LA-ICP-MS and petrography to assess ceramic interaction networks and production patterns in Kuntur Wasi, Peru

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1. Introduction

This article presents the final results of a four-year analysis program of the ceramics from the Formative ceremonial center of Kuntur Wasi (950–50 cal. BCE) in the Department of Cajamarca, in the northern Peruvian highlands. The analysis included low-power digital microscopy, petrography and X-ray diffraction (XRD), and culminated with 128 samples subjected to laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Our objectives were four: 1. Assess the organization of ceramic production at the local level; 2. Identify the nonlocal wares; 3. Delineate the axes of interaction; and 4. Pattern cultural variation as seen from ceramic distribution. These last two objectives tie into the problem of coast-highland relationships, circulation of goods and ideas (or styles), and population movement. This inquiry was prompted by the important stylistic and architectural changes observed at the beginning of the second building phase of Kuntur Wasi, interpreted as the manifestation of the intrusion of a group from another area, possibly coastal (Onuki and Inokuchi, 2011; Onuki et al., 1995). Would these changes be reflected in the composition of the ceramics? What kind of ceramics moved? How far? How many? Which are the routes of circulation? Do we have different interaction networks? The results of compositional analysis were examined with these questions in mind.

We will first present the archaeological context, style and mineral composition of the ceramics, and regional geology before detailing the LA-ICP-MS methodology, statistical analysis, and final results. A first level of data interpretation combines the chemical results with the mineralogical data. The corpus is then examined at the macro level with discriminant analysis, considering the provenance, style, and archaeological phases to reach a better understanding of the site development and its interactions with neighbouring regions during the Formative period.

Note that LA-ICP-MS provides selective compositional information on the area where the laser is positioned, in our case the clay body. Petrography gives an account of the mineral composition, size and distribution of the non-clay inclusions in the ceramic body and yields information on production practices and technology. The two techniques complement each other and, when combined with stylistic and archaeological data, are powerful means to address provenance, production strategies, interregional interactions, and socio-cultural
changes. This is based upon the fact that the overall composition of a ceramic is related to the geology of the area, aka the type of material used, as well as the ceramic practices of the ancient potters when preparing and firing their wares.

1.1. Archaeological context and ceramic styles

Kuntur Wasi is located at 2300 m asl in the northern highlands of the Cajamarca Department, Peru (Fig. 1). The Japanese Kuntur Wasi Archaeological Project excavated the site from 1988 to 2002, and again in 2012 and 2013. The site is contemporaneous in part with the famous ceremonial site of Chavin de Huantar some 330 km to the south and in part with the site of Pacopampa 90 km to the north, Huacaloma in the Cajamarca basin 40 km east, and with the site of Las Huacas in the Middle Jequetepeque Valley 45 km west.

Four archaeological phases were identified: Idolo (ID; 950–800 cal. BCE), Kuntur Wasi (KW: 800–550 cal. BCE including the Sangal Complex), Copa (CP: 550–250 cal. BCE) and Sotera (ST; 250–50 cal. BCE), corresponding to nine architectural subphases (Inokuchi, 2010; Onuki and Inokuchi, 2011; Onuki et al., 1995). The Kuntur Wasi phase marked a shift in architecture, with a new large-scale architectural complex, stone monoliths, water canals, special burials, and stylistic changes in the ceramic repertoire (Inokuchi, 2010, 2014; Onuki et al., 1995). The following Copa phase witnessed an intensification of building activity and an augmentation of people who participated in the activities related to the temple. During the final architectural subphase of the Copa phase the major part of the ceremonial architecture was abandoned, and during the Sotera phase Kuntur Wasi ceased to function as a ceremonial center. At the regional level, this last phase marks the end of the Formative Period and beginning of new polities and interaction networks.

The changes observed in Kuntur Wasi are reflected in the ceramics, in terms of their style, production and distribution patterns. 61 ceramic types were recognized (Inokuchi, 2010): 16 types from the Idolo phase, 25 types from the Kuntur Wasi phase (with 8 types belonging to the “Sangal Complex”), 14 types from the Copa phase and 6 types from the Sotera phase (Inokuchi, 2010). During the Idolo phase, the styles of ceramics show similarities with other contemporary sites of the northern highlands such as the Cajamarca Basin (e.g. Huacaloma) and the Pacopampa area. Within the Kuntur Wasi phase, two broad ceramic categories were identified: a) ceramics displaying strong coastal stylistic influences (KW-KW ceramics), and b) ceramics with local characteristics in terms of style and paste, forming the Sangal Complex (KW-SG ceramics) which appeared sometime during the Kuntur Wasi phase. The KW-KW fine ceramics represent wares with highly polished surfaces, a very compact paste, and graphite decorated vessels. The KW-KW stirrup-spout bottles bear similarities in forms and decorations with Cupisnique ceramics. The Copa phase ceramics display a local style, standardized forms and decorations. In the last phase, the Sotera phase, ceramics are again influenced by the Cajamarca basin (e.g. Layzón site).

The ceramics analyzed (Fig. 2) were chosen on the basis of style, form and paste characteristics as seen in low-power digital microscope to be representative of the ceramics found in Kuntur Wasi. Here, it is important to stress the difference between stylistic influence and provenance based on compositional grounds. Stylistically nonlocal ceramics are not necessarily nonlocal productions and we try to make that distinction in the text. This is a major point in particular for the question of coast to highland interaction or population movement. The impact of contacts or interregional relationships cannot be judged solely on the amount and type of objects circulating, and the ability to copy or adapt certain stylistic traits by the potters at any point of the distribution network should not be underestimated. The Middle Jequetepeque Valley, is in the chaupiyunga ecological zone, an Andean region between the Pacific coast and the highland, from about 600 m to 2000 m elevations, dry and with low population density (see Santoro et al., 2010 for a discussion about this zone as a geographical ethnocategory). It is a transit corridor that could well have hosted populations with coastal or highland allegiances, each producing ceramics accordingly. Thus, a vessel showing a coastal style could have been produced in the Middle Jequetepeque Valley and transited up to Kuntur Wasi, some 50 km away, a two day’s walk. New research focusing on sites in the chaupiyunga are revealing a much more complex picture of settlement and interactions than thought before (Tsai, 2016). These studies deal with the period just following Kuntur Wasi’s demise. However, Yoshio Onuki (1985) had already pointed to the importance of this zone for the Formative Period.

1.2. Summary of prior ceramic petrographic studies, and correspondence to chemical data

As the results of the petrographic study have been presented elsewhere (Druc et al., 2013, 2016; Druc and Inokuchi, 2016; Inokuchi et al., 2014), we will only summarize them here. Note that the resolution power of a petrographic microscope, which operates in transmitted light, allows identifying the inclusions that are larger than the clay minerals. It helps assess the work of the potter looking at granulometry, grain distribution, porosity, type of material (mineral or organic) present. Based on these observations, the Kuntur Wasi ceramics were classified into five groups, subgroups, and atypical cases. A comparison with local geology and sampled clays, sediments and modern ceramics allowed determining the local or foreign character of the archaeological ceramics. For Kuntur Wasi, Petrogroup A is characterized by volcanic pyroclastic components, with pumice, quartz, plagioclase and biotite. This is the typical local temper, in the past as in the present, mined from pyroclastic deposits found in the nearby Cuscuden Mountain, 8 km north of the site. Petrogroup B stands out for the presence of medium to coarse intermediate intrusive rock fragments in the ceramic paste. It is indicative

Fig. 1. Location of Kuntur Wasi and area of study. Original map drawn by Kinya Inokuchi, Eisei Tsurumi and Yuko Ito, modified with permission to show the main sites mentioned in the text.
of a nonlocal provenance as this material is not found in the vicinity of Kuntur Wasi. Petrogroup C is characterized by nonlocal volcanic inclusions, Petrogroup D represents ceramics with inclusions of mix compositions, volcano-sedimentary in majority, which could derive from the use of quaternary sand deposits. Ceramics in Petrogroup E display subvolcanic material with fragments of plagioclase as monocrystals or in aggregates derived from porphyritic andesite, some quartz and mafic minerals (mostly pyroxene). A subvolcanic deposit with similar composition was found less than 5 km from the archaeological site.

One note should be introduced concerning our definition of local and nonlocal. Based on petrographic analysis and ethnographic study we propose a local production sphere of 8 km around the archaeological site, be it for the production place(s) or material acquisition. This choice rests upon the similarity of the pyroclastic temper seen in many Kuntur Wasi site ceramics (Petrogroup A) and the pyroclastic material used by the actual local potters of Mangallpa who mine their temper from Cerro Cuscuden on the flank of which their village is located, 8 km north of the archaeological site. Geological survey failed so far to find a similar
pyroclastic pumice-rich source closer to the archaeological site. Other tempers (Petrogroup E and part of Petrogroup D) seen in the archaeological ceramics could also be called local based on geological survey around the site. The nonlocal compositions (Petrogroups B, C, and some Petrogroup D ceramics), however, do not show mineral correspondence with the geology around Kuntur Wasi. These are typically ceramics tempered with intrusive material (e.g. granodiorite fragments and derived minerals) with outcrops in the Jequetepeque Valley or ceramics showing a range of composition not locally found, like the hornblende- and plagioclase-rich pastes seen in the Cajamarca Basin. Based on petrographic, geological and ethnographic observations for the region, we also believe that most ceramics were produced with two materials (a clay base and the addition of a tempering material).

It is also important to understand that the petrogroups group ceramics with similar non-plastic inclusions, granulometry and paste texture, while the chemical groups derived from LA-ICP-MS are based upon similar chemical clay matrix composition. It is therefore possible to have in the same petrogroup, ceramics pertaining to different chemical groups: their tempering material is similar but different clays have been used. Inversely, there can be ceramics with different tempers in the same clay chemical group. When both coincide, we can propose that only one material was used or that a similar clay base and similar temper were mixed. This is the case for the potteries or community(ies) responsible for the production of the volcanic-tempered wares found in Kuntur Wasi.

We now turn to the LA-ICP-MS analysis to explore the compositional variability revealed by petrography, and address provenance and interaction networks. We present first the samples and methodology used, then detail the statistical analysis of the chemical data.

2. Materials and methods

LA-ICP-MS has been chosen for its ability to analyze many major, minor and trace elements with a high sensitivity, minimum sample preparation and deterioration (quasi invisible to the eye), low cost as compared with neutron activation, and to obtain data on the clay matrix. The information provided complements the petrographic data. The analysis focused on the clay matrix of 128 archaeological ceramics, clays and ethnographic samples from different areas around the site, the Cajamarca basin, and the Jequetepeque Valley (Table 1). In addition, four archaeological ceramic fragments came from the site of Las Huacas in the Middle Jequetepeque, excavated by Dr. Eisei Tsurumi (2010). These samples are from the Tembladera phase (1250–800 BCE), which overlaps with the Idolo phase of the Kuntur Wasi site (Table 1). The ceramic fragments were analyzed without prior preparation to the laser ablation. The clay samples were mixed with ultra-pure water to form pellets or discs and were fired between 800 and 900 degrees C in an electric kiln. Petrography, low power microscopy, and X-ray diffraction provided information on the mineral composition of these samples for cross-data interpretation (Druc et al., 2013, 2016; Inokuchi et al., 2014).

The analysis was conducted at the Elemental Analysis Facility (EAF) at the Field Museum of Natural History in Chicago. The methodology followed by the EAF laboratory has been described elsewhere in detail (Dussubieux et al., 2007; Sharratt et al., 2009). The instrument used is a Analytik Jena quadrupole mass spectrometer coupled to a New Wave UP213 laser, which ablates the sample. To address ceramic heterogeneity, 10 spots are ablated per sample with a laser diameter of 100 μm (0.1 mm). For comparison, for glass, a homogeneous material, only four ablations are performed with a laser diameter of 55 μm. This insures that a relatively large volume of representative material is sampled. The analysis focuses on the clay, which can naturally contain silt and very fine grains, and the targeted area is chosen to avoid larger inclusions. A CCD (a charge coupled device image sensor) camera attached to the laser allows for the inspection of the surface of the sample and the selection of an area free of heterogeneity (or temper grains). When it is possible, ablations are performed on a freshly cut surface as far away as possible from the external surface of the artifact as in some cases surface contamination can occur (Golitko et al., 2012). Additionally, signal acquisition begins after a 20s pre-ablation period to avoid surface contamination as much as possible. The composition of the ceramic is calculated from the average of the ten measurements carried out on each sample after elimination of any “abnormal” measurements, resulting in RSDs above approximately 20%, that could result from the ablation of temper grains or from any other heterogeneity in the ceramic fabric under the sample surface. The 29Si isotope was used for internal standardization. Concentrations for major elements, including silica, were calculated assuming that the sum of their concentrations in weight percent in glass is equal to 100% (Gratuze, 1999).

Two different materials with known concentrations also called standard reference materials (SRM) were used to calculate the concentrations of major, minor and trace elements. SRM NIST 679 and 610 are used for the calculation of the major and the minor elements whereas, only NIST 610 was used for the calculation of trace element concentrations. NIST 610 is a soda-lime-silica glass doped with trace elements in the range of 400 to 500 ppm. Certified values are available for a very limited number of elements. Concentrations from Pearce et al. (1997) were used for the other elements. For more details on the validity of this approach, see Dussubieux et al. (2007). For the Kuntur Wasi site samples, seven elements presented a very large relative standard deviation due to the fact, for some of the elements at least, that they were present close to or below the detection limits: Cl, Se, As, Ag, In, Ba, Au. They have been eliminated from the data for statistical analysis. Na was not detected for clay sample SG30–2. In order to keep that sample and element for the analysis, a very low Na value was given to replace the missing value (lowest Na value found in the data divided by 10). This proved to be a good alternative, as analysis without Na or with the mean Na value to replace the missing value did not give meaningful groupings and lowered the explained variance.

Fifty chemical elements (major, minor and traces) were retained for statistical analysis conducted with the program SPSS. All elements were transformed to base 10 logarithms to address the unequal variances between major and trace elements. The use of Z scores from the standard deviation transformation showed slightly lower percentage of total variance explained and was not chosen for analysis. The amount of explained variance with principal component analysis (PCA) on log transformed data was 58.6% for the first two factors, 66.9% first three and 89% for the first nine factors as opposed to 58.2%, 65.9% and 85.7% with standard data.

Statistical analysis included looking at elemental distributions, and conducting a PCA, hierarchical cluster analysis (HCA), and discriminant analysis (DA) using the first nine PCs and Mahalanobis distances to evaluate group membership probabilities (see Neff, 2002: 26–27, 34–35).

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**Table 1**

Summary of samples analyzed for LA-ICP-MS analysis (see Supplementary Table 3 for a list of samples with petrographic, archaeological and stylistic data).

<table>
<thead>
<tr>
<th>Samples</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuntur Wasi site ceramic fragments</td>
<td>95</td>
</tr>
<tr>
<td>Idolo (ID) phase ceramic fragments</td>
<td>19</td>
</tr>
<tr>
<td>Kuntur Wasi phase (KW)</td>
<td></td>
</tr>
<tr>
<td>KW-KW ceramics</td>
<td>26</td>
</tr>
<tr>
<td>KW-SG ceramics (Sangal Complex)</td>
<td>9</td>
</tr>
<tr>
<td>Copa (CP) phase ceramic fragments</td>
<td>26</td>
</tr>
<tr>
<td>Soteria (ST) phase ceramic fragments</td>
<td>15</td>
</tr>
<tr>
<td>Mangallpa-Jangala (MA, MM, JA) area comparative ethnographic ceramics and soil samples</td>
<td>7</td>
</tr>
<tr>
<td>San Pablo (SP)-Sangal area (SGa) comparative soil/clay samples</td>
<td>4</td>
</tr>
<tr>
<td>Cajamarca (CA) comparative ethnographic ceramics, temper, and clay samples</td>
<td>6</td>
</tr>
<tr>
<td>Middle jequetepeque (MTJ) comparative sand/clay and ceramic samples</td>
<td>16</td>
</tr>
</tbody>
</table>
Discriminant analysis was performed looking at different grouping variables and several rounds of analysis were conducted to obtain more robust groups. Due to the diversity of samples and mineral compositions, chemical compositions were expected to vary greatly. While PCA allowed us to examine the variability in our corpus and the variables (chemical elements) that contributed most to this variability, the HCA grouped the samples by chemical similarities, and DA evaluated how well a sample fitted a group based on the chemical dissimilarities between groups and statistical distance of that sample to the group's centroid in statistical space. The original groups were predetermined and the program calculated group membership probabilities and predicted group assignments.

3. Results

3.1. Statistical analysis results

In the following sections, the results of the different statistical analyses performed are detailed. The highest level of information was extracted from the final two sets of discriminant analyses yielding increasingly refined predictive models. However, all analyses presented important steps in the decision-making process and information that led to the final data interpretation. The consistent marginalization of certain clay samples in the first round of analyses prompted their elimination. This provided better groupings of samples for further analysis. Although tight compositional matches are not expected between fired clay samples and the ceramic clay matrix due to the production process, we considered that fired clays found in a cluster with ceramics indicated similar composition. When clay samples are outliers, this should not be understood as an incompatibility to compare raw materials and ceramics, but to compositions differing significantly from the other samples. This indicates that none would have been used to produce any of the ceramics analyzed. This was the case for Cajamarca clays CA13, CA5 from Shudal and Aylambo mines respectively and for MTJ3, a hillside coarse clay collected on the left side of the Middle Jequetepeque Valley at Pampa de Yatahual. The Cajamarca samples that better compared to the rest of the ceramic group were ceramic fragments and one sandy-clay from traditional production. Results were explored looking at scatter plots of the first two principal components, HCA, and DA membership probabilities. They are detailed below.

3.1.1. Principal components analysis

The PCA analysis was performed on the covariance matrix with varimax rotation, then with unrotated factor solution, to similar results. Eigenvalues, factor scores were saved in a coefficient matrix. The first two principal components explain 58.6% of the variance in the data. The first nine components explain 89% of the data. According to the components' matrix, factor 1 (40.77% of variance explained) is heavily determined by Sn, La, Ce, Pr, Y, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu (all above 0.800 and above 0.870 for the elements in bold). Most of them are trace elements from the lanthanide series. Tin (Sn) is usually part of the oxide cassiterite (SnO₂) frequently found in aluminous rocks. The lanthanides are often present together in nature, oxidizing quickly when exposed to air, and frequently found in clays. Factor 2 (17.70% of variance explained) is influenced by Si, Mg, P, K, Mn, Fe, Ti, Li, Be, Sc, V, Co, Cu, Rb, Nb, Cs, Ta, Un, Eu, Th. The seven first elements are major and minor elements. Fig. 3 presents the scatter plot of the first two regression factors of the principal components analysis.

The corpus analyzed is not homogeneous in terms of find location, style, and mineral composition, and a diversity of clay compositions was expected. It is no surprise that no clear groups are seen in the PCA scatter plots of the first two regression factors (Fig. 3). Nevertheless, the graph shows a distribution separating most of the Copa phase ceramics from the remaining Kuntur Wasi site ceramics (grouping variable 3 represented by ‘x’ in Fig. 3). These Copa ceramics are tempered with subvolcanic material (Petrogroup E) different from the other temperused. The clustering of these ceramics indicates that not only the temper but also the clay base for these Copa vessels is different from the other ceramics at the site. This reinforces the impression of a homogeneous production area and tradition. This Copa group includes the two clays MA22 and MM14b from Mangallpa, which confirms the local production of this group. Idolo and Kuntur Wasi (KW-KW) ceramics form another cluster, less well defined than the Copa group, indicating more variability or diversity in raw materials. They are also produced with a different temper than the Copa-group ceramics.

The modern Mangallpa samples are found close to a group of ceramics from the Kuntur Wasi site with pyroclastic material in their paste, indicative of a local production. However, the Jequetepeque comparative samples cluster with ceramics from the Idolo and Kuntur Wasi phases of the Kuntur Wasi site. This is the case of a white and red bottle from Las Huacas, two Rojo Grafitado bottles from the Kuntur Wasi site (KW176p and KW179p), fine grey bottle KW44, Rojo Fino bottle KW161p, and the beige bowl KW171p. Due to the intrusive-rich mineral composition of these ceramics, this group could be linked to the Middle Jequetepeque Valley where sands with such mineral compositions are found. Six ceramics from the Kuntur Wasi site are outliers and do not cluster together. They are from different archaeological phases but share a similar volcanic temper composition. The lack of homogeneity in their clay composition suggests the exploitation of discrete small clay deposits.

3.1.2. Hierarchical cluster analysis

Hierarchical cluster analysis was performed using the Ward’s method of linkage and squared Euclidian distances. A first HCA was conducted using the chemical elements as variables and a second using the first nine PCA components (Fig. 4). The results were fairly similar, although...
the samples were not grouped in the same order. The analysis shows a
good discrimination between groups. Several clusters correlate to
the mineral composition of the samples, as is the case for the Copa
subvolcanic-temper group, for example, or to the local or nonlocal char-
acter of the vessels, with the Cajamarca, Kuntur Wasi region, and Middle
Jequetepeque samples clustering separately. Stray ceramics or compar-
ative materials found in these groups (like Kuntur Wasi vessels group-
ing with samples from the Cajamarca or Middle Jequetepeque
regions) are considered originating from these regions.

3.1.3. Discriminant analysis

Discriminant analysis (DA) was performed with 124 samples using
the first nine principal components of the PCA, a procedure mentioned
in Neff (2002: 35). The analytical parameters included 1) within-groups
covariance matrix, 2) Fisher’s coefficient, 3) stepwise method, and 4)
Mahalanobis distances. All groups were considered equal. A mix of
two grouping variables were used: 1. Location or archaeological
phase; 2. Mineral composition based on petrographic and low-power
microscope analyses. In DA, the samples with a low percentage of
group membership probability show as unassigned or are reassigned to a group for which they present a higher membership’s probability. We evaluated this reassignment when the probability of membership to a group was below 5%. The mineral composition of the sample was examined and the proposed attribution was accepted or rejected. Then, following a procedure used by Mary Ownby (Desert Archaeology Inc., personal communication), another DA was performed based on the new group assignments. This process was conducted three times. The results were then interpreted. It allowed us to highlight some particularities or trends in ceramic distribution. Note that the p values here and in Table 3 (see Supplementary Data) express the probabilities of group membership (p). The higher the p value, the higher the probability of a sample to pertain to a given group.

As noted in other statistics, the ceramic samples from the Copa phase show the highest homogeneity. For this group, a 75% membership probability was considered the cut off for group attribution. Samples with lower probability of membership were unassigned or reassigned. For the other groups, 70% was the cut off. In the last DA round, the samples were assigned to the groups with highest probability as follows: 75% for the Copa group or 70% and above for the other samples are considered high membership probability; between 50% and 74.99% or 69.99% are low membership probabilities but still pertaining to the assigned group; samples with less than 50% probability were reassigned to the group with 2nd highest probability membership. Probability of group membership was also evaluated in reference to mineral, stylistic and archaeological data. This procedure help refine group constitution. When using ‘mineral composition’ as grouping variable, the membership probabilities of belonging to the predicted volcanic or subvolcanic groups could be better assessed. We know that the target of the two analyses - chemical and mineral - is different, but also complement each other. We posit that if mineral similarities are seen among samples, it is probable that some chemical homogeneity for the clay matrix will be recognized too. This reasoning is based upon the fact that a community of potters working with the same temper often also mine the same clay resources within the same region, as is the case for the Mangallpa potters (Druc, 2011). This does not mean that the clay and temper sources are the same but that the same community of practice is involved. Poor membership probabilities or unassigned samples indicate that several different clays were used to produce ceramics with similar temper. When using “location” as grouping variable, such as Cajamarca, Middle Jequetepeque, Las Huacas, failure to assign the chemical samples to these predicted groups and attributing them to another group indicate that the samples’ clay matrix compares better to ceramics from other locations. Vessel circulation is then an issue to examine.

In summary, the LA-ICP-MS analysis of the archaeological and comparative samples highlights the presence of several compositional groups. The Idolo phase samples cluster in a very loose group with many outliers, attesting to an important variability in chemical composition of the clay matrix. This suggests the use of a variety of clay sources and the existence of several production areas and or providers. The volcanic-tempered ceramics found in Kuntur Wasi, whatever the archaeological phase, however, cluster together (DA1), suggesting the continued use of the same clay and temper types, and a local technological tradition, based on comparison with geological and ethnographic samples. Another loose chemical group (DA2) is constituted of early ceramics (Idolo and KW-KW phases) with igneous acid to intermediate intrusive mineral compositions. This type of composition points to a mid coastal valley origin where intrusive bodies are found, but the compositional variability of the ceramics calls for multiple providers. The KW-SG ceramics of the Kuntur Wasi phase and Sotera phase samples are spread out in the statistical space pointig to various producers and sources used. The most compact group is represented by several Copa phase ceramics (DA3), which also happen to be tempered with the same type of material (subvolcanic temper). The latter seems to have been mined from an outcrop close San Pedro, less than 4 km from the archaeological site. Copa vessels with this recipe and a control of granulometry were produced in high quantity and it is highly possible that at this time a community of potters was established close to the Kuntur Wasi site. The few non-Copa ceramics in this DA3 group suggest that the use of this clay resource area was known before its intensive exploitation by the Copa potters and also used after, at a much less intensive scale.

The characteristics of the nine main compositional groups obtained through the last round of discriminant analysis and details regarding each group’s constituents can be found in the Supplementary Data. Table 2 (Supplementary Data) lists samples’ information including discriminant analysis results, petrographic grouping, form, style and find location. Interpretation of the results to address questions of provenance, network interactions and general production patterns are discussed next.

### 4. Discussion and conclusion

The overall variability of Kuntur Wasi compositions reflects a variability of producers, productions and areas of manufacture exploiting different clay (and temper) resources. The distribution of samples as it was the case for petrographic data shows an evolution of strategies of production and differences in technological traditions across time.
There are notable differences between Idolo/Kuntur Wasi phases (KW-KW ceramics) and the Copa phase, both in terms of the amount of non-local vessels and ceramic production. While six out of the 19 Idolo ceramics analyzed petrographically (32%) present non-local mineral compositions, the bulk of the ceramics is supplied by small-scale local ceramic productions following a tradition using pyroclastic temper (aka the local tradition), which lasts till the end of the existence of the site. During the Kuntur Wasi phase, we observe an influx of nonlocal ceramics (KW-KW ceramics, 19/33, 57%) showing mineral similarities with different regions within a 50 km radius: the Middle Jequetepeque (24%), the Cajamarca area (15%) and other unidentified regions (18%). This is best illustrated in Table 2. By contrast, the ceramics from the Sangal complex (KW-SG) are in majority local and produced with pyroclastic temper. The organization of production changes during the Copa phase, where nearly all the production is local and more intensive. 67% (23/34) of the ceramics produced with a new recipe exploiting a new temper source (subvolcanic, Petrogroup E), and the rest with the usual local pyroclastic temper. During the Sotera phase, five out of 13 (38%) vessels analyzed are nonlocal or with a atypical paste, and production does not seem to be organized or intensive. For a tabulation of local Kuntur Wasi ceramics by form and phase, see Table 4 in the Supplementary Data.

The tightest chemical and petrographic groups, displaying similarity in clay composition, temper, and paste preparation (as exemplified by granulometry and texture) is represented by the Copa-phase group with subvolcanic temper (DA group 3, Petrogroup E), followed by the local pyroclastic group (DA group 1, Petrogroup A). The pyroclastic group shows temper homogeneity but some clay and texture variability, which suggests a less tight community of potters than the one operating during the Copa phase and using subvolcanic material. But we must keep in mind that the local tradition lasted a long time and that good clay beds might be less extensive than the pyroclastic sediments of Mount Cuscuden. The Copa community of potters, which must have worked near the site of Kuntur Wasi or at least exploited the nearby subvolcanic sources, produced a large quantity of similar forms and styles.

The analysis results also tend to rule out that potters from different regions using clays from their area would extract their temper from a common, same area. The idea of itinerant potters traveling with their wares would also not be applicable for the cases studied here. Rather, our study revealed for the first time the co-occurrence of different ceramic traditions with potters working locally to supply the center with different types of wares.

4.1. Interaction networks

Looking at interregional contacts and ceramic distribution the following was recognized: 1) Stylistic similarities with the northern highlands in the Idolo phase ceramics; 2) Stylistic influences from the coast in the KW-KW ceramics; 3) Stylistic influences from the Cajamarca basin in the Sotera phase ceramics (Inokuchi et al., 2014). In addition to styles, ceramics moved from one region to the other, as nonlocal compositions linked to the Jequetepeque Valley and Cajamarca area were identified. Table 2 summarizes the nonlocal attributions for the Kuntur Wasi ceramics combining chemical, petrographic, and stylistic data. We see that Middle Jequetepeque or coastal valley provenances occur mostly during the Idolo and Kuntur Wasi phases, while ware distribution from the Cajamarca Basin happened throughout the existence of the site. Forms and ceramic types also differ according to the provenance area. Note that the predominance of interactions with the coastal valley during the Kuntur Wasi phase attested by the distribution of ceramics parallels the stylistic influences observed for this period and accompanies the architectural changes that occurred during that time. The Kuntur Wasi phase also sees a peak in nonlocal ceramics (KW-KW vessels).

The types of ceramics moving up valley were bottles and bowls, mostly of ID- and KW-KW Rojo Grafitado, KW-KW Negro Grafitado and Gris, Rojo or Negro Fino types, plus occasional other types, and a few KW-KW ollas (see Table 2 and Fig. 5). These ceramics may have been part of special distribution networks with the Middle jequetepeque or adjacent valleys during that time period. One should also consider that ceramics may not have been the only objects or products moving along these networks, and that networks could be multiscalar and serving multiple purposes, mirroring the organizational concepts of multicraft production or coproduction discussed for example in Izumi Shimada, 2007’s edited volume. These concepts would be interpreted here in the sense of collaboration between producers and ‘distributors’ (if not the same), as well as sharing network knowledge, connections, distribution routes, and taking advantage of the circulation of other products (and people).

In regards to the initial proposal of a group of people settling in Kuntur Wasi at the beginning of the Kuntur Wasi type, the small amount of bottles and bowls circulating up-valley may not support this hypothesis, or at least not of a large group of persons. However, it does point to relationships with communities down in the coastal valley, probably in the chaupiyunga zone. Attention should be called to the Rojo Grafitado bottle found in the coastal site of Puemape displaying the same intrusive-temper characteristics seen in the nonlocal Rojo Grafitado ceramics found in Kuntur Wasi (Druce, 2015a,b). Other Rojo Grafitado bottles are found on other ceremonial sites and Cupisnique cemeteries from the same region with apparently similar intrusive-rich compositions based on a preliminary study of Cupisnique bottles hosted in the Larco Museum in Lima. Until more mineral and chemical analyses are done it is difficult to confirm the presence of a special production and distribution network for these vessels, but the chances are high. Several ollas from the Kuntur Wasi-KW and Sotera phases were also qualified as imports according to petrographic analysis (see Table 2). They must have pertained to another interaction network, which
for many vessels must have involved the Cajamarca area. This is based upon mineral characteristics, in particular for vessels of Rojo sobre Anaranjado type, which stylistically has been linked to the northern highlands (Huacaloma). LA-ICP-MS analysis confirmed these links.

With the Copa DA3 group are also found a few earlier ceramics from the Idolo and Kuntur Wasi phases, meaning that the source of material was already known prior to the Copa phase. For the Tembladera samples, it might be worthwhile to mention that a preliminary study by the first author of 83 ceramics from Las Huacas with a digital low-power microscope revealed that 33% of vessels from the Hamacas phase present intrusive material in their paste, against 52% in the following Tembladera phase, and only 12% in the last phase, Lechuzas, marking a shift in production strategies. Thin section petrography is needed to confirm a possible relationship with Kuntur Wasi. Many of the Middle Jequetepeque comparative materials are outliers and do not cluster together, suggesting a wide range of clay compositions throughout the valley. The clay beds sampled were probably not used to produce any of the ceramics found in Kuntur Wasi.

Relationships between Kuntur Wasi and Cajamarca in the form of pottery interaction network are proposed for all but the Copa phase and involved mostly bowls and ollas, but always in small number (Table 2, Fig. 5). The same applies to the small number of bottles and bowls moving from the coastal valley(s) to Kuntur Wasi. These amounts are not enough to call this trade. So what are we witnessing? Should we look at spatial or rather at social propinquity as suggested by Barbara Mills (2016)? Vessel circulation is only a very small part of a much larger picture involving group interactions at Kuntur Wasi (see Inokuchi and Druc, in press). Social network analysis (Mills et al., 2013; Terrel, 2013) would be an interesting approach in this regard. The movement of pots (and their carrier) towards Kuntur Wasi as outlined in this study, and the fact that many of the nonlocal ceramics are (visually) nice bottles and bowls, seem to dismiss these vessels as moving because of their content, but rather due to their socio-cultural significance. At the local level, the identification of two local producing communities which differ in type of material used, resource area mined, and production standardization, are testimonies of the activity generated by the presence of this ceremonial center. It also attests to a variety of production strategies and networks at play, with differing radii, ceramic products and partners. This pattern of multiple actors and functions of the items produced and moving, probably mirrors the interactions that occurred around other Andean centers of this period, albeit differing in degree and extend. This is rarely considered in its full extent and complexity. Also, the relationships with the middle valley(s) suggested in this study support Yoshio Onuki’s statement about the importance of the chaupiyunga zone during the Formative Period of northern Peru (Onuki, 1985).

In summary, the impression given by the ceramic production and distribution strategies suggested by the results of the chemical and petrographic analyses is that of a dispersed population around a still small temple at the beginning of the ceremonial center existence (Idolo phase) with scattered producers not located close to the center. This situation changes during the Kuntur Wasi phase, notably in terms of architecture but not necessarily for the organization of local ceramic production. However a larger interaction network was in place, which included the circulation of certain prestige ceramics, if we think of the KW-KW Rojo Grafitado bottles. During the Copa phase, it seems that new, small scale workshops were established or that producers were more numerous and clustered: production output is higher (more vessels of the same type and form), a new paste composition is in favor using subvolcanic temper material and displaying more homogeneity than for other phases. The old, local way of producing with pyroclastic material is still in vigor, without noticeable technological changes, and probably involving another community than the one at work close to the temple. These observations suggest that the number of consumers or the demand from the temple leaders must have been higher. During the subsequent, Sotera phase, when the ceremonial function of the site stopped the ceramic composition both chemical and mineral is much less homogeneous. The quarries used are more diversified, the material is often coarser and the overall production quality (material preparation, mixing, firing) seems lower than for the Copa phase. The type and amount of vessels recovered suggest a more disperse and less intense ceramic production in par with the reduction of activities at the site.

Kuntur Wasi was clearly a center that attracted goods and people from a wide regional area. In terms of interregional network, vessel circulation is registered between Kuntur Wasi and the Jequetepeque Valley for the Idolo and Kuntur Wasi (KW-KW) phases, and with the Cajamarca area throughout the existence of the site. The type of wares brought to Kuntur Wasi differs according to the region of provenance, which might reflect the type of consumers or function for which it was destined. Most nonlocal bottles are attributed to the Middle Jequetepeque Valley, and a few to Cajamarca.

A word of caution in regards to provenance attributions is necessary. Attributions are based upon comparison with the comparative material we have, mainly from the Middle Jequetepeque. Other regions with similar compositional characteristics could offer better matches and the comparison with samples from the lower valley or coastal region might suggest other provenance options. So far, considering the geology, the Middle Jequetepeque is our best provenance region for the intrusive-rich material observed in several of the Kuntur Wasi nonlocal ceramics. As for the ID and KW-KW Rojo Grafitado wares, to confirm or rule out a Middle Cupisnique Quebrada provenance would require samples from that area.

Finally, the ability to accept, reject or interpret the statistical results of the chemical data, which vary according to the statistical procedure chosen, relies largely on the knowledge provided by optical microscopy and petrographic analysis. This is the case even so the LA-ICP-MS analysis targeted the clay matrix. A cross-examination of LA-ICP-MS and petrography results yielded an understanding of ceramic production that could not have been achieved with either of these techniques alone. Also, LA-ICP-MS confirmed the correct mineral analysis of many ceramic cross-sections that were analyzed with a digital microscope as no thin section was available. This proves that optical or digital low-power microscopy can be successful in correct group attribution.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Data availability statement

The samples analyzed were exported to the United States under the Resolución Directoral Nacional N° 2073 of the Instituto Nacional de Cultura in Lima on September 24, 2010 and the Resolución Viceministerial N° 087–2013-VMPIC-MC of the Ministerio de Cultura of Peru on December 13, 2013. The samples are stored in Blue Mounds, Wisconsin, in the hands of the first author and available for study. Reports in Spanish were filed with the Ministry of Culture of Peru, and English versions are on-file documents available upon request with the first author of this study.

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Appendix A. Supplementary data

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References


