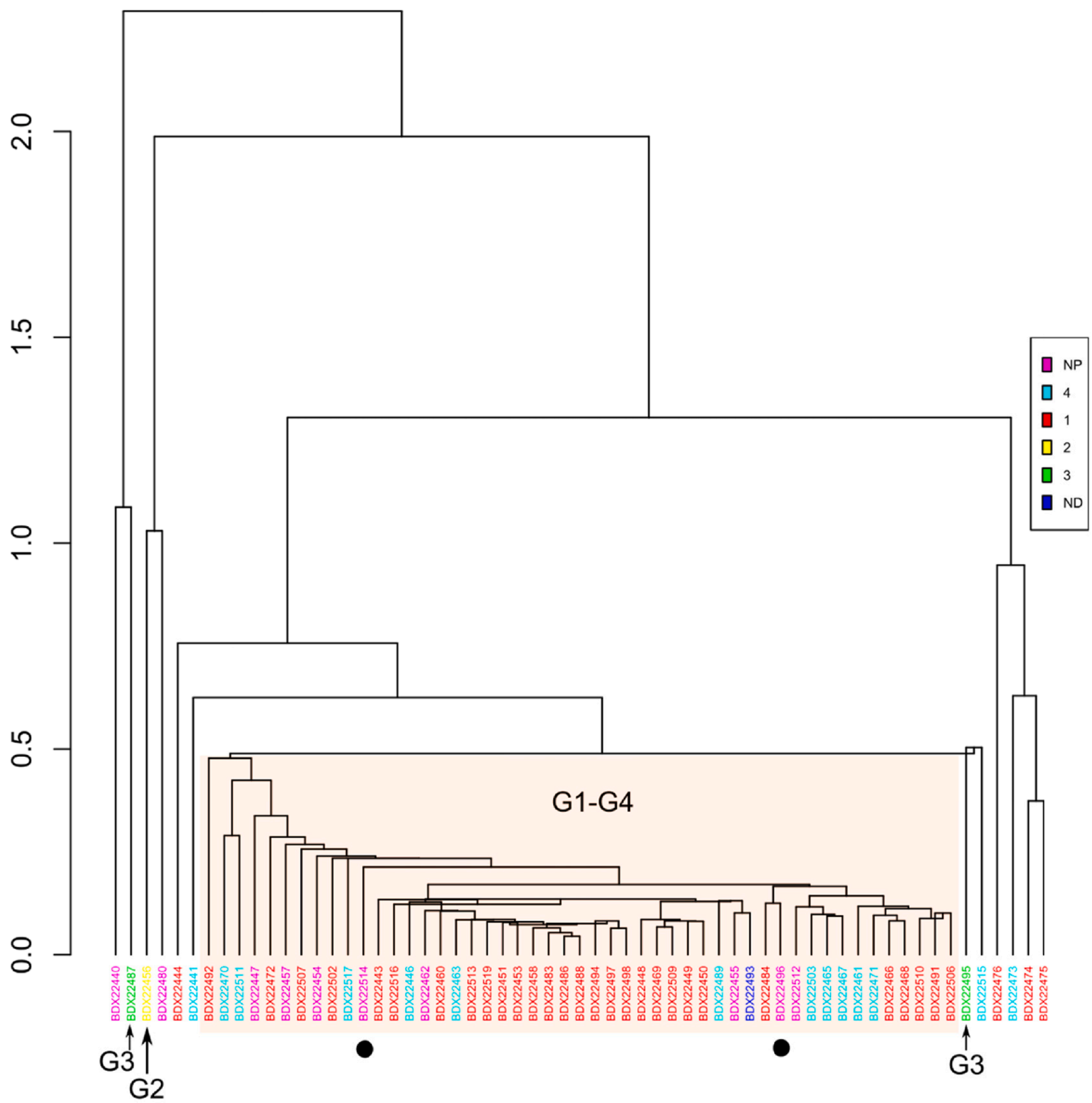

Fig. 9. Hierarchical Cluster showing the relationship of the individuals taking into account their belonging to the petrographic groups. Two subgroups can be distinguished at each. The black points correspond to the production wastes found at Armatambo. The acronym NP corresponds to samples that do not have prepared thin sections and the acronym ND corresponds to thin section samples that could not be determined to a petrographic group.

through a preparation stage, the artisan performs a dry triage of the clays or by mixing them with water, to remove unwanted constituents.

