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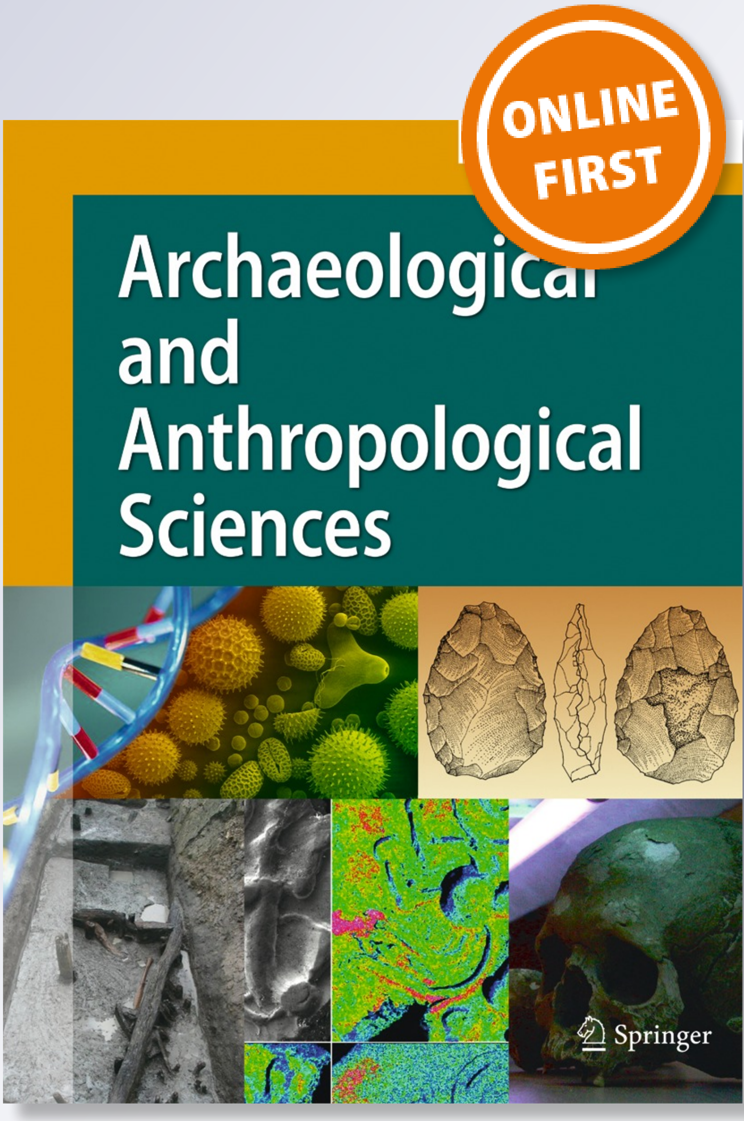

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ORIGINAL PAPER

Experimentation with ceramic pastes containing high amounts of pyroclastic materials: their relation to the manufacture of Inka vessels

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Abstract Pyroclastic inclusions constitute an important component of the ceramic pastes associated with the Inka period in the Argentine northwest. The study presented here attempted to reproduce experimentally the pre-Hispanic techniques used to manufacture ceramics with these components. A set of briquettes was created with similar percentages of pyroclastic and sand inclusions, as well as a set with no added inclusions. The results obtained indicated a reduction in vessel weight with high levels of pumice inclusions, which would confer a functional advantage regarding the efficiency of medium- and long-distance transportation of products.

Keywords Argentine northwest · Inka period · Experimental replication · Pyroclastic inclusions · Ceramic pastes

Introduction

Archaeological ceramic research carried out during recent decades has revealed the fact that pyroclastic inclusions, found in high proportions, represent a significant component of the pastes associated with the Inka period in northwestern Argentina (1480–1532 AD) (Cremonte 1991, 1994; Páez 2010a, b, 2011; Páez et al. 2007; Páez and Arnosio 2009). These pastes have also been identified as far south as the province of Mendoza, at the southern edge of the range of the *Tawantinsuyu* (Prieto et al. 2007). We emphasize the temporal aspect of this phenomenon because it is the main point upon which creation of an exclusive category can be based, within which great stylistic diversity in ceramic decoration and morphology can be found.

The first identification of this technological characteristic was made with the pastes of ceramic sherds from the Inka sites of Potrero Chaquiago and Ingenio del Arenal Médanos, both located in the province of Catamarca, Argentina. In these sherds, vitreous inclusions were present in densities that varied between 18 and 30 %, and they were rounded in shape. Analysis revealed that these inclusions were volcanic glass, incorporated into the pastes through grinding of the type of soft volcanic stone known as pumice (Cremonte 1991, 1994). This initial identification was used as the basis for further interpretations regarding work organization in the context of Inka politics. Specifically, an effort was made to provide archaeological confirmation of existing theories based upon ethnohistory for the central Andean region as well as for various "peripheral" areas of the empire. Towards this goal, the analysis performed regarding northwest Argentina suggested the presence of transitory populations that may have existed as part of the political re-organization advanced by the Inka state (Lorandi and Boixadós 1987–88). *Altiplano* groups, who manufactured ceramics with whitish lutite inclusions, may have been resettled by the state in the valleys of Catamarca, where they may have replaced this prime material with volcanic glass, thereby creating pastes that were visually similar but structurally different (Cremonte 1991).

On the other hand, the administrative and ritual relevance has been discussed for certain sites, as with the case of El

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Shincal in the province of Catamarca, where a great number of ceramic items would have been used during celebrations sponsored by the Inka state (Giovannetti 2009; Giovannetti et al. 2013). Certain proposals regarding the production, movement, and use of Inka state ceramics suggest that a system that was controlled by the state would have been based mainly on the use of local potters, imposing ceramic styles but not necessarily production techniques (Williams 2004). According to some theories, it is believed that the circulation would have been restricted given the weight and fragility of the items under analysis. However, several studies have shown that the production, use, and circulation of ceramic items were not limited to only one modality within the scheme of object interaction and movement in the Inka state structure. The social relationships and interaction networks within each conquered region were diverse, since several historic and social factors had led to a great socio-political heterogeneity in the *Tawantinsuyu* structure. The intrinsic characteristics of each ethnic or political group, the forced movement of settlements, the nature of incorporation into the *Tawantinsuyu* (coercive or negotiated), and environmental factors, among other elements, played a central role in the articulation of the geopolitical cartography of the provinces (Murra 1975; LeVine 1987; D'Altroy 1987, 2003; Rostworowski 1999). We believe that in some cases, the ceramic production was rooted strongly with the local potters, which led to a significant diversity in terms of production (D'Altroy and Bishop 1990; Spurling 1992; Hayashida 1998; González Carvajal 1998; 2004). Ceramic pots that have iconographic and morphologic roots in the Inka culture, such as aribaloids and duck-shaped plates, were made by local specialists that continued producing their own ceramics concurrently. The same can be said about those sites to where mitimae settlements may have been moved, as with the case of Potrero Chaquiago in the northwest of Argentina (Lorandi et al. 1991). Therefore, the problems related to the movement and distribution of items deserves deeper analysis.

The aim of this work was to make an interpretative contribution regarding the technological practices of ceramic production during the Inka period in the northwest of Argentina. In order to do so, we experimentally built several types of ceramic items that were similar to those found at archaeological sites dated to the Inka period, in order to compare the weight characteristics of the items. We based our study on the hypothesis that the arrival of the Inkas brought about certain technological changes regarding the production of ceramic goods. This is related to improving the efficiency of transporting those items, which would have had to be moved from production sites to other settlements where different political and ceremonial activities were carried out. This work therefore tries to shed some light on such premises using the results of the experiments.

Ceramic production and circulation during the Inka period in the northwest of Argentina

Our hypothesis regarding the technological change in the production of certain ceramic pastes during the Inka period in the northwest of Argentina involves the premise that items were moved from one site to another. We addressed this from two points of view. First, we reviewed work that shows that the movement of such items took place, either Inka-type ceramic items or those that were not Inka-type in style but were also circulated systematically. Second, we used our own results from the Inka sites of El Shincal de Quimivil and Pucará de Lomas Verdes, located in the central region of the province of Catamarca, Argentina, and in the Tafí valley, province of Tucuman, Argentina, respectively. We obtained our samples for experimental replication from both sites.

Many studies have shown that the economic policy of the Inka state was diverse, depending on each conquered group and region, and the same can be said about ceramic production, with some examples of direct control and some examples where production control was blurred (D'Altroy et al. 1998). Even so, two situations seem to have been common to Inka economic policy, which established the circulation of prestigious and valuable goods. On the one hand, there was the concept of goods redistribution through a system of gifting and counter-gifting, which the elites from Cusco made wide use of to make alliances, return help, and use the workforce for state enterprises (Hyslop 1990; Bray 2003a, b; Sternfeld 2007). On the other hand, which is also related to the first, festivities and meetings sponsored by the state took place where symbolic paraphernalia conveyed by different types of objects were evident (Dillehay 2003). For the manufacture of such ceramics, ethnohistorical evidence suggests that the Inka state would have provided the ceramists with the necessary raw goods (Murra 2002).

However, the state-produced ceramics seemed to follow different paths than the domestic ceramics, the practice of which was still similar to those of pre-Inka times, even though the restructuring of the economic policy within the state brought about significant changes in the newly conquered regions. D'Altroy et al. (1998) point out that those changes led to, for example, a search for greater specialization in the production of certain resources, the control of raw materials and a search for new sources, as well as to a change in certain use contexts, such as consumption within hospitality spaces and sponsorship by the state. In the northwest of Argentina this can be seen, for instance, in the establishment of administrative centers, such as Potrero Chaquiago in the province of Catamarca. This site, built for the administrative requirements of the Inka state, would have included a specific space that would have served as a workshop for the production of high-quality ceramics, such as Famabalasto Black on Red, typical of the eastern regions of the province of Santiago del Estero. Archaeological and ethnohistorical studies suggest that mitimae artisans that specialized in the production of this style may have moved to the area (Lorandi 1983, 1984, 1991; Williams and Lorandi 1986; Lorandi et al. 1991; D'Altroy et al. 1998). Famabalasto Black on Red seems to have been distributed across wide regions of the northwest of Argentina; it can be found in multiple archaeological sites and it must have been used as an element of the social elite because it was used in graves, state buildings and at sites with mixed components (state and local) (Lorandi 1984). Sherds with pyroclastic contents have also been found at this site (Cremonte 1991, 1994).

In Tafí valley (Tucumán), vessels that correspond to groups coming from different regions outside the valley territory have been identified, such as the fragments corresponding to Pacaje and Belén items, coming from the north and south of the territory, respectively (Manasse and Páez 2007). Until now, no evidence that indicates mitimae ceramists had been moved as part of Inka policy has been identified; therefore, complete items may have been circulated as part of different practices related to the establishment of the Inka state in Tafí (Páez 2010a). Again, in this area, significant quantities of sherds tempered with pumice were found. Table 1 summarizes the decorative ceramic styles present in one of the sites assigned to the Inka period in Tafí valley.

The studies we have carried out at the Shincal de Quimivil site, an important Inka capital in the southern provinces (Farrington 1999; Raffino 2004), show that an important amount of provincial Inka-style ceramics was used in the festivities that were sponsored by the state (Giovannetti 2009; Giovannetti et al. 2013). But what is even more interesting is that within the large assemblage of remains that have been analyzed (more than 15,000 at this point), several ceramic fragments coming from very distant regions have been identified (Table 1).

In our opinion, this wide classification would correspond to the movement of foreign items so that they could be used by local elites during festivities and/or political events related to them. We are not going to go into further detail, as this is not the aim of the work presented here, but with these examples we attempt to show how the circulation of pottery in the Inka period in the provincial regions would have been a common practice related to gifts and counter gifts and to the use of state paraphernalia in those places where power had to be shown as state hospitality.

The problem of vitreous inclusions in pottery

An extensive analysis of pottery with vitreous inclusions was carried out by Páez (2010a), focused on ceramic materials from Tafí valley (Tucumán, Argentina). This characteristic was identified in ceramics with varying styles and morphologies, all of which were associated with the Inka period of northwest Argentina. Among these vessels were aribaloids and duck-shaped plates, two forms associated with the presence of the Inka state in the provinces (Bray 2004), as well as other open and closed forms decorated in local styles characteristic of the Regional Development Period (900–1480 AD), use of which would have continued after the arrival of the Inkas. Specifically, these styles represent those known as Belén and Santa María, both characteristic of the *valliserrana* region in the Argentinean provinces of Catamarca and Salta (Fig. 1).

Our understanding of the regional presence of this characteristic has made it apparent that, in addition to being present at the locations mentioned above, it also had a wide distribution involving numerous, far-removed sites in northwest Argentina (Fig. 2). This demonstrates the importance of these ceramics in terms of both the manufacturing practice and their status as a structural factor within the dynamics of Inka production.

Table 1 Decorative styles and their source of origin, present at the archaeological sites of El Shincal and Pucará de las Lomas Verdes

Decorative style	Provenance	El Shincal (Catamarca)	Pucará de las Lomas Verdes (Tucumán)
Yavi	Puna region (Argentina and Bolivia)	X	
Famabalasto Black on Red	Lowlands of the province of Santiago del Estero (Argentina)	X	X
Sunchituyok	Lowlands of the province of Santiago del Estero (Argentina)	X	
Santa María	Yocavil and Calchaquí valleys in the provinces of Catamarca and Salta (Argentina)	X	X
Belén	Hualfin valley in the province of Belen (Argentina)	X	X
Engraved Famabalasto Black	Yocavil valley in the province of Catamarca (Argentina)	X	X
Yocavil	Yocavil valley in the province of Catamarca (Argentina)	X	
Chilean Diaguita	Semi-arid northern Chile	X	
Inka Royal	Central Andes (Peru)	X	
Pacajes or Saxamar	Bolivian altiplano (Bolivia)	X	X

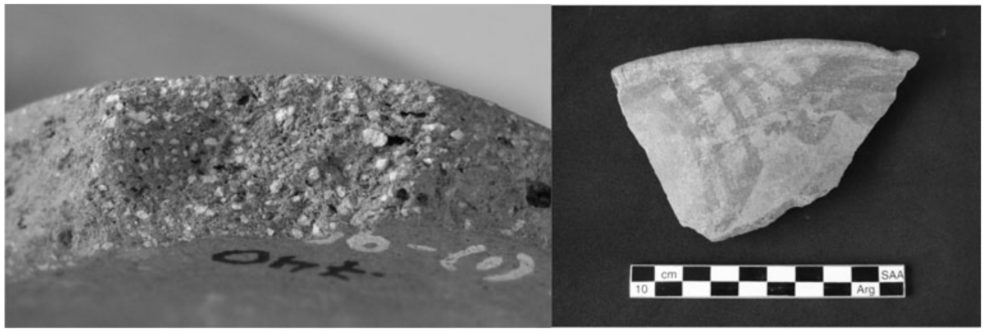

Fig. 1 Ceramic fragment with high levels of pumice inclusions proceeding from Tafí valley (a local style from the Inka period)

In previous work, we have proposed that the manufacturing technique used for the creation of vessels with high amounts of pyroclastic content would have involved intentional mixing of clays with tephra fall deposits of low or medium compaction. In this way, the pumice components would be incorporated as well as the crystalline fraction found in the pastes (Páez and Arnosio 2009). The mixing of the tephra with the plastic fraction would have taken place with the goal of creating vessels with a high density of non-plastic inclusions, and greater homogeneity in terms of components and characteristics.

One of the aspects that first captured our attention, when comparing ceramic sherds with high amounts of added pyroclastics with sherds lacking this feature, was the variation in terms of weight. This would be directly related to the natural vesiculation of the pumice fragments (50–80 % in pore volume), which gives them a low density of generally less than 1 g/cm^3. The low density of the pumice, which allows it to float in water, is a characteristic that would result, according to our hypothesis, in a reduction in the final weight of the ceramics.

In relation to this subject, experimental studies on the use of unconventional prime materials in the modern ceramic industry have demonstrated functional advantages to using volcanic ash (Hevia 2006). In these laboratory experiments, clays were combined with volcanic ash in varying proportions and fired at a range of temperatures. The results revealed, in pastes prepared with the addition of 40–45 % ash and with firing temperatures of 900–950 °C, the following:

1. low-density bricks (1.2 to 1.5 g/cm^3);
2. bricks with a resistance to flexing, similar to that of tile.

Nevertheless, it is important to note that the proportions used in those experiments differed from those recorded for archaeological ceramics. As mentioned above, for the pastes analyzed from Tafí valley, the estimated proportions of pyroclastics vary from approximately 10 to 30 %, and the firing temperatures used were probably also lower. According to indirect estimates obtained using X-ray diffraction, these temperatures would have been around 850 °C (Páez 2005).

However, although the comparison with archaeological vessels is not exact, these industrial studies do provide evidence of the benefits of using pyroclastic prime materials when the potter's intention is to create lightweight and strong vessels. This latter aspect regarding breakage has also been explored in the archaeological literature, concerning the ability of pottery vessels to survive impact (Tite et al. 2001).

Toughness can be a significant factor when it comes to assessing the shock phenomenon among items resulting from the movement and rubbing produced by transporting them. In this sense, the presence of added temper particles results in an advantage, i.e., the toughness of a ceramic containing it, compared with that associated with a homogeneous clay matrix, and this situation is increased with a higher percentage of temper (Tite et al. 2001).

Furthermore, the porosity of pastes with added pyroclastics is greater than that of vessels that lack such inclusions but are otherwise similar in stylistic characteristics, which may be a result of the effects of expansion and contraction of the silica. This factor would affect the resistance of the vessels to breakage, as cracking initiated by a mechanical effect is more quickly halted by the series of empty spaces that is generated around the pumice inclusions. According to Tite et al. (2001, p. 315), "In this case, [ceramic with a high temper concentration and a low firing temperature] the elongation of the crack will be arrested sooner through deflection of the fracture and its bifurcation at the temper/clay matrix interfaces, in addition to the fracture being stopped by the pores. Under these circumstances, although weakened, the vessel can survive and can continue to be used." These authors contrasted the above with pastes created with low temper concentrations and high firing temperatures, where the spreading of fractures is relatively unchecked, causing vessels to become unusable.

In our case, given our hypothesis related to a technological change connected with a desired higher efficiency in the transportation of items, we felt it would be more interesting to focus on the toughness of items rather than their resistance to fracture. An item that is tougher would be more durable when it comes to transporting quantities of them

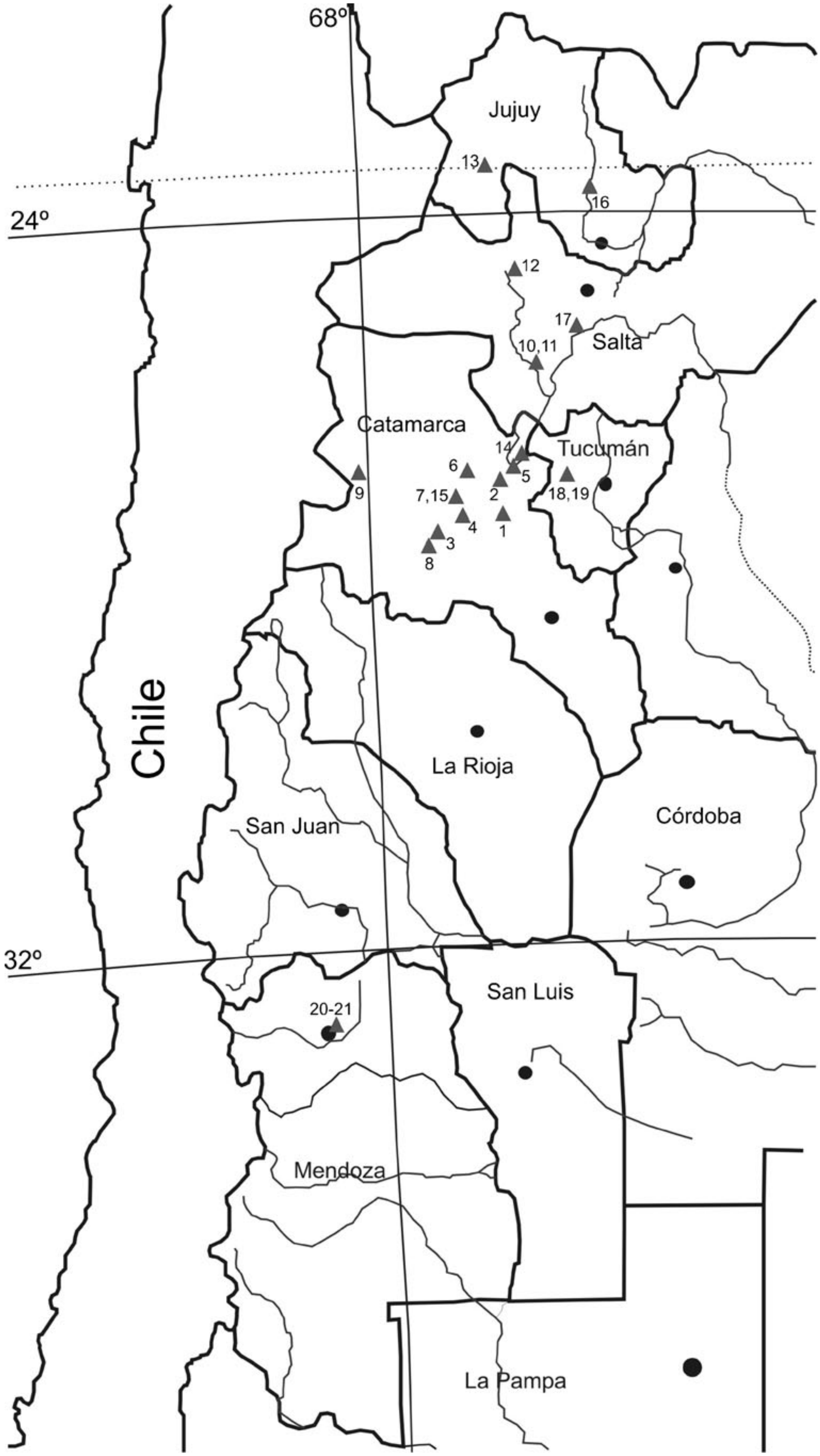

Fig. 2 Distribution of archaeological sites containing pottery with high levels of pumice inclusions. *1*, Potrero Chaquiago (Catamarca); *2*, Ingenio del Arenal Médanos (Catamarca); *3*, El Shincal (Catamarca); *4*, Quillay (Catamarca); *5*, Punta de Balasto (Catamarca); *6*, La Angostura (Catamarca); *7*, Hualfín Inka (Catamarca); *8*, Tambillo Nuevo (Catamarca); *9*, Tambo San Francisco (Catamarca); *10*, Compuel (Salta); *11*, Pucará y Tambo de Angastaco (Salta); *12*, Potrero de Payogasta; *13*, Susques (Jujuy); *14*, Fuerte Quemado (Catamarca); *15*, San Fdo, del V, de Hualfín (Catamarca); *16*, Quebrada de Humahuaca (Jujuy); *17*, Cabra Corral (Salta); *18*, LCZVIIIS1 (Tafí valley, Tucumán); *19*, LC(1) (Tafí valley, Tucumán) (Salta); *20*, Ruinas de San Francisco (Mendoza); *21*, Alberdi e Ituzaingó (Mendoza)

together, where constant movement would cause friction resulting from rubbing.

Also, Schiffer (2003) highlights the importance of differentiating material properties, formal properties and the performance characteristics of vessels. The latter is concerned with the interactions of objects and people in the post-manufacture activities and should be considered in explanations of technological choices.

Our goal of performing a more extensive analysis of the performance modifications found in ceramic pastes with the addition of pyroclastic materials led us to carry out an experimental study orientated initially towards evaluation of the variations in weight produced. First, we attempted to reproduce as closely as possible the composition and characteristics of the archaeological pastes described above. Second, we compared these with pastes in which only the contents of the natural clay were incorporated as inclusions. Finally, we compared the pastes with added pyroclastics with pastes with equivalent proportions of different added materials. Specifically, we used river sand because this is one of the most common components recorded in archaeological pastes from northwest Argentina.

Pastes with high and low levels of pyroclastic contents

Intensive volcanism has occurred from the Miocene to the present along the Andean mountain range, represented by stratovolcanoes and calderas, which make up the main volcanic arc. To the east of this arc a wide range of volcanic activity also occurs, mainly in the areas of northwestern Argentina, northern Chile and south-western Bolivia. This region is known as the Altiplano-Puna Volcanic Complex (APVC) (De Silva 1989), and forms part of the Central Volcanic Zone. Materials erupted from the APVC cover a surface area of 70,000 km^2 and have a minimum estimated volume of 10,000 km^3.

Further south, from the central region of the province of Mendoza to the extreme south of the province of Santa Cruz, significant volcanic activity has also occurred. This area is known as the Southern Volcanic Zone, and is formed by numerous volcanic centers, some of which are still active.

The products produced in the volcanic centers of the main Andean range with the widest areal distribution are tephra fall deposits. These originally had a continuous distribution and covered extensive areas of thousands of square kilometers. However, transport agents such as water and wind redistributed a large portion of this pyroclastic material quickly and mixed it with terragenic material in aeolian, fluvial, and alluvial deposits. The Pampaen loess is an example of the impact that eruptive events have had in the Andean range, where vitreous material has been carried by wind and incorporated into the soils of the plains (1–25 %) along with other components (Teruggi 1957; Teruggi and Imbellone 1983). The composition of the archaeological ceramics from this Pampaen region reflect the geological characteristics of the area, where sediments used in the manufacture of ceramics contain tiny angular particles and fragments of amorphous rounded material (González de Bonaveri et al. 2000).

The published information available regarding the presence of pyroclastic materials in archaeological ceramic pastes describes their occurrence not only in high proportions (10–30 %) but also in significantly lower percentages, as low as 1 %, where the inclusions may have occurred naturally as part of the clay used for manufacture (Páez 2010a, b). Therefore, based upon the differing characteristics and proportions of the pyroclastic materials recorded, two modalities of ceramic manufacture can be established, each with different implications for the production of ceramics and the functional performance of the vessels produced.

Ceramic pastes with low glass content

Analyses of the mineral composition of some clay deposits from regions such as Tafí valley have indicated the presence of quantities of vitreous components similar to those identified in some archaeological ceramic pastes with low proportions. Such clays would be natural sources for direct and unintentional incorporation of vitreous materials into the ceramic pastes (Páez 2010a, b). Pastes with a low glass content occur in vessels of a wide variety of styles and morphologies, and are present in Inka pottery as well as in a broad range of styles attributable to earlier times, including some produced centuries before the arrival of the Inkas. The Regional Development Period and Inka period pottery from Tafí valley represent a well-documented example. In this case, pyroclastic inclusions are small (0.10–0.25 mm) or medium (0.25–0.50 mm) in size, with larger sized particles found only in very low proportions (Páez 2010a). Using AutoCAD 2009 software, which allows the calculation of areas, the proportion of the total area of vitreous particles versus the total ceramic area was calculated in five cases to be no more that 0.2 % (Table 2). Given these low proportions, in addition to the small particle sizes, it seems virtually impossible that this vitreous material could have been separated visually by the potters in order to incorporate it intentionally into the paste.

The particle shapes are variable, although there is clearly a slight predominance of subrounding and rounding, according to the parameters found in Barraclough (1992). The friability of these components must be borne in mind, as they are susceptible to increased rounding through the friction that takes place during aeolian or fluvial transport.

Table 2 Percentage values for the presence of vitreous material in low proportions in the pastes from Tafí valley. The table includes the identification number of the individual sherds, the corresponding archaeological site, and the percentage of vitreous material identified

Identification	Site	% Vitreous material
EL 35	STuc.Tav. 15	0.04
EL 343	STuc.Tav. 15	0.15
LC(1)167	LC(1)	0.17
LC(1)233	LC(1)	0.11
LC50-P-64	LCZVIIIS1	0.12

References: STuc.Tav. 15: El Linde site; LC(1): Chasco Álvarez site; LCZVIIIS1: Pucará de las Lomas Verdes site

The mineral associations also have to be considered. In general, the crystalline fraction (felsic and mafic minerals) dominates the assemblage of non-plastic inclusions, with lithoclasts (small lithic fragments of plutonic, volcanic, and metamorphic origin) and ground pottery also present. All of these components are present in much higher proportions than the pumice.

Based upon these analyses of shape, size, and density, it is most likely that the vitreous content in these pastes has occurred as a natural component of the clays used in the manufacture of the vessels, and its incorporation was not intentional on the part of the pre-Hispanic potters.

Ceramic pastes with a high glass content

The second modality considered differs from the first not only in the proportion of vitreous material but also in the shape, size and selection of the clasts. According to Páez (2010a, b), the shapes and sizes of the pyroclastic particles observed microscopically in the Tafí valley ceramic pastes originating exclusively during the Inka period show a high degree of homogeneity. Most of the shapes recorded show little angularity, and fall into the category of subrounded/rounded. Size analysis shows the highest representation of medium (0.25–0.50 mm) and coarse (0.50–1.00 mm) particles, with small-sized particles (0.10–0.25 mm) present only in very low proportions (Fig. 3). This undoubtedly reflects a careful size selection process. Such selection is not seen in the crystalline fraction, where only small-sized particles of quartz, mica and other associated minerals are observed. In summary, two trends can be distinguished in the size of the clastics included in the pastes: one related to the larger pyroclastic vesicular glass particles and the other associated with the crystalline minerals, which are present in predominantly small sizes.

With regard to the morphology of the vitreous fragments, two types of vesicles can be identified: spherical and tubular, whether integrated in the same fragment or making up the structure of separate individual fragments (Fig. 3f). In these cases, the type of vesiculation indicates the speed and depth at which magma fragmentation took place. If this process occurred at shallow depths, roughly spherical vesicles are formed because there is insufficient time for elongation of vesicles to occur during magma flow. On the other hand, if the flow velocity exceeds that of the air bubble formation, a tubular shape will be produced in response to this movement (Heiken and Wohletz 1991).

The presence of lithoclasts in this type of paste is reduced. The most well-represented particles are those of plutonic origin, followed in decreasing order by volcanic, metamorphic and sedimentary particles. In all cases, there is a predominance of coarse sizes and rounded shapes, which at least discounts the idea of their incorporation through grinding. On the other hand, in pastes with high levels of pyroclastic components, ground ceramic fragments (grog) have not been incorporated. The presence of these two types of inclusions would therefore seem to reflect two mutually exclusive manufacturing techniques (Páez 2010b).

Data were also obtained using the point-counting method for quantification of vitreous material/pumice. For the total number of points counted, the number corresponding to pumice was determined, and a percentage calculation was made in terms of sample volume. The results of this method showed pumice content values of between 15 and 20 %, a significant percentage and one notably higher than in those ceramic pastes with low glass content (Table 3).

Experimental study: materials and methods

Our experimental study of ceramics with pyroclastic inclusions was performed through the creation of briquettes (tablets of standardized size), with controlled percentages of pyroclastic inclusions added (Fig. 4). For purposes of systematic comparison, a set of briquettes was also created with similar percentages of sand inclusions, as well as a set with no inclusions added.

Two distinct types of clay deposits were used in order to account for differences that may have existed in their non-plastic prime materials, which could potentially affect the characteristics of the briquettes. One set of samples was produced using clay from the La Bolsa sedimentary profile (Tafí valley, Tucumán), while the other source came from an area near El Shincal known as La Cañada (Londres, Catamarca). The pyroclastic inclusions used came from a single source in Antofagasta de la Sierra, in the Puna region of Catamarca, which had been collected as a geological sample of volcanic tuff with a medium level of consolidation. The sand used came from the last section of the Tafí river.

Briquettes were produced with similar standardized volumes of approximately 25 ml. First, two briquettes were produced, one from each of the two clay sources [La Cañada (LC) and La Bolsa (LB)], without intentional addition of any

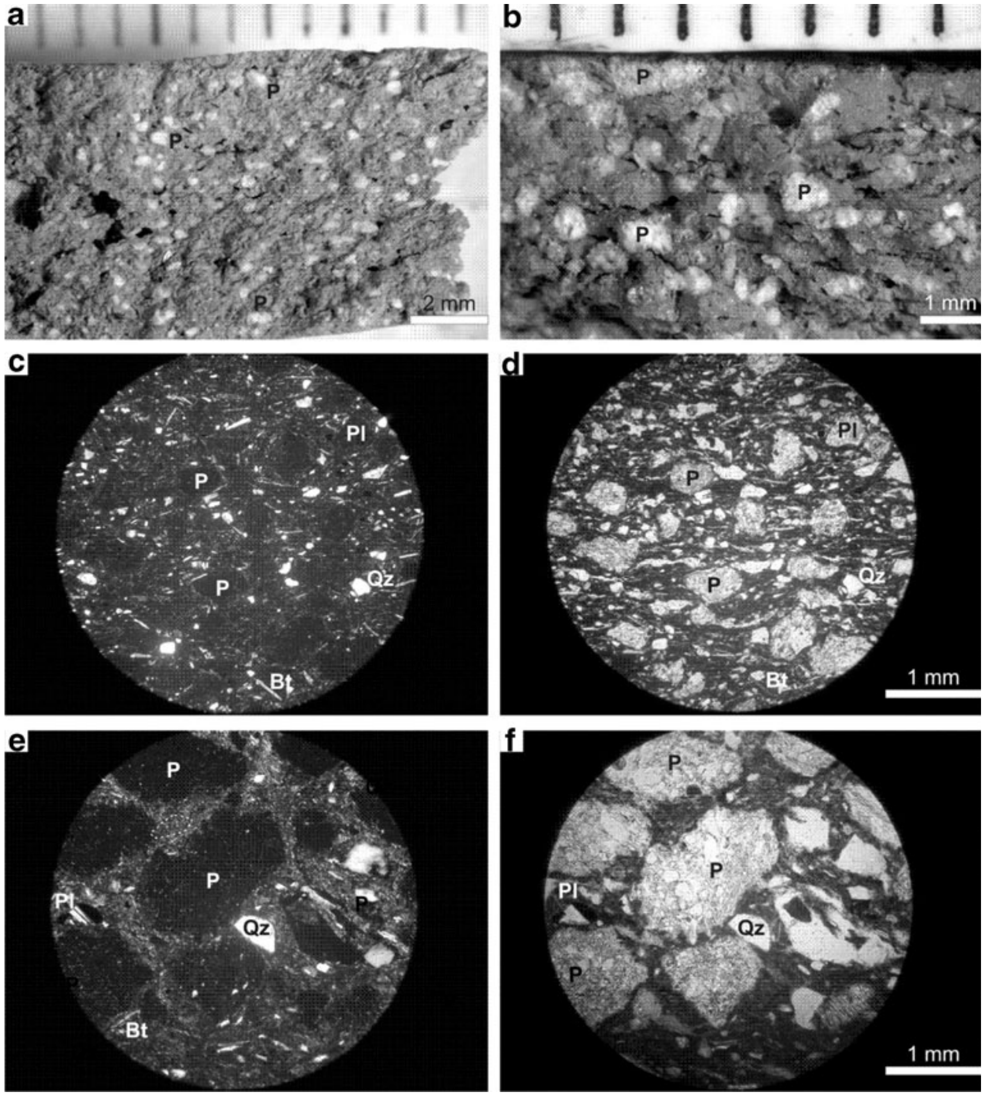

Fig. 3 Photomicrographs of ceramic pastes with high levels of pumice inclusions. **a**, **b** Observations with a binocular microscope at low magnification (×20 to ×40), which indicate the pumice (*P*). **c**–**f** Observations with a petrographic microscope at different magnifications. Inclusions of pumice (*P*), crystals of plagioclase feldspar (*Pl*), quartz (*Qz*), and biotite (*Bt*), and orientated voids are observed. **c**, **e** Polarized light; **d**, **f** non-polarized light

non-plastic components. Next, a series of briquettes was produced with various percentages of inclusions introduced (Table 4).

The preparation of the samples with inclusions introduced was carried out using beakers and graduated cylinders. The

Table 3 Percentage values for the presence of vitreous material in the pastes with high proportions from Tafí valley. The table gives the sherd identification number, the corresponding archaeological site and the number of counted points upon which the quantification was based

Identification	Context	Number of points	% Vitreous material
LC(1)	LC(1)	2,794	17.18
PME-1	LCZVIIIS1	3,078	18.35
PME-16	LCZVIIIS1	3,221	18.78
PME-17	LCZVIIIS1	3,873	15.16
PME-18	LCZVIIIS1	4,050	15.21

References: LC(1): Chasco Álvarez site; LCZVIIIS1: Pucará de las Lomas Verdes site

Fig. 4 Briquettes with controlled percentages of inclusions added. **a** 30 % sand (Tafí); **b** 30 % pyroclastic inclusions (Tafí); **c** 30 % pyroclastic inclusions (El Shincal); **d** 20 % sand (Tafí); **e** 30 % pyroclastic inclusions (Tafí); **f** 20 % pyroclastic inclusions (El Shincal)

Table 4 Proportions of clay and inclusions used for creation of the briquettes

	Clay		Inclusions	
	%	ml	%	ml
Briquette 2	95	23.75	5	1.25
Briquette 3	90	22.50	10	2.50
Briquette 4	85	21.25	15	3.75
Briquette 5	80	20.00	20	5.00
Briquette 6	70	17.50	30	7.50

tephra fall sample required gentle grinding in a mortar to disaggregate the material and create a size fraction corresponding to that observed archaeologically. The sand was added as it naturally occurred, but with grain sizes larger than 1 mm removed, as they may have caused breakage in the briquettes during firing. These inclusions were then mixed with the clay, and the briquettes were formed and fired at a temperature of 850 °C. The final step was measurement of the weights using a precision electronic balance.

It should be mentioned that all of the samples shown in Table 3 were made from the clay from La Cañada (Londres), while the samples with 10, 20, and 30 % inclusions, which were the percentages most closely related to archaeological specimens, were made with the clay from La Bolsa (Tafí valley).

The total number of briquettes made and analyzed was 18, which consisted of:

(a) two briquettes made with pure clay, one from La Bolsa clay (Tafí valley) and the other from La Cañada clay (Londres);
(b) ten briquettes made with La Cañada clay, five with the tephra fall material, and five with river sand;
(c) six briquettes made with La Bolsa clay, three with the tephra fall material and three with river sand.

Results

The measurements taken of briquette weights allowed some basic observations to be made regarding the objectives of the experimental study (Table 5), as follows.

Relationship between the weight of the pure clay briquettes and those with pyroclastic contents

Case 1, La Cañada

A reduction in weight was seen with the pastes with pyroclastic contents, even in the samples with the lowest proportions added (5 %), and this loss in weight remained proportional with increasing densities of inclusions incorporated. The maximum values of weight loss were seen with the incorporation of 20 and 30 % pyroclastic content, these being substantial. Using these data, estimations were made regarding the weight reduction for a hypothetical archaeological vessel: an Inka jar weighing 5 kg. This example suggested that with 20 % inclusions, which is the most common proportion in archaeological pastes, the reduction would be 0.4145 kg (414.5 g). In other words, given two jars of equal volume, one would weigh 5 kg if made with pure clay (no added inclusions), and the other 4.585 kg with a 20 % density of pyroclastic inclusions.

Even higher weight reduction values were obtained when 30 % inclusions were added. Summaries of each of the density variables, together with their corresponding application to the hypothetical example, are presented in Table 6.

Case 2, La Bolsa

In a similar manner, for the case of briquettes made with La Bolsa clay from Tafí, a weight reduction was seen beginning with the lowest percentages of tephra fall deposits incorporated. In the samples with 20 and 30 % proportions, reductions of 8.50 and 11.93 %, respectively, were seen in relation to the paste made with pure clay. Compared with the similar briquettes made from the La Cañada clay, the weight reduction values obtained with the La Bolsa clay showed slight differences (Table 6).

Returning to the hypothetical jar example, the weight reduction was 425.5 g with 20 % inclusions, which increased to 596.5 g with a further increase in the pyroclastic contribution.

Relationship between the briquettes with added sand and the briquettes with added pyroclastic contents

Case 1, La Cañada

In contrast with the results seen for the addition of tephra fall materials, the addition of sand created increases in briquette weight, starting with the lowest percentages (5 %) and becoming more pronounced with higher amounts. This effect occurred with both the La Cañada and La Bolsa samples.

It can be expected, therefore, that when comparing the weight of briquettes having equivalent proportions of either pyroclastics or sand, significant differences will be seen in terms of lower weights for those that contain the vitreous material. In the first case analyzed (Table 7), this difference in weight reduction was progressive, with values close to or greater than 20 % in pastes with proportions of inclusions of 20–30 %. Applied to the hypothetical example, two jars of equal volume and 20 % inclusions of either pyroclastics or

Table 5 Weight in grams of the briquettes created using pure clay from La Cañada (LC) and La Bolsa (LB), and with inclusions added (tephra fall deposit and sand) for both clays

%clay/inclusions/25 ml	Weight (g)					
	Tephra deposit		Sand		Pure clay	
	LC	LB	LC	LB	LC	LB
100/0					52.26	49.28
95/5	51.37		52.98			
90/10	50.33	47.50	54.88	51.11		
85/15	49.77		56.63			
80/20	47.93	45.09	58.75	54.71		
70/30	45.47	43.40	60.32	57.60		

sand would have a difference in weight close to 1 kg, the vessel with added sand weighing 5 kg and the one with added pyroclastic components weighing 4.079 kg. As mentioned above, this difference in type of added material not only leads to a clear reduction in weight, but also creates greater resistance to breakage, bestowing this added advantage on vessels with high contents of non-plastic contents. The same would be expected if the proportion of inclusions was increased to 30 %, with even more pronounced differences anticipated.

Case 2, La Bolsa

An identical situation was seen when comparing the weights of the briquettes made from the La Bolsa clay from Tafí valley (Table 7). In this case, the differences were slightly less, as was also seen in the comparison between briquettes made with tephra fall materials added and those made with pure clay. This probably reflects intrinsic differences in the characteristics of the two clay sources.

In summary, in both cases 1 and 2 the same pattern was seen: (a) an increase in weight for briquettes with added sand versus briquettes of pure clay, and (b) a decrease in weight of briquettes with pyroclastic content compared with those incorporating sand in equivalent proportions. Despite minor variations, the values obtained in both cases were largely similar and therefore both support the interpretations made.

Discussion and conclusions

Reduction in vessel weight, which would confer an advantage on the use of pyroclastic materials, is seen not only in

Table 6 Summary of decreased weight according to the proportion of pyroclastic inclusions (PI) compared with pure clay, and application to a hypothetical archaeological example. Case 1 (La Cañada) and Case 2 (La Bolsa), respectively

Density of PI (%)	% Reduction in weight	Hypothetical example applied (5-kg jar)	
		Decrease (kg/g)	Final weight (kg)
Case 1. La Cañada (LC)			
5	1.70	−0.085/85.0	4.915
10	3.69	−0.1845/184.5	4.8155
15	4.76	−0.238/238.0	4.762
20	8.29	−0.4145/414.5	4.5855
30	13.00	−0.65/650.0	4.350
Case 2. La Bolsa (LB)			
5	–	–	–
10	3.61	−0.1805/180.5	4.8195
15	–	–	–
20	8.50	−0.425/425.0	4.575
30	11.93	−0.5965/596.5	4.4035

Table 7 Summary of the decrease in weight according to the proportion of pyroclastic inclusions compared with the same proportions of sand (S), and application to a hypothetical archaeological example. Case 1 (La Cañada) and Case 2 (La Bolsa)

Density of S (%)	% Reduction in weight	Hypothetical example applied (5-kg jar)	
		Decrease (kg/g)	Final weight (kg)
Case 1. La Cañada (LC)			
5	3.04	−0.152/152.0	4.848
10	8.29	−0.4145/414.5	4.586
15	12.11	−0.6055/605.5	4.395
20	18.42	−0.921/921.0	4.079
30	24.62	−1.231/1,231.0	3.769
Case 2. La Bolsa (LB)			
5	–	–	–
10	7.06	−0.353/353	4.647
15	–	–	–
20	17.58	−0.879/879	4.121
30	24.66	−1,233/1233	3.767

comparison with pastes with equivalent proportions of sand but also with vessels with no intentionally added inclusions. The use of pyroclastic materials can be seen as a technological option that can achieve:

1. a reduction in weight that, when high proportions are used, can be around 10 % in relation to pure clay and 20 % in comparison with the use of sand
2. greater resistance to vessel breakage with incorporation of higher amounts of non-plastic inclusions.

The experimental replication of pastes with various proportions of pyroclastic content has allowed us to confirm securely the first of these two proposals. The reduction in weight is most notable with higher proportions of added inclusions (10–30 %), similar levels to those observed archaeologically.

In agreement with prior studies of pre-Hispanic ceramics, the use of this manufacturing technology would have had important implications regarding production, being linked to standardization in the preparation of pastes, which involves both the nature of the pyroclastic deposit utilized as well as the proportions in which the material is mixed with the clay (Páez and Arnosio 2009; Páez 2010a, b, 2011). Archaeologically we have seen a pattern in which vessels with high percentages of non-plastic inclusions, from 10 to 30 %, are represented in greater quantities than those with the same decorative styles but lacking pyroclastic components.

The identification of this characteristic in contexts associated with the Inka period in northwestern Argentina suggests a technological change compared with the manufacturing process during earlier periods of pre-Hispanic sociocultural development. In those earlier periods, the presence of vitreous volcanic material in archaeological pastes seems to have occurred only in low proportions and appears to been a natural phenomenon, explained by its presence in the clays used in manufacture (Páez 2010b).

There is also a highly significant pattern involving the presence of high proportions of pyroclastic components in decorated ceramics of the Inka, Belén and Santa María types. This use of the technique involves vessels with a high symbolic value that were probably used in festive contexts or for elite practices. This reveals that the majority of the Inka plates and jars would have been part of the paraphernalia associated with state-level practices (Bray 2003a, b, 2004). It is likely that, in these contexts, high levels of exchange of objects would have been part of a regular and commonly occurring system. In this regard, ethnohistorical information highlights the importance of the movement of objects in the context of pilgrimages and special festivals on the coasts and in the mountains of Peru (Rostworowski 1999). Rostworowski (1999) specifically points out the interchange of goods and the system of exchange, rooted in the altitude-linked ecological settings of the pilgrims' places of origin and those of their gathering places. Along the same line as the ethnohistorical work, Murra (2002) has argued for the existence of particular centers of ceramic production (*los olleros del Inca*) specializing in the production of provincial Inka ceramics. This leads logically to the idea of an intensive movement of manufactured goods, based above all upon the need for their use in contexts of festive congregation, both for welcoming the assembled multitudes, for example through distribution of *chicha*, and as part of the gifts and offerings. The concept of production in specialized centers would also explain to a large degree the standardization seen in the manufacturing of pastes with a high pyroclastic content. Another key element for testing this is the fact that we have not found a single ordinary pottery shard, i.e., one without decoration and used for cooking, that has a high proportion of pyroclastic inclusions in the paste. Apparently the manufacturing of rough vessels would not have been carried out by specialists, but would have occurred in the same place as the intended use. It seems to be clear that the workload, experience and skill to make a vessel of Inka, Santamaría, or Belén type cannot be compared with the production of ordinary vessels for cooking, which, among other characteristics, do not have paint on their surface.

Regarding this, transportation would have taken place with the use of droves of llamas. Our proposal helps to visualize a scenario where each llama would have carried several ceramic items onwards from their place of origin. We think only empty ceramic items were transported. The pottery would have been used as preparation, cooking, serving, or consumption vessels (or other uses, such as sahumar during rituals) at the places where the feasts and ceremonies were held. Also, a large number of vessels were used as part of the political commensalism of the elites when offered at meetings. Each llama can carry up to 40 kg. If we think of objects such as dishes, which do not commonly exceed 1 kg, then more than 40 objects of this type could have been carried on a single animal. Many dishes with pyroclastic components have been found in northwest Argentina archaeological sites (Páez and Giovannetti 2008). It is more difficult to make a similar calculation for aribaloids because they vary greatly in size, from small items of 2 kg to large items of 20 kg. Most pyroclastic inclusions in ceramic remains belong to aribaloids. If these were carried empty, there could have been up to ten on a single animal in the case of the smaller examples.

Our proposal, based upon the results presented in this work, supports the idea that a new production technology was achieved through the mixing of clay and pyroclastic deposits. This would have favored the creation of vessels that were lighter in weight and more resistant to breakage, and which could be transported, in large quantities, over medium and long distances with a high level of efficiency. This would have been part of the structure of a state that tended to sponsor large-scale communal events, probably related to a strong mechanism for ideological control (Uribe 2004; Giovannetti 2009).

In this sense, it is important to analyze how this technological change would have occurred within pottery production during the Inka period in northwest Argentina. Taking into account the possible existence of ceramic manufacturing centers, