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Do you dig your grave with your teeth? Potential interest of the elementary analysis of ancient ceramics regarding public health (Pre-Columbian era, Ecuador).

Abstract:

Background: Following several studies considering the potential toxicity of food-type containers, we hypothesized elemental analysis would help us test a collection of Ecuadorian ceramic sherds from Andean and Amazonian sites. We later anticipated this method would enable us classify the sherds, with a match between their composition and the site they were extracted from.

Material and methods: µ-XRF spectrometer analyses were carried out on the internal, core and external faces of 48 ceramic sherds coming from 4 different archaeological sites. Major elements values (Si, K, Ca, Al, Ti, Mn, and Fe) were transformed into oxides and data were constrained to 100%, making our results semi-quantitative. A principal component analysis (PCA) was then performed on the additive log-ratio (ALR) transformed data to identify main compositional axes and plot the sherds. Besides, a hierarchical cluster analysis (HCA) (Euclidian distance, Ward's method) was applied on the coordinates of the individuals from the PCA to estimate the chemical similarity between the ceramic samples.

Results and discussion: The lead detected on the internal face of the ceramics locally produced in Quito was generally below the limit of quantification, while the lead concentration mean in the Cosanga ceramics was 180 ± 34 µg/g. The lead concentration values in the Pucará ceramics and the type labelled MN were of the same order. Arsenic, mercury, cobalt, chromium and antimony values proved to be below the quantification limits. No particular hazard was consequently identified regarding the exposure of past populations to potentially toxic pottery. The PCA on the ALR transformed data evidenced 2 main axes. The first main axis PC1 (F1) made it possible to graphically distinguish the "local Quito" ceramics - characterized by relatively high CaO and Sr values, and relatively low Pb values - from the "Cosanga" ceramics; although both were excavated in Rumipamba (Quito), the Cosanga ceramics were imported by local societies in Quito, who had constant contact and exchange processes with the Eastern societies and the Cosanga culture during the Integration period. The second main axis PC2 (F2) made it possible to refine the distribution of the samples (intra group variation), mainly due to Fe_2O_3, TiO_2, K_2O, and Zn. Three of four samples from Pucará were close to the ceramics locally produced in Quito, which is consistent with a geographical proximity. Two of the three samples labelled MN were located between the "local Quito" and the Cosanga ceramics groups. The HCA was applied on the first five factors to take into account about 80% of the total variance of the sample set. The dendrogram discriminated two main clusters, demonstrating a significant clustering pattern of certain fragments belonging to the same craft tradition, essentially the Cosanga ceramics *vs* the Local Quito ones.

Conclusion and perspectives: The use of the pottery ware we studied was safe as concerns lead and arsenic - both of them being elements of concern since absorbed digestively -, and other toxicological elements classically tested in ceramic craft. We managed through elemental analysis followed by a principal component analysis and a graphic representation to clearly identify 2 groups of pottery ("Local Quito" and "Cosanga") out of 4 different locations, 3 different periods and 4 cultural traditions corresponding to 4 different populations. Although our method of quantification has suffered from the absence of consideration regarding the lead leachability to the content, we aim in the near future at testing the samples we presented for lead leachability (acetic acid test) and comparing them with ceramic samples from other locations.

Keywords: toxicological analysis; elemental composition; lead; pre-Columbian; ceramics; principal component analysis.

Background:

As a result of several studies considering the potential toxicity of ceramics [1], [2], water pipes [3], or any food-type container, we wanted to test non-European artefacts. As part of a partnership and scientific cooperation agreement between the Ecuadorian Institute of National Cultural Heritage (INPC) and the Quai Branly-Jacques Chirac Museum, our choice targeted a collection of Ecuadorian ceramics from Andean and Amazonian sites.
Elements of historical background are set out in Appendix 1.
From 48 ceramic sherds excavated between 1981 and 2008 from 4 different sites in Ecuador (2 locations in the Rumipamba archaeological site, 1 site in Pucará de Rumicucho and 1 site in Tola Montaño, as shown in Figure 1), we tried to determine through elemental analysis of the internal surface whether the ceramic sherds - handmade centuries ago with little knowledge about material toxicity – were neutral or inert on a toxicological point of view. Besides, we anticipated analyzing the elemental ceramics composition would enable us to classify the sherds in a reliable and reproducible way as regards the sites they were excavated from, the manufacturing periods, and/or the cultures who molded them.

Material and methods:

Material

48 ceramic sherds listed in Table 1, divided as such:

- 41 excavated in Rumipamba, amongst such:
  - 31 labelled “Cosanga ceramic” (KLR12464 to KLR12494) excavated between 2000 and 2008 in the area identified by “CT17, PROC.502/519”. The Cosanga ceramics stretched between 18x17 (smallest sherd) and 70x36 mm (biggest sherd). 2 representative samples have been displayed in Figure 2;
  - 10 labelled “local Quito” (KLR12495 to KLR12504) excavated on 02/12/1985 in the area “CT30, south wall” and “CT30, PROC 1379”. The Quito ceramics stretched between 48x45 mm (smallest sherd) and 93x80 mm (biggest sherd). 3 sherds demonstrated a reddish brown slip on their convexity and 2 a reddish brown on the whole or one of their concavities; 1 sherd (KLR12496) was slipped (red) on its concavity with a blackened base section; 1 sherd (KLR12497) was blackened on the exterior side with a red slip on the half exterior side, while another one (KLR12498) was blackened on both sides; 1 sherd was doubtful and no slip was visible on the last one. 5 representative samples have been displayed in Figure 3.

  What enabled archeologists to discriminate those two materials was the thickness of the walls of the vessels: the local Quito paste is known to be thicker, while the Cosanga is much thinner (stretching from 4 mm to 1 cm) and known as eggshell. In addition to that, the presence of mica as a temper[1] in the KLR12464 to KLR12494 ceramics confirmed the Cosanga origin. The archaeologists estimated the whole pottery to date back to 900-1200 AD (Early Integration period).
- 4 excavated on 03/07/1981 in Pucará de Rumicucho, 20 km northwest of Quito (KLR12505 to KLR12508) in the area identified by “S27-28 E7-8, level 3, layer C, sector D, sub-sector East”; the sherds stretched between 42x31 mm (smallest sherd) and 95x90 mm (biggest sherd). The sherds could be dated either from the pre-Inca occupation periods, or more probably from the Inca time of domination. 2 of them demonstrated either an orangey slip (KLR12505) or a reddish-brown slip (KLR12507) on their convexities, while the 2 last ones were not slipped. The 4 samples have been displayed in Figure 4.
- 3 excavated on 17/09/1984 in La Tolita (Mango Montaño), an island at the mouth of the Santiago river in Esmeraldas province (KLR12509 to KLR12511), in the area identified by

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[1] A temper is used to reduce the plasticity of the clay materials and reduce shrinkage and cracking during the drying and the firing process.

"BI VII, level 1"; the sherds stretched between 40x20 mm (smallest sherd) and 55x30 mm (biggest sherd). The sherds may be dating from 450 BC-890 AD (corresponding to the Tolita period of influence), but a later occupation up until 1250 AD can't be excluded. No slip was visible on either of the sides. 1 of them (KLR12511) demonstrates black lines on its convexity. The 3 samples have been displayed in Figure 5.

Most of the samples studied are small-sized body vessels samples. Thus, it was not always possible to determine the vessel morphology with certainty; analysis was carried out on what we believed to be the internal part of the samples, defined by concavity or either presence or absence of slip.

μ-XRF (X-ray Fluorescence) Spectrometer Analysis

μ-XRF (X-ray Fluorescence) spectrometer analysis μ-XRF analyses were carried out using an ARTAX-800 equipped with a Mo target anode to screen the presence of toxic elements. The beam size was 60 μm. A high tension of 50 kV and a current of 600 μA were used. Each sample was analyzed on 20 points with a measurement time of 15s. Absolute calibration of the concentrations was done using the DCCR-method (Direct Calibration from Count Rates) provided by the Bruker Spectra software using a pressed pellet of the standard reference material NIST-2711. The results can only be considered semi-quantitative, because of differences between the matrices of the NIST-2711 standard and that of the samples. A total of 13 elements were measured (Si, K, Ca, Al, Ti, Mn, Fe, Cu, Zn, Rb, Sr, Zr, Ba, and Pb). Major and minor elements values (Si, K, Ca, Al, Ti, Mn, and Fe) were transformed into oxides and data were constrained to 100%. Trace elements were expressed as elements in parts per million (ppm, or μg.g-1). The low-Z elements Na, Mg, and Al could not be measured with the instrument settings used. Indeed, the secondary X-rays emitted by these elements have very low energies which are absorbed by the sample matrix or the air environment between the sample and the detector. Even though Al can generally be detected in all the samples, then due to the relatively high concentrations of this element in clay material, it cannot be properly quantified without a Helium purge or a vacuum pump to reduce the environmental absorption. Because the low-Z elements have not been measured, the standardized values given for the major and minor elements cannot be considered as quantitative.

Compositional Data Treatment

Prior to multivariate analysis, data were transformed. Elemental compositions provided by geochemical analyses are compositional data subject to the constraint of a constant sum and therefore only carry relative information about the samples [4]. Indeed, the variables are not independent, and one cannot vary one element without also inducing the variation of the others, or at least of one other one. The meaningful information of a given variable lies in its ratio to the other variables, and not in the concentration itself. Since compositional data are not considered to belong to the Euclidean space, but rather to a geometrically closed vector space (Aitchison's simplex), many statistical tools based on distance-measurements and correlation coefficients are therefore prone to yield systematic erroneous results. The use of the log-ratio transformation provides a way to overcome the problems of distances and biased covariance matrices [5]. Among the proposed solutions, the additive log-ratio (ALR) transformation has been selected for this study, with the following transformation:

$$alr(x) = [\log\left(\frac{x_1}{x_D}\right)\log\left(\frac{x_1}{x_D}\right)\ldots\log\left(\frac{x_{D-1}}{x_D}\right)]\ \ [6]$$

where the ratios involve the division of each of the first (D – 1) component by the final component. This transformation has previously been used in ceramic provenance analysis based on geochemical data [7]–[9].

A hierarchical cluster analysis (HCA) (Euclidian distance, Ward's method) was then applied on the coordinates of the individuals from the PCA (principal component analysis) to estimate the chemical similarity between the ceramic samples.

Results

The elemental results for internal surface are shown in Table 2. The lead detected in the ceramics locally produced in Quito was generally below the limit of quantification while the lead concentration mean in the Cosanga ceramics was 180 ± 34 µg/g. The lead concentration values in the Pucará ceramics and the type labelled MN were of the same order, although judged not relevant because of the small number of sherds available for the analysis. Arsenic, mercury, cobalt, chromium and antimony values, all these elements being known as classical toxics in pottery, proved to be below the quantification limits.

Comparison of the data through boxplot and Dunn pairwise comparison test mainly showed differences between the Cosanga ceramics and the ceramics locally produced in Quito, all discovered in the Rumipamba district in Quito. The Cosanga ceramics were higher in potassium (K_2O), titanium (TiO_2), and rubidium (Rb), while the ceramics produced in Quito had a higher content of calcium (CaO) and strontium (Sr).

The PCA on the ALR transformed data in Figure 6 evidenced 2 main axes, PC1 (F1) and PC2 (F2), showing a clear distinction between the Cosanga ceramics on the left of the plot (blue circles) and the ceramics locally produced in Quito on the right (red squares). The first main axis (PC1; its total inertia is 27.4%) made it possible to distinguish "local Quito" ceramics from "Cosanga" ceramics. “Local Quito” ceramics were characterized by relatively high CaO and Sr values, and relatively low Pb values. Conversely for “Cosanga” ceramics. The second main axes (PC2; its total inertia is 24.7%) made it possible to refine the distribution of the samples (intra group variation), mainly due to Fe_2O_3, TiO_2, K_2O, and Zn. It is worth noting that three of four samples from Pucará were close to the ceramics locally produced in Quito. Two of the three samples labelled MN were located between the “local Quito” and the Cosanga ceramics groups. The total inertia of the factorial plane is 52.1%.

The distribution of the samples in plot PC1-PC3 was similar to PC1-PC2. The main difference was the location of the three samples labelled MN which have negative coordinates on the PC3, reflecting low amounts of Zr and Cu compared to the other samples.

The HCA was applied on the first five factors to take into account about 80% of the total variance of the sample set. The dendrogram in Figure 7 discriminated two main clusters: the first one included all the ceramics labelled “Rumipamba, Cosanga ceramics” as well as two ceramics labelled “MN”. The second one encompassed all the ceramics labelled “Rumipamba, Local Quito”, the ceramics “Pucará” and one sample labelled “MN”. Figure 7 also displayed the likely presence of two subgroups into the Cosanga ceramics group with a low degree of intra-group similarity.

Discussion

It is admitted that ceramic ware paste and coating contain numerous oxides, some of which may be toxic for humans. Besides the well-studied lead, migration of other toxic and non-toxic elements may happen, such as mercury, arsenic, barium, cobalt, chromium, or antimony. As discussed later, the effects of each element depend on its route of administration (inhalation, dermal exposure, ingestion); in our hypothesis of ceramic tableware, ingestion constitutes the hazard.

The individual characteristics of ingested lead, arsenic, mercury, cobalt, barium, antimony and their compounds in terms of human toxicity have been listed in Appendix 2.

Lead (Pb) occurs in Earth’s crust primarily as the mineral galena (lead(II) sulfide) and, to a lesser extent, as anglesite (lead(II) sulfate) and cerussite (lead carbonate) formerly used for white coloring [10]. When it comes to humans, absorption is higher in children than in adults and is lower in the presence of food. Up until 2010, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) recommended a PTWI (Provisional Tolerable Weekly Intake) of 25 µg/kg bw (body weight) to all age groups. Because the analyses do not indicate a threshold for the key effects of lead, the Committee concluded that it was not possible to establish a new PTWI that would be considered health protective [10].

Oral absorption of metallic mercury is very low (<0.01%). For inorganic mercuric compounds administered orally, absorption can reach 10 to 15% [11]. Arsenic and its inorganic compounds are mainly absorbed through the digestive tract (absorption can be up to 95%) [12]. Cobalt would be less concerning in the particular case of ceramics, since the way of contamination would be aerial rather than by ingestion or dermatological contact [13]. The toxicity of chromium would be expressed mainly by chronic inhalation of dust, rather than by ingestion – the digestive absorption being poor – [14]. As for antimony, the effects depend on the route of administration; the toxicity is mainly driven by inhalation and dermal exposure [15].

To be concise, lead and arsenic seem to be the more concerning elements given their digestive absorption.

From the elemental analysis of the ceramics we carried out, no particular hazard was identified regarding the exposure of past populations to potentially toxic pottery. Lead and other classical toxics were either in very small concentrations, or below the technical limits of quantification.

Surprise was not great at not finding any lead, as this one is usually added for refined slipped or glazed pottery: the high level of lead allows mineral elements to be linked together without merging. This lead, fusing itself at low temperature, acts like a glue. The result is a ceramic produced at low temperature, the body of which, known as the biscuit, will better fix the layer of slip or "engobe", which is the support for the decorations and the glaze. This process, in addition to saving fuel, ensures the various elements (biscuit, white slip, paint, glaze) to marry without accident during the long phase of cooking and cooling [16]. In this particular case, the ceramics we tested were of basic manufacture, with only 6 of 48 (the ones locally produced in Quito) presenting a surface treatment. None of the ceramics analyzed showed a concerning lead concentration, the more decorated being surprisingly the poorest in lead, confirming the fact that addition of lead as a temper was not carried out.

The French general limitations related to tolerable lead concentration have been published in the Public Health Code as such: in the absence of chemical analysis, maximum surface concentration of total lead measured using a portable X-ray fluorescence device should be equal to 1 milligram per square centimeter (1 mg/cm²); if a chemical analysis was to be carried out, the maximum mass concentration of acid-soluble lead measured in the laboratory would be equal to 1.5 milligrams per gram (1.5 mg/g) [17]. These figures are general limitations applicable to many surfaces, for instance wall paintings. With a maximum lead concentration of 290 $\mu g.g^{-1}$, the ceramics we analyzed ranked well below the limit (5.2 times less concentrated than the limitation for the most concentrated Cosanga sherd).

However, with regard to ceramics, French regulations are defined in terms of the possibility of transfer of lead elements from the container to the content. Thus, ceramic objects held for sale, offered for sale or sold for contact with foodstuffs, food products and drinks must not yield quantities of lead greater than the following limits: for a non-fillable or a fillable object the height of which is ≤ 25 mm, Pb: 0.8 mg/dm^2; for any other fillable object: 4.0 mg/L; for a cookware with a capacity greater than three liters: Pb: 1.5 mg/L. The determination of lead release is carried out in the laboratory using an acetic acid solution [18]. Thus, the certainty of a toxicologically inert material can only be provided by incubating the samples with 4% acetic acid and then using spectrometry to measure the elements [19], [20]. The fact that our study only offers results in terms of surface concentration is a limitation, although we think that the low levels of lead found do not favor the preoccupying transfer of these elements to the food content. For instance, while high lead glazes are defined as containing 45–60% PbO [21], our highest internal surface lead concentration is 0.029%. Though, incubating acetic acid on fragmented samples would be of limited use, since it is the whole pot or vessel that should be incubated to determine accurately the lead leachability to the content. Moreover, the lead leaching rate may have been the greatest at the time when the pottery was new and used, and may have decreased as the pottery was getting old. On the contrary, the cracks may favor the release of lead from paste to food, artificially making the current leachibilities high [22]. More generally, the tendency towards leaching ability depends on several factors, amongst which firing conditions and temperatures [23]. Experimentation and interpretation are consequently touchy when it comes to old fragmented pieces of ceramics.

Although the majority of the samples being not slipped nor decorated in the surface and then probably of similar composition in their entire thickness, we also performed the analysis on the paste core and on the external surface. Lead concentrations in the core and on the external surface were very similar to the values measured on the internal surface. No arsenic, mercury, cobalt, chromium or antimony was measured either. Hence, we only reported the data from the internal surface.

One last point concerns the fact that scientific research is used to testing the release of usual toxic elements; however, the ingestion of inert materials (earth, clay, silicas, chalk, sand, etc.) is a factor in disorders, in particular iron deficiency anemia [24]. Within the framework of a healthy population, the consumption of silicas leached in small quantities does not present a particularly worrying character. This can however prove to be problematic in vulnerable populations (children, immunocompromised) exposed to chronic consumptions, particularly in the chrono-cultural context of a contact between European Conquistadors bringing germs, and an immuno-naive indigenous population. The risk associated with the ingestion depends on the element ingested, the quantity absorbed, and the bioavailability of the element, depending upon the form or state of a chemical element [25]. Minerals such as copper, iron, manganese and zinc, can be in elemental, ionic, colloidal or chelated forms, all of which affecting the rate of absorption. Some are changed by the contents of the gut, e.g. if a meal has been consumed [26]. While meal components may interact with minerals, increasing, decreasing or delaying their absorption, elements can also interact with each other: for example, calcium decreasing iron absorption [27].

Beyond toxicological analysis, the elemental analysis of the ceramics made it possible to distinguish the Cosanga ceramics, rich in K_2O, TiO_2, Rb, and Pb, from the ceramics locally produced in Quito, rich in CaO and Sr. Although the analysis did not identify any elements of concern in our special case, getting to know environmental toxicity and its potential consequences on public health is helpful to put into perspective the behaviors, lifestyles and even migratory processes of past populations.

The PCA on the log-ratio transformed data made it possible to graphically locate the ceramics along a PC1 axis allowing to highlight the lead component of Cosanga ceramics vs the CaO and Sr component of locally produced ceramics. The calcium component of Quito ceramics can be the consequence of a soil richer in limestone, or proceed from the use of a temper (crushed limestone has been used as a temper since the Neolithic era in Europe [28]). While the first major population movements would have started around 3550 BC [29], the local societies in Quito had constant contact and exchange processes with the Eastern societies and especially the Cosanga culture during the early integration period. In a more general perspective, the Integration period sees the regrouping of the small chiefdoms into much larger entities, controlling larger territories, where circulate multitude of merchants distributing various goods [30]; this is the reason why Cosanga material has been found in Rumipamba, although quite different from the local production in its composition.

While in 1920, Jijón and Caamaño started describing a ceramic material they called “Panzaleo”, Pedro Porras gave a new name to the culture, re-baptizing it as “Cosanga-Píllaro” in 1975. The material is characterized by a thin light brown ceramic in which mica inclusions are distinguished, which is consistent with the sherds we have found and identified “Cosanga” by archaeologists. It is described as rarely frosted and has geometric decorations painted in red or white, or in negative on a natural background [31]. The dates are still an issue: although a large set of C14 dating seems to indicate that the clays were mostly molded between 900 AD and the Inca occupation, numerous finds carry the chronology back to older periods. Awareness is progressively taken that this material is found in a vast geographical area that goes from Carchi to Tungurahua, and from Puerto Quito to Tena. However, the findings are concentrated in the eastern part of this range, especially in the inter-Andean corridor in the provinces of Imbabura, Pichincha, Cotopaxi, and in the eastern plain in the province of Napo [31]. Thus, it is not surprising to have been provided with sherds excavated in the Rumipamba district (Pichincha) but labelled “Cosanga”. Cultural traditions have a strong fluvial tropism that comes from the lower Amazon. One can ask himself what is pushing it west. A religious aspect cannot be excluded: in fact, certain data from the beginning of the colonial era allude to the belief of certain Amazonian populations in the existence of a "land without evil", materialized by movements of human groups led by a kind of prophets, starting from the lower or middle Amazon in the direction of the Andean plains [31]. Publications report the presence of Cosanga ceramics in Pichincha with great abundance, originating from the east of the Eastern Cordillera and from the high Amazon rainforests of northern Ecuador [32].

As to the archaeology of the Sierra Norte during the Integration period, it is known for its homogeneity in the elaboration of ceramics (provinces of Pichincha and Imbabura) [32], here embodied by the local Quito sherds. A previous study found strontium and barium concentrations

respectively equal to 360 +/- 110 ppm and 810 +/- 190 ppm [33]. With means equal to 430 ppm for strontium and 1111 ppm for barium, the Rumipamba samples proved to be quite similar.
It is worth noticing that the Pucará ceramics were elementally and graphically close to the Quito ones. This similarity is correlated with a geographical proximity, Pucará de Rumicucho being located at 20 km northwest of Quito. However, it is reported that at the time of the Inca Empire, very standardized ceramics were produced by the State in specific production centers. Significant quantities of Inca pottery could be excavated only in villages where there were caciques closely linked to the Inca: the system of "redistribution" functioned essentially in one direction, for the benefit of the center [34, p. 446]. Sources agree that Inca ceramics are remarkably standardized in form and decoration, a fact that is no doubt related to the role of ceramics in Inca administration and feasting, with ceramics having played an active role in Inca imperial negociations [33]. Some ceramics produced in the state capital, Cuzco, were traded over long distances into provincial regions [33]. Consequently, it is very likely that the pottery excavated in Rumicucho originates from another location, either in Ecuador or in Peru.
The intra-group variability mainly related to the elements K, Ti, Fe and Mn, without being able to draw any conclusion: within the same geological layer, the natural composition of the clays may differ depending on the place of collection or the depth.
A limitation to our results would be the fact that the analyses were originally performed to screen the presence of toxic compounds. Consequently, the analytical protocol and instrument settings do not correspond to standard archaeological provenance studies with principal component analysis based on extensive elemental screening [35]. However, the graphical results based on a limited number of elements proved to be relevant regarding the Rumipamba excavated ceramics, with a clear distinction between the Cosanga and the locally produced ones: one reason is the more similar the samples are within the same set, the more efficient this method is. In this specific case, the ceramics date from the same period, and were unearthed in the same place. Elemental screening coupled to scatterplots at linear scale has already proved successful in previous publications to discriminate Ecuadorian sets of ceramics [35].

The dendrogram showed a great mixing of compositional elements, which was consistent with the regional nature of the samples and the assumption of great mobility of ceramics and diversity of production contexts. However, it also demonstrated a significant clustering pattern of certain fragments belonging to the same craft tradition. The likely presence of two subgroups within the Cosanga group with a relatively high degree of dissimilarity was consistent with the fact these pieces were imported from Cosanga remote and various locations. The Pucará samples were grouped with the locally produced Quito ceramics; as mentioned previously, the ceramics found in the fortress of Pucará were certainly imported; their provenance is therefore uncertain. MN samples were grouped with Cosanga samples for 2 of them, and locally produced samples for the third one; this is believed to be due to the lack of samples. Had a larger sample set been used, it is likely that these samples would have been grouped with identified similar characteristics.

The ceramic analysis of Real Alto and San Lorenzo del Mate potsherds have shown that since phase lb Valdivia (3800-3300 BC), potters were selecting clays [36] and manipulating ceramic fabric according to their intended use [37]. The absence of ornamentation would correlate in our study with a daily rather than a ceremonial use. The fact that this pottery comes from areas known to be places of living is an additional argument to support a vocation for daily use. The presence of blackened sides imply some of them were used for cooking. More extensively, one will mention the contemporary use of colour and pigments in Ecuadorian pottery [38]: the quality of Jama-Coaque (240 BC to 1532 AD) ceramics, both in figurative shapes and colours, is remarkable; some influences from northern Mesoamerican cultures may be inferred from the use of post baking painting over anthropomorphic, animal, and mixed anthropomorphic and zoomorphic figures of the Tumaco-La Tolita, Jama-Coaque and Bahía cultures. Though, these artefacts were quite different from those studied here, and reserved for rituals and ceremonial use.

Conclusion and perspectives

We presented results from an initial μ-XRF study of pre-Columbian ceramics from 4 different archaelogical sites in Ecuador. It enabled us to state the use of this pottery ware was safe as concerns lead and arsenic (both of them being well absorbed digestively), and other toxicological elements classically tested in ceramic craft. We also managed through elemental analysis followed by a principal component analysis and a graphic representation to clearly identify 2 groups of pottery ("Local Quito" and "Cosanga") out of 4 different locations, 3 different periods and 4 cultural traditions corresponding to 4 different populations. The Pucará and Mango Montaño groups were partly located on the fringes of the two first groups either in the PCA plot or in the dendrogram, but could not be particularized: too few samples were present to allow a conclusion to be drawn on possible geochemical differences. New elemental analysis on a larger number of samples could enable us to investigate further on the provenance of these ceramics.

While keeping in mind the limits of the study, there is little chance ancient populations might have been affected by any kind of pathology linked to the use of the ceramics we tested. Nonetheless, our method of quantification has suffered from the absence of consideration regarding the lead leachability to the content. We aim in the near future at testing the samples we presented in this study for lead leachability, and comparing them with ceramic samples from other locations, either in our possession or in the literature.

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We have no Conflict of Interest related to the subject studied.

Figure 1 - Ecuador : geographical context and archaelogical sites

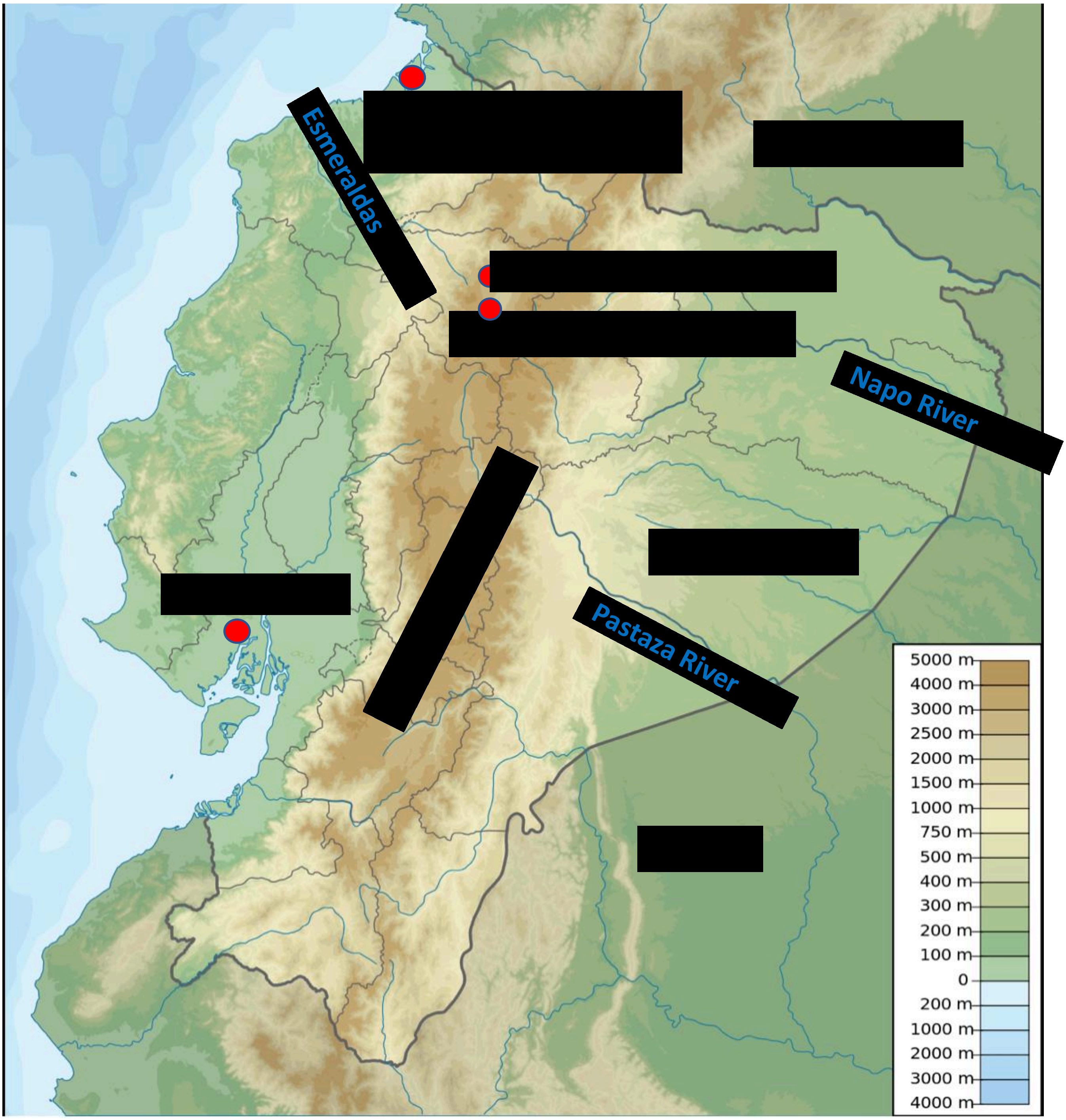


Figure 2 - 2 representative samples of the 31 Cosanga ceramics excavated in Rumipamba (Quito) between 2000 and 2008 - no slip visible (KLR12465, 12477)

Figure 3 - 5 representative samples out of 10 locally produced ceramics excavated in Rumipamba (Quito) on 02/12/1985 (KLR12498, 12496, 12499, 12502, 12503)

Figure 4 - 4 ceramic sherds excavated in Pucará de Rumicucho (Pinchincha) on 03/07/1981 (KLR12505, 12506, 12507, 12508)

Figure 5 - 3 ceramic sherds excavated in La Tolita (Mango Montaño) on 17/09/1984 (KLR12511, 12509, 12510)

Appendix 1 - Historical background: elements of context and presentation of the 3 archaelogical sites the 48 ceramic sherds were excavated from

General elements	
Five major chronological periods in pre-Columbian Ecuador	Traditionally, the long pre-Columbian history of Ecuador has been divided into five major chronological periods [30]: the Paleoindian (10,000-4,000 BC); the Formative period (3,500-300 BC) during which society itself began to form and settle permanently in a certain territory, with technological advances that made life easier (pottery, textiles, etc.) and made it possible to ensure subsistence almost all year round through agriculture [39]; the Regional development period (300-700 AD) marked by the proliferation of "chiefdoms" and the diversification of architecture; the Integration period (700-1480/1533 AD), which sees the regrouping of the small chiefdoms into much larger entities controlling larger territories, where multitude of merchants circulate distributing various goods; the Inca period (1480-1533 AD) during which the Tahuantinsuyo (i.e the Inca Empire) presents three essential features: it is a mountain organism, centralized and without any notion of a clear and materialized border, as we understand it today [34]. The first European caravels travelling along the Pacific coast of Ecuador some 500 years ago encountered a string of small kingdoms, confederations and indigenous clans. In spite of the Conquistadors being almost exclusively interested in the gold of coastal people, the latter had nonetheless developed other delicate arts and achieved refinements, amongst those ceramics.
Archaelogical sites: location, datation and contexts	
Mango Montaño (La Tolita)	The Mango Montaño site is located in La Tolita region, associated to the period of regional development. The Tolita culture (450 BC-890 AD) spread its influence on the eponymous island, and beyond, from 400 AD, throughout the territory of the Laguna. The excavation sites have characterized the presence of a ceremonial center on the island of La Tolita itself (decorated containers in various shapes, numerous remains of statuettes and some examples of ornaments in the funeral offerings), as well as in the area of La Laguna [40]. Humans are presented in all their forms and at all ages, while the figurations of non-humans are innumerable [30]. However, utilitarian objects, very rudimentary, are very abundant and represent about 90% of the debris of occupation [40]. Around 350 AD, the ceremonial center located on the island lost its hegemony in the region. In La Tolita, testimonies of occupation progressively become increasingly rare, to the extent that no vestige posterior to the 5th century AD was unearthed [41]. Despite the ideological decline of the ceremonial center, the populations of the territories near the island continued to live there, producing a material culture similar to that of the Tolita tradition and called The late Tolita (850-1250 AD) [40]. Human bones were also found on the Mango Montaño (200 BC-400 AD) site [42].
Rumipamba (Quito, Pinchincha)	Regarding old Quito – the main ceramic sherds provider site in our study –, a few groups were identified as having settled during the Integration period: the Cochasquíes and Cayambis, who lived in districts that would correspond today to the

	cantons of Cayambe and Pedro Moncayo, both vicinities of Quito [43, p. 53]. Rumipamba in particular is a vast park located in the very heart of Quito, and limited to the west by the volcanic massif of Pinchincha. The site was first identified during the survey of the Quito valley that took place in 1996 when a company was planning to build a housing complex [43, p. 90]. As a result of these findings, the first scientific investigations led by the INPC began in 1998 with an archaeological survey, identifying a large amount of cultural material. All this evidenced a multicomponent occupation from the Late Formative to the Integration period, and the research area was divided into sectors [43, p. 90]. The entire site has been delimited over an area of 30 hectares (302,351 square meters), watched over by the Central Bank and the Salvage Fund (FONSAL). Rumipamba benefits from the declaration issued in August 2002 by the Ecuadorian state through the National Institute of Cultural Heritage, recognizing it as Cultural and Ecological Heritage of the city of Quito [43, p. 89].
Pucará de Rumicucho (Pichincha)	Eventually, while some regions (Esmeraldas, Amazonia) seem to have remained outside any direct Inca influence, the latter is clearly manifested in the inter-Andean region between Quito and the current border with Colombia. This resulted in a military control, based on a network of strongholds, the “pucará” [34]. The Quechua word " Pucará" is generally translated as fortress or “fortified place”. The elaborate constructions are few and most often a very simple device made up of a few walls or ditches surrounding the top of an isolated mound or hill [44]. Ditches and walls draw on the aerial image concentric circles "nested" around an elevation [44]. Pucará of Rumicucho is a fortress perched on a hill at the altitude of 2401 meters [45]. The site measures 370m x 78m [44], and was probably first occupied by pre-Inca cultures. The Incas then added their usual styles to the existing buildings and walls [45]. Rumicucho is one of the few pucarás in Ecuador where a substantial amount of Inca material has been discovered, including household items such as fabrics, ceramic pots for making Chicha (oriental pipe with a long flexible pipe connected to a flask of flavored hot water), the Inca fermented drink, bone tools, shells and metal objects. Rumicucho was a multifunctional base for residence and ceremonies, transit, trade control and defense. The archaeological site is made up of 5 staircase terraces. The first and second terraces were used for rituals and celebrations; the third terrace was reserved for ceremonies, and the two last ones were probably used for accommodation and workshops. Rumicucho was probably also used for astronomy and observing solar events (aquinox ceremonies), as it is about 1 kilometer from the equator and aligns precisely with the Cayambe volcanoes located 50 kilometers to the east and Cotopaxi located 80 kilometers to the south [45].

Table 1 - Measurements and aspect of the 48 ceramic sherds excavated in 4 different sites in Ecuador between 1981 and 2008

KLR n°	Other n°	Site - Type	Dimensions (cm)	Slip-Engobe?
KLR12464	*23B3-92-513-07-20*	Rumipamba, Cosanga ceramic	30x19	No slip visible
KLR12465	*23B3-92-504-07-16*	Rumipamba, Cosanga ceramic	70x36	No slip visible
KLR12466	*23B3-92-519-07-23*	Rumipamba, Cosanga ceramic	48x29	No slip visible
KLR12467	*23B3-92-582-07-10*	Rumipamba, Cosanga ceramic	30x28	No slip visible
KLR12468	*23B3-92-519-07-25*	Rumipamba, Cosanga ceramic	30x30	No slip visible
KLR12469	*23B3-92-517-07-13*	Rumipamba, Cosanga ceramic	26x24	No slip visible
KLR12470	*23B3-92-50-07-1*	Rumipamba, Cosanga ceramic	30x20	No slip visible
KLR12471	*23B3-92-517-07-14*	Rumipamba, Cosanga ceramic	27x15	No slip visible
KLR12472	*23B3-92-502-07-69*	Rumipamba, Cosanga ceramic	20x19	No slip visible
KLR12473	*23B3-92-502-07-3*	Rumipamba, Cosanga ceramic	20x18	No slip visible
KLR12474	*502,16*	Rumipamba, Cosanga ceramic	28x25	No slip visible
KLR12475	*510,44*	Rumipamba, Cosanga ceramic	22x22	No slip visible
KLR12476	*23B3-92-501-07-33*	Rumipamba, Cosanga ceramic	55x47	No slip visible
KLR12477	*23B3-92-502-07-3 (9)*	Rumipamba, Cosanga ceramic	43x40	No slip visible
KLR12478	*23B3-92-502-07-53*	Rumipamba, Cosanga ceramic	35x25	No slip visible
KLR12479	*23B3-92-502-07-56*	Rumipamba, Cosanga ceramic	34x22	No slip visible
KLR12480	*23B3-92-519-07-62*	Rumipamba, Cosanga ceramic	29x23	No slip visible
KLR12481	*23B3-92-519-07-10 (9*	Rumipamba, Cosanga ceramic	24x21	No slip visible
KLR12482	*23B3-92-519-07-9 (9)*	Rumipamba, Cosanga ceramic	47x45	No slip visible
KLR12483	*23B3-92-626-8 (9)*	Rumipamba, Cosanga ceramic	18x17	No slip visible
KLR12484	*23B3-91-502-07-3 (9)*	Rumipamba, Cosanga ceramic	23x16	No slip visible
KLR12485	*23B3-92-512-07-3 (9)*	Rumipamba, Cosanga ceramic	Poly-fragmented	No slip visible
KLR12486	*502-9 (1)*	Rumipamba, Cosanga ceramic	49x40	No slip visible
KLR12487	*502-9 (2)*	Rumipamba, Cosanga ceramic	57x30	No slip visible
KLR12488	*502-9 (3)*	Rumipamba, Cosanga ceramic	33x28	No slip visible
KLR12489	*502-9 (4)*	Rumipamba, Cosanga ceramic	30x26	No slip visible
KLR12490	*510.44 (1)*	Rumipamba, Cosanga ceramic	44 x 32 et 28x19	No slip visible
KLR12491	*510.44 (2)*	Rumipamba, Cosanga ceramic	19x15, 13x10, 2x2	No slip visible
KLR12492	*537,164*	Rumipamba, Cosanga ceramic	25x15	No slip visible
KLR12493	*502-19*	Rumipamba, Cosanga ceramic	24x20	No slip visible
KLR12494	*502-157*	Rumipamba, Cosanga ceramic	29x17	No slip visible
KLR12495	*No number*	Rumipamba, local Quito	Poly-fragmented	Doubtful
KLR12496	*No number*	Rumipamba, local Quito	73x56	Reddish slip on the concavity, blackened base section
KLR12497	*No number*	Rumipamba, local Quito	93x80	Blackened exterior + slip on the half exterior
KLR12498	*No number*	Rumipamba, local Quito	65x60	Blackened exterior and interior
KLR12499	*23B392 – 1379.6*	Rumipamba, local Quito	93x72	Reddish-brown on the convexity
KLR12500	*23B392 – 1379.10*	Rumipamba, local Quito	80x55	Reddish-brown on one of the concavity surface
KLR12501	*23B392 – 1379.15*	Rumipamba, local Quito	66x62	Reddish-brown on the convexity
KLR12502	*23B392 – 1379.7*	Rumipamba, local Quito	70x42	No slip visible
KLR12503	*23B392 – 1379.9*	Rumipamba, local Quito	62x55	Reddish-brown on the concavity
KLR12504	*23B392 – 1379.20*	Rumipamba, local Quito	48x45	Reddish-brown on the convexity
KLR12505	Pucoro, 527-28-E-7-8	Pucara, 527-28-E-7-8	95x90	Orangey slip on the convexity
KLR12506	Pucoro, 527-28-E-7-8	Pucara, 527-28-E-7-8	31x30	No slip visible
KLR12507	Pucoro, 527-28-E-7-8	Pucara, 527-28-E-7-8	28x18	Reddish-brown on the convexity
KLR12508	Pucoro, 527-28-E-7-8	Pucara, 527-28-E-7-8	24x18	No slip visible
KLR12509	MN, B1, VII, 2	MN, B1, VII, 2	55x30	No slip visible
KLR12510	MN, B1, VII, 2	MN, B1, VII, 2	40x20	No slip visible
KLR12511	MN, B1, VII, 2	MN, B1, VII, 2	35x26	Dark lines on the convexity

Appendix 2 - Oral toxicity of potential poisonous elements in soils and ceramics

Toxic	Toxicity
Lead (Pb)	Ingested lead is transferred to soft tissues, including liver and kidney, and to bone tissue, where it accumulates with age. Lead readily crosses the placenta and is transferred into breast milk [10]. It causes reversible (anemia, digestive disorders) or irreversible (nervous system damage, encephalopathy and neuropathy) disorders. In high doses, lead can infer encephalopathies, neuropathies and death in adults and children. It also causes digestive effects (e.g. colic, abdominal pain). Lead has effects on blood pressure, on kidney function in adults as well as on reproduction and development in children regarding the central nervous system (CNS) (impaired neurodevelopment with a specifical reduction of intelligence quotient (IQ), attention disorders) in children, even at low doses [46].
Arsenic (As)	All of the inorganic compounds have significant acute toxicity via the digestive tract, characterized by intense digestive disorders, hemodynamic disorders, multiple organ involvement finally leading to death. In the event of chronic exposure - via the respiratory route as well as the digestive system - effects on various organs are observed, in particular characteristic skin lesions, neurological, cardiovascular and respiratory effects. Genotoxicity data are limited in humans. Exposure to inorganic arsenic is associated with an increased risk of bronchopulmonary (respiratory and digestive exposure), bladder and skin (digestive exposure) cancers. There are limited data on possible effects on fertility in men. Developmental effects (fetal and infant death, heart defects, retardation of growth and neurodevelopment, increased susceptibility to infections) are observed, associated with exposure via drinking water [12].
Mercury (Hg)	After transport in the blood (1/4 in the red blood cells, 3/4 in the plasma), mercury is mainly distributed in the kidneys (especially in the proximal tubes). Mercury and its compounds are responsible for gastrointestinal, neurological and cardiovascular effects. Chronic pulmonary exposure to mercury induces neurological, respiratory and hepatic damage, the severity of which increases with the duration and concentration of exposure. Orally, mercuric salts cause gastrointestinal, cardiac and immunological effects. Very little information is available regarding the carcinogenic potential of mercury and its compounds. Some benign and malignant tumors have been reported in the kidneys following exposure to mercuric chloride [11].
Cobalt (Co)	Cobalt may infer neurological (e.g. hearing and visual impairment), cardiovascular and endocrine deficits [47]. The animal model seems to suggest a link between cobalt and tumor process.
Barium (Ba)	Chronic ingestion of barium and its compounds induce bone deposits with osteonecrosis, especially in the maxilla and femur. A few studies report the presence of hypertension, chronic bronchitis, poorly defined cardiac disorders among populations exposed professionally or by environmental contamination (mainly barium-laden water). They are, however, all partial or open to criticism from a methodological point of view and therefore not demonstrated [48]. Barium oxide and hydroxide can however be caustic to digestive mucous membranes [48].
Chrome (Cr)	The acute ingestion may cause a symptomatic picture of caustic lesions of the digestive tract which may result in buccoesophageal burns with sometimes edema of the glottis, bloody vomiting, severe epigastric pain and dysenteric syndrome, later resulting in major hydroelectric disorders, cardiovascular collapse, and renal failure due to tubular damage [14].

Antimony (Sb)	The animal model suggests cardiovascular, gastrointestinal, hematological, hepatic and other systemic effects (weight loss, increased serum cholesterol and decreased nonfasting serum glucose levels) [15].

Table 2 - Elemental composition of 48 ceramic sherds excavated in 3 different sites between 1981 and the early 2000s (Ecuador)

KLR n°	Other n°	Site - Type	SiO2 (wt%)	K2O (wt%)	CaO (wt%)	TiO2 (wt%)	MnO (wt%)	Fe2O3 (wt%)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Zr (ppm)	Ba (ppm)	Pb (ppm)
KLR12464	*23B3-92-513-07-20*	Rumipamba, Cosanga ceramic	88,22	1,8	1,17	0,84	0,1	7,87	50	190	130	470	190	1370	190
KLR12465	*23B3-92-504-07-16*	Rumipamba, Cosanga ceramic	88,74	2,63	1,08	1,11	0,07	6,37	20	210	140	200	160	1210	190
KLR12466	*23B3-92-519-07-23*	Rumipamba, Cosanga ceramic	76,1	4,74	4,59	1,12	0,27	13,18	120	190	190	380	210	1260	170
KLR12467	*23B3-92-582-07-10*	Rumipamba, Cosanga ceramic	77,27	3,51	3,41	1,32	0,16	14,33	80	190	140	330	160	1250	160
KLR12468	*23B3-92-519-07-25*	Rumipamba, Cosanga ceramic	86,85	2,78	1,38	1,1	0,08	7,8	100	220	140	320	160	1100	170
KLR12469	*23B3-92-517-07-13*	Rumipamba, Cosanga ceramic	82,43	3,34	1,69	1,36	0,1	11,08	90	270	170	280	160	1260	180
KLR12470	*23B3-92-50-07-1*	Rumipamba, Cosanga ceramic	79,58	3,5	2,9	1,33	0,12	12,56	70	230	120	460	170	1580	180
KLR12471	*23B3-92-517-07-14*	Rumipamba, Cosanga ceramic	77,97	3,89	2,52	1,6	0,15	13,86	70	180	140	290	140	820	170
KLR12472	*23B3-92-502-07-69*	Rumipamba, Cosanga ceramic	77,66	3,85	3,32	1,58	0,15	13,44	80	250	170	410	180	10	200
KLR12473	*23B3-92-502-07-3*	Rumipamba, Cosanga ceramic	82,08	2,89	1,88	1,57	0,13	11,45	110	200	150	290	170	1270	190
KLR12474	*502,16*	Rumipamba, Cosanga ceramic	81,24	3,87	1,64	1,55	0,08	11,62	30	340	180	310	160	1260	200
KLR12475	*510,44*	Rumipamba, Cosanga ceramic	81,17	2,71	2,8	2,4	0,12	10,81	40	180	140	270	160	1250	150
KLR12476	*23B3-92-501-07-33*	Rumipamba, Cosanga ceramic	76,5	5,21	5,3	3,27	0,1	9,62	20	190	130	240	330	940	140
KLR12477	*23B3-92-502-07-3 (9)*	Rumipamba, Cosanga ceramic	84,85	2,9	1,61	1,4	0,12	9,11	140	230	150	430	170	1090	180
KLR12478	*23B3-92-502-07-53*	Rumipamba, Cosanga ceramic	73,32	5,42	8,66	1,37	0,11	11,12	20	210	140	270	160	1170	180
KLR12479	*23B3-92-502-07-56*	Rumipamba, Cosanga ceramic	81,68	3,47	2,05	1,32	0,11	11,38	60	170	150	170	160	850	190
KLR12480	*23B3-92-519-07-62*	Rumipamba, Cosanga ceramic	89,25	1,73	1,65	0,72	0,05	6,59	20	150	70	290	160	250	250
KLR12481	*23B3-92-519-07-10 (9*	Rumipamba, Cosanga ceramic	82,34	3,55	1,84	1,47	0,25	10,55	30	200	130	200	140	790	150
KLR12482	*23B3-92-519-07-9 (9)*	Rumipamba, Cosanga ceramic	82,05	3,62	1,65	1,35	0,1	11,23	50	190	160	210	180	690	170
KLR12483	*23B3-92-626-8 (9)*	Rumipamba, Cosanga ceramic	79,56	3,4	2,43	1,75	0,12	12,74	20	230	130	200	140	630	180
KLR12484	*23B3-91-502-07-3 (9)*	Rumipamba, Cosanga ceramic	77,25	4,7	2,47	2,01	0,48	13,09	60	340	160	610	160	670	240
KLR12485	*23B3-92-512-07-3 (9)*	Rumipamba, Cosanga ceramic	81,43	2,93	1,46	1,25	0,13	12,8	70	270	140	140	160	1020	190
KLR12486	*502-9 (1)*	Rumipamba, Cosanga ceramic	82,31	3,93	1,84	1,19	0,09	10,64	60	270	140	270	170	1090	160
KLR12487	*502-9 (2)*	Rumipamba, Cosanga ceramic	89,18	2,03	1,14	0,84	0,06	6,74	80	180	150	190	160	790	160
KLR12488	*502-9 (3)*	Rumipamba, Cosanga ceramic	82,03	3,01	3,85	2,74	0,12	8,24	200	240	160	450	180	1330	170
KLR12489	*502-9 (4)*	Rumipamba, Cosanga ceramic	79,11	3,83	2,99	1,93	0,14	12	30	220	120	760	200	2700	150
KLR12490	*510.44 (1)*	Rumipamba, Cosanga ceramic	84,02	3,51	1,95	1,19	0,12	9,21	30	180	130	300	150	580	220
KLR12491	*510.44 (2)*	Rumipamba, Cosanga ceramic	80,04	3,18	2,55	1,76	0,11	12,37	30	180	100	340	170	1650	110
KLR12492	*537,164*	Rumipamba, Cosanga ceramic	80,5	3,79	3,31	1,07	0,14	11,2	100	200	170	300	160	1560	200
KLR12493	*502-19*	Rumipamba, Cosanga ceramic	81,78	3,31	1,33	1,4	0,09	12,09	80	250	170	240	170	1390	290
KLR12494	*502-157*	Rumipamba, Cosanga ceramic	83,44	2,67	1,8	0,92	0,1	11,07	30	170	140	270	160	910	170
KLR12495	*No number*	Rumipamba, local Quito	68,77	2,08	9,04	1,29	0,24	18,58	50	160	110	650	150	1090	0
KLR12496	*No number*	Rumipamba, local Quito	76,7	2,16	7,56	1	0,13	12,45	50	200	120	900	160	1420	0
KLR12497	*No number*	Rumipamba, local Quito	79,45	2,26	5,7	0,77	0,19	11,63	80	150	110	680	160	1180	0
KLR12498	*No number*	Rumipamba, local Quito	81,48	2,53	6,27	0,83	0,1	8,79	60	150	120	890	220	1230	180
KLR12499	*23B392 – 1379.6*	Rumipamba, local Quito	77,72	2,31	7,25	0,92	0,7	11,11	80	190	120	720	170	1140	0
KLR12500	*23B392 – 1379.10*	Rumipamba, local Quito	79,34	1,95	8,89	0,84	0,16	8,82	60	140	100	670	140	660	0
KLR12501	*23B392 – 1379.15*	Rumipamba, local Quito	74,77	2,71	9,4	1,15	0,18	11,8	150	200	120	780	150	860	0
KLR12502	*23B392 – 1379.7*	Rumipamba, local Quito	81,59	1,86	7,29	0,8	0,11	8,34	60	140	100	730	150	770	0
KLR12503	*23B392 – 1379.9*	Rumipamba, local Quito	77,87	1,85	6,92	1,01	0,3	12,05	80	220	160	880	200	2090	0
KLR12504	*23B392 – 1379.20*	Rumipamba, local Quito	78,52	2,6	8,78	0,74	0,14	9,22	130	170	100	820	170	1360	0
KLR12505	Pucara, 527-28-E-7-8	Pucara, 527-28-E-7-8	76,24	2,53	6,98	1,1	0,14	13,01	40	100	90	560	150	1010	0
KLR12506	Pucara, 527-28-E-7-8	Pucara, 527-28-E-7-8	75,54	2,72	7,84	1,08	0,15	12,68	90	110	80	420	140	1270	0
KLR12507	Pucara, 527-28-E-7-8	Pucara, 527-28-E-7-8	83,94	1,51	4,75	0,81	0,1	8,88	50	90	610	610	160	1530	0
KLR12508	Pucara, 527-28-E-7-8	Pucara, 527-28-E-7-8	84,8	2,35	5,4	0,31	0,06	7,09	90	130	70	630	160	1350	0
KLR12509	MN, B1, VII, 2	MN, B1, VII, 2	82,52	2,99	6,7	1,24	0,16	6,39	30	120	90	520	150	970	190
KLR12510	MN, B1, VII, 2	MN, B1, VII, 2	83,59	3,44	2,94	0,96	0,1	8,96	20	150	60	240	160	640	230
KLR12511	MN, B1, VII, 2	MN, B1, VII, 2	74,28	1,21	6,32	5,55	0,29	12,35	50	130	50	520	160	1250	220

Figure 6 - Results of the PCA on the ALR transformed data relating to the 48 ceramic sherds from 4 different sites (Ecuador)

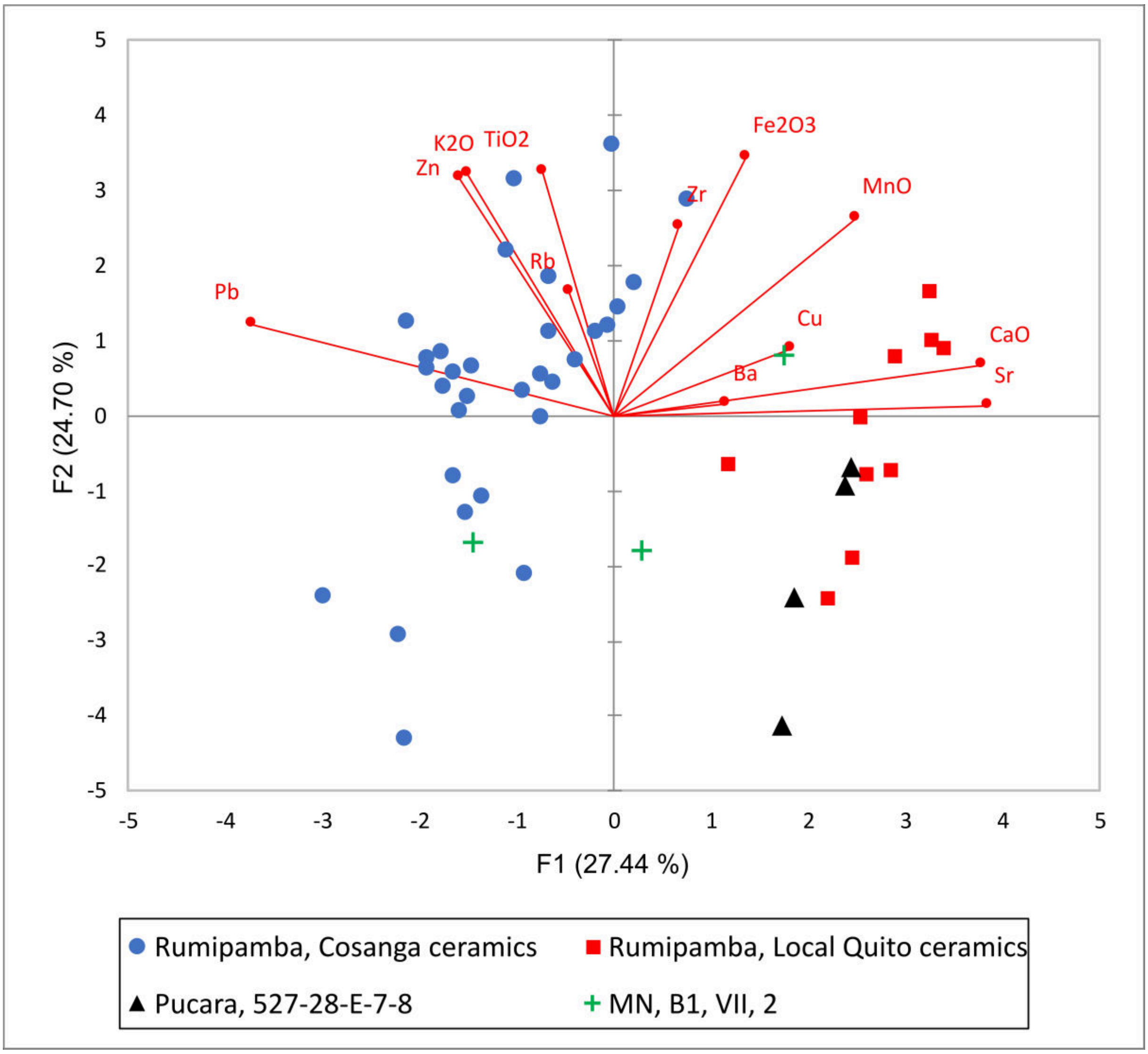
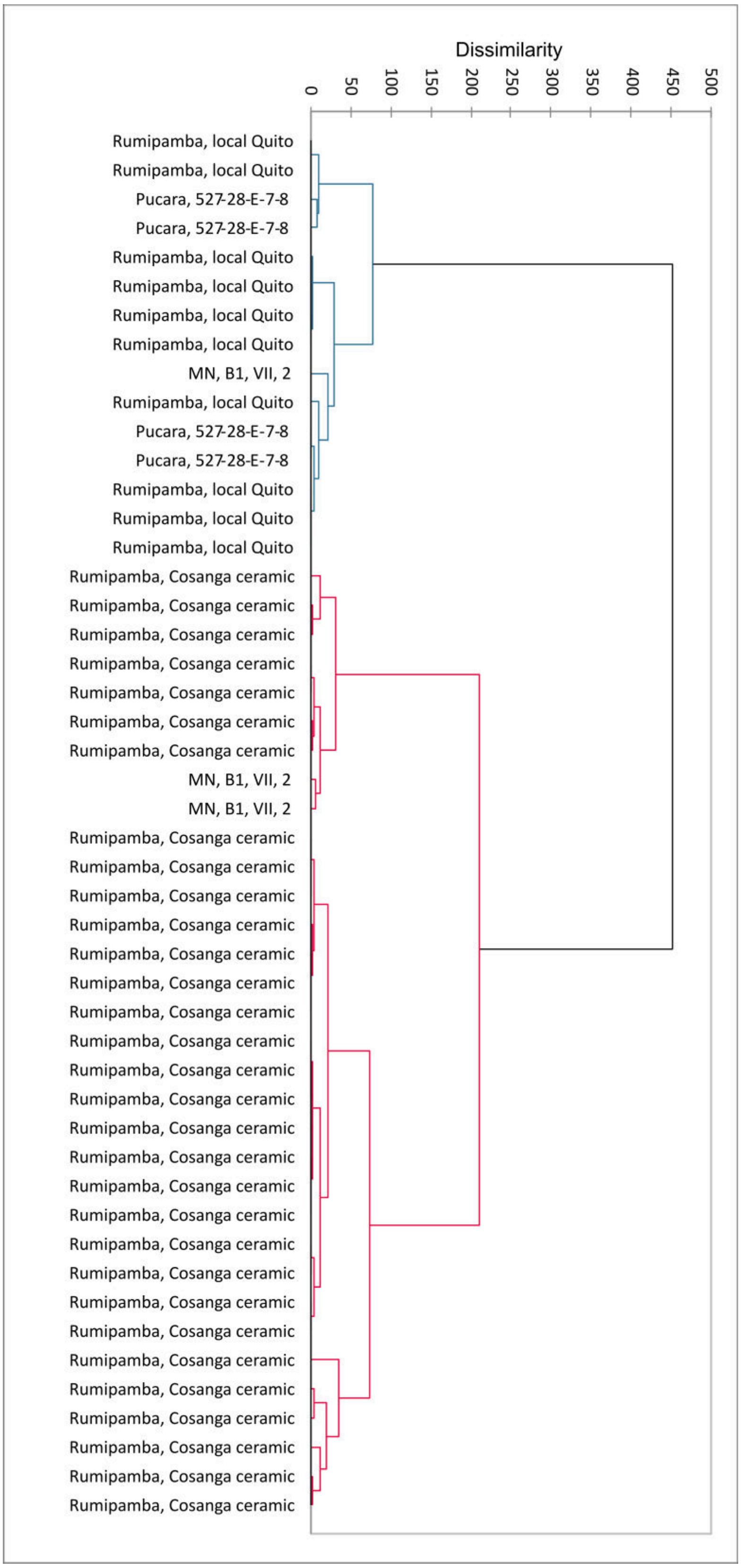


Figure 7 - Dendrogram featuring 48 ceramic sherds from 4 different sites (Ecuador)



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