In the case of Group 2, it does not present a homogeneity in the granulometry, as observed in group 1, but presents a continuous granulometry, consisting of the presence of non-plastic inclusions of different sizes, ranging from 50 μm to 2 mm. These inclusions have an angular to sub-angular shape, which would be related to the type of raw material used in the production of these containers. They may come from a sedimentary deposit that has not undergone significant displacement and whose inclusions have not undergone a significant erosion process.

Considering the characteristics of the above-mentioned groups, we can demonstrate that one of the main differences between the petrographic groups is related to the types of sediment from which the clays would have been derived and/or to a technical aspect. From the shape of the inclusions, we can suggest that there is a difference in the types of deposits. Thus, Groups 1, 3, and 4 originate from an alluvial deposit, given the rounded to sub-rounded shape of the inclusions, a product of weathering and erosion due to long-distance transport. The technical aspect corresponds to the size of the inclusions which are very homogeneous, this would imply a treatment of the clay to eliminate the large inclusions (sieving) and not to add non-plastic inclusions.

In the case of Group 2, the sedimentary clay used has not undergone a significant process of erosion by movement. This type of deposit is identified in different areas of the Chillón valley and in the areas of the middle valley of the Rímac river, but not in the area of the alluvial fan of the Rímac river near the site of Armatambo. However, the continuous granulometry observed in this group could be the result of a different technical gesture than in the other groups. The artisans would have crushed the rocks, obtaining grains of variable sizes, which they would have used as tempering agents, which explains why we observe more angular or subangular inclusions in this group.

If we consider that the vessels were made with clays from two types of sedimentary deposits (alluvial and colluvial), and if we add the technical information corresponding to the treatment of the clays before the elaboration of the forms, we propose the existence of five fabrics within the ceramic corpus studied at Armatambo. These five fabrics could be linked to different production areas, the first in the vicinity of Armatambo, the second in the lower valley of the Chillón River and a

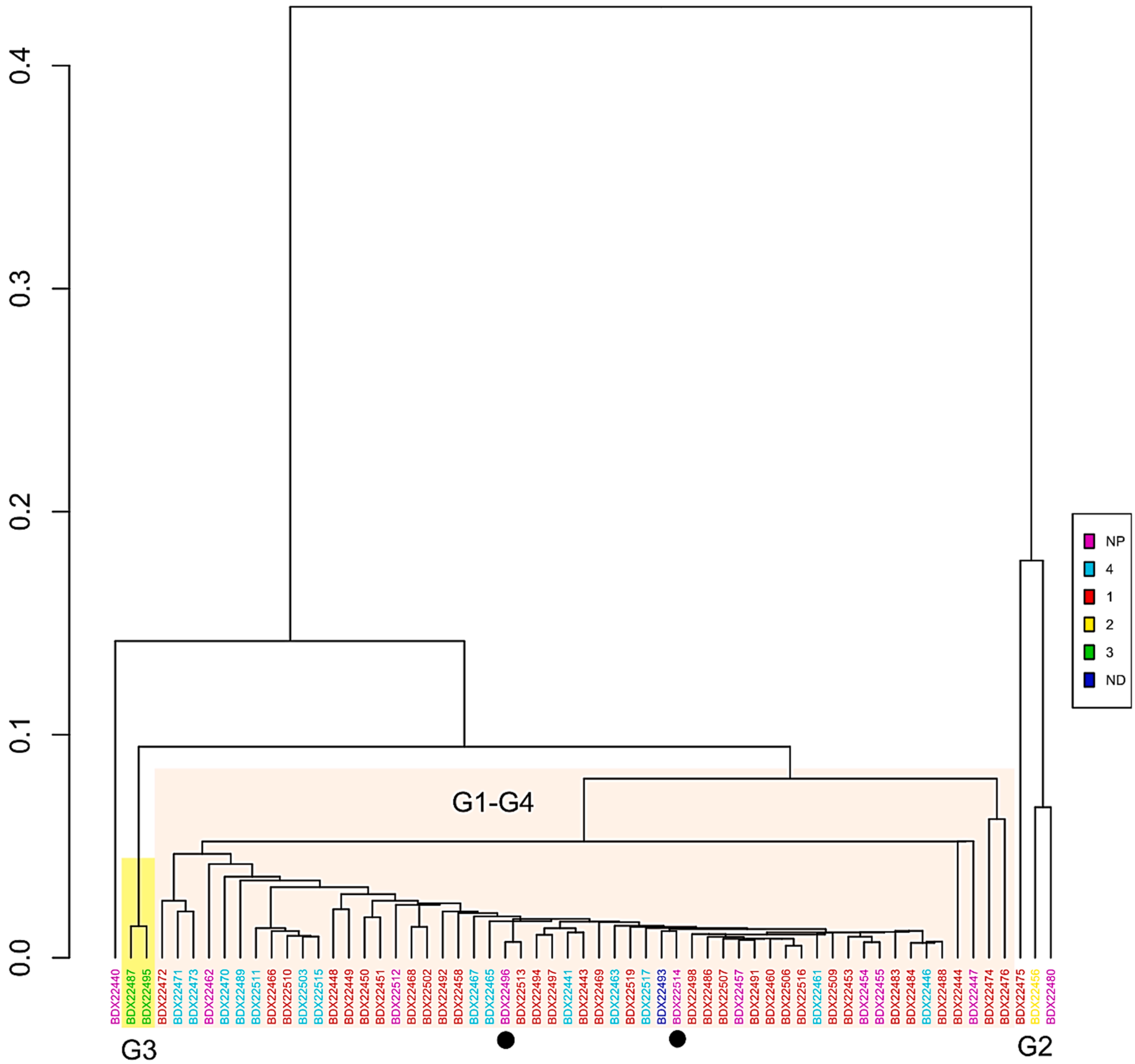

Fig. 10. Hierarchical cluster using the normalisation *N*-MORD values. List of elements used in normalization: La, Ce, Pr, Nd, Sm, Eu, Gd, Td, Dy, Ho, Er, Tm, Yb and Lu. The black points correspond to the production wastes found at Armatambo. The acronym NP corresponds to samples that do not have prepared thin sections and the acronym ND corresponds to thin section samples that could not be determined to a petrographic group.

third option in the Rímac valley. Archaeological evidence suggests the existence of pottery production in these areas.

It has been found that there is no direct relationship between the petrographic group and vessel type. It has been shown that, within a petrographic group, different types of vessels (pots or jars) can be found, and this practice was observed in samples from the Middle Ychsma and samples from the Late Ychsma. This shows that there is no exclusive recipe for one type of vessel.

The second part of our work corresponded to the chemical analysis, mainly by ICP-MS, and to the statistical treatment of the data obtained. First, hierarchical cluster analysis (HCA), shows that the individuals composing Group 2 (BDX22456) and Group 3 (BDX22487 and BDX22495) differ from the rest of the individuals. In the case of group 3 (BDX22487), the ICP-MS results show a marked difference in the content of MgO (3.2 %), CaO (5.39 %), Ti_2O (1.58 %) and Fe_2O_3 (10.33 %), which doubles the percentage of these elements for the rest of the individuals. In the same line, the use of basaltic normalization in the REE allowed refining the results of the first HCA. Thus, from the visual analysis of the normalized hierarchical cluster containing the ICP-MS and petrographic data (Fig. 10), we can posit the existence of a large group composed mainly of individuals classified as part of Group 1 and Group 4, while Group 2 and Group 3 show a lower degree of similarity and are located at the extremes of the cluster. This evidences a similarity between the petrographic results and the ICP-MS data.

In addition, in both HCAs, it can be observed that samples BDX22496 and BDX22514 (sherds that show the deformation that occurred during firing and are interpreted as a production residue) have a high relationship with the majority of the analyzed samples that make up the main cluster formed by Group 1 and Group 4. These two ceramics are used as examples of local production for comparison purposes. Although these samples correspond to the Late Ychsma phase, the ICP-MS results show that there is a high similarity between these two samples and the rest of the samples of this cluster, regardless of their chronological affiliation, both Middle Ychsma and Late Ychsma. This suggests to us that the raw material used during these two periods would not have changed and would have been used regardless of the processing method. In addition, the ICP-MS results show that different sedimentary clays would not have been used in the elaboration of the different vessel forms, both in the Middle Ychsma and Late Ychsma of Armatambo.

The ICP-MS results confirm what had been defined with the petrographic groups, the non-existence of an exclusive recipe for a type of vessel, in which a workshop does not produce an exclusive type of vessel, but could produce different forms with the same recipe. This is a constant in the Middle Ychsma and Late Ychsma for the site of Armatambo. From this, we can also deduce the existence of local production at the Armatambo site.

From our initial results compared with the geological and archaeological data, we can propose as a hypothesis three raw material supply zones (Fig. 11). The first supply zone is located adjacent to the Armatambo site, corresponding to the Morro Solar geological group and the Lima Group (Léon & De la Cruz 2003; Aleman et al. 2006), which corresponds to an alluvial deposit. The second zone, potentially corresponding to Group 2, is located on the left bank of the Chillón River about 28 km north of Armatambo, and is characterized by magmatic rock formations (diorites and granodiorites) and colluvial deposits. In addition, the archaeological record of this area indicates the presence of two sites considered to be centers of pottery production. While the site of Armatambo presents evidence of ceramic production (Díaz and Vallejo 2002), the second area identified in the map (Fig. 11) presents two sites with clear material evidence, which allow us to identify them as ceramic production centers during the Late Intermediate and Late Horizon periods. The first of these centers is Huaca Naranjal (Maquera 2008), located on the left bank of the Chillón River. This site has an occupation from the Middle Ychsma phase to the Late Ychsma phase and numerous remains of debris, tools and raw materials were found in the surrounding area. The second site, Huaca Aznapuiquio, is located 2.5 km south of Huaca Naranjal. This archaeological site is considered to be a ceramic production center during the Late Horizon, when the Inca Empire already controlled this region, for this reason, it is proposed that this site was built during the Inca administration to produce Ychsma style ceramics (Espinoza et al. 2008). These examples show the importance of this area in the production of ceramics during the Ychsma period. The third zone corresponds to the middle valley of the Rímac River. A study conducted on clay samples from this zone and 101 Ychsma ceramic samples from the Pachacamac site (Oré 2013), analyzed by LA-ICP-MS, showed a correlation between a group of ceramic and clay specimens. Thus, this is important data that allows us to consider that the clay deposits in this area were exploited for the production of Ychsma ceramics. It should be noted that magmatic rock formations such as diorites and granodiorites can be identified in this area, as well as colluvial deposits. A weakness of this area is that there is no evidence of nearby production centers associated with the Late Intermediate or Late Horizon periods.

7. Conclusions

The study of the ceramic material from Armatambo allowed us to identify-four petrographic groups and one subgroup. With this information, along with the ICP-MS data, we can propose, as a hypothesis, the existence of three areas of raw material supply and two areas of production. The first is in the area associated with the site of Armatambo. The second zone we propose is the area of the lower valley of the Chillon River, where the archaeological sites of Huaca Naranjal and Huaca Aznapuquio are located. The archaeologists' proposal for these sites is that they are ceramic production centers that would have been in operation during the Middle Ychsma and Late Ychsma. These proposals are based on the material evidence found in these sites that correspond to tools, molds, and waste, which are materials associated with ceramic production. The third possible zone, proposed based on archaeological data, would be located in the middle valley of the Rimac River.

For Armatambo, the results of our analysis indicate that there were no changes in the raw materials during the Middle Ychsma and Late Ychsma periods. The petrographic and chemical data show that most of the different vessels were made with the same type of clay. Additionally, we can propose that there was ceramic production at the site of Armatambo. This proposition is based on the results of the analysis of the samples considered as production waste corresponding to the Middle

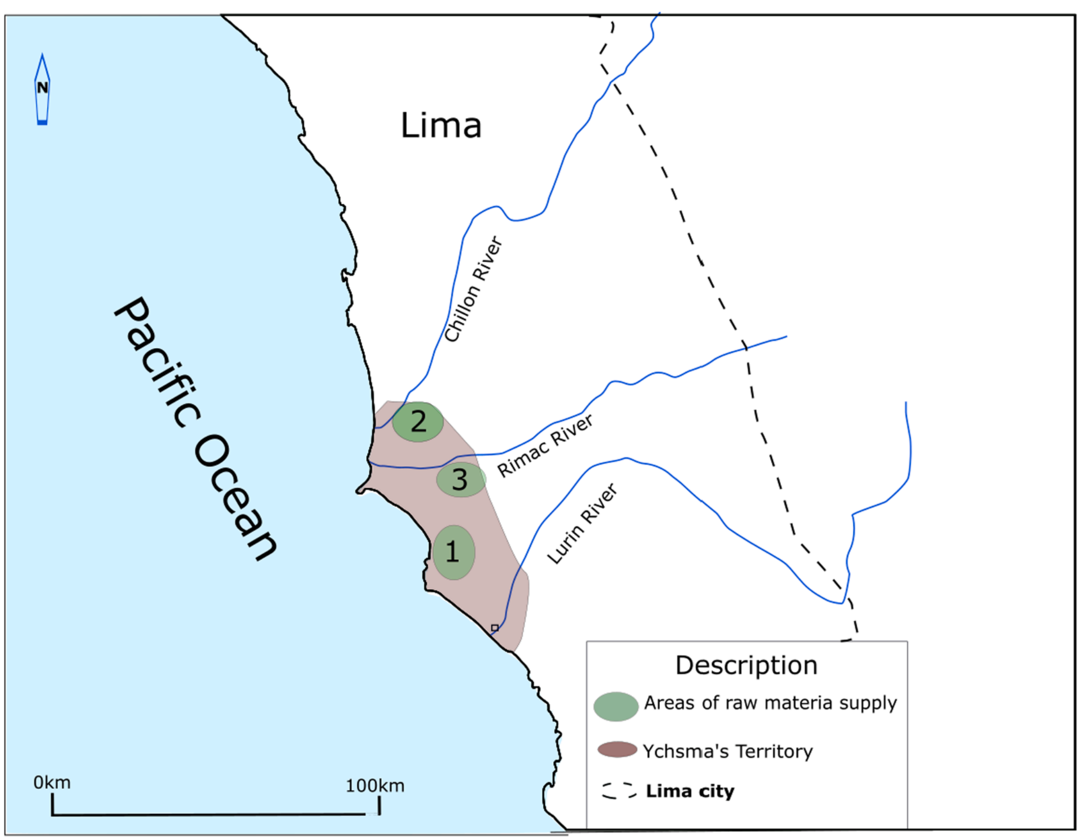

Fig. 11. Map showing the three possible areas of the provenance of the raw materials used in the production of potteries.

Ychsma, which showed a high relationship with most of the samples analysed, corresponding to both the Middle Ychsma and Late Ychsma. Local production is also supported by archaeological evidence of tools and burning areas found in Armatambo (Díaz and Vallejo 2002).

These results show us the importance of knowing the location of the raw material exploitation zones and defining the location of the pottery production centers to understand the type of social and economic relationships between the different sites on the central Peruvian coast during the Late Intermediate to Late Horizon. In this sense, the study of the ceramic materials from Armatambo is an excellent example, given the importance of this site, the capital of a lordship, which would not have had enough and would have required vessels from other production centers; this material could have come from neighbouring areas, such as the lower valley of the Chillón River. This is a possibility that will have to be corroborated with new analyses of the geological material from these areas and samples from these archaeological sites.

It is important to mention that, unfortunately, there is a scarcity of studies on this region that address studies of raw material provenance and possible contacts between sites in different valleys. Therefore, our work aims to provide a solid basis for future archaeological and archaeometric studies in the region.

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CRediT authorship contribution statement

Dante Pareja: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Javier Iñañez:** Formal analysis, Funding acquisition, Data curation, Resources, Supervision, Validation, Investigation, Methodology, Writing – review & editing. **Ayed Ben Amara:** Validation, Writing – review & editing. **Luisa Díaz:** Validation, Writing – review & editing. **Gorka Arana:** Data curation. **Rémy Chapoulie:** Supervision, Funding acquisition, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103772.

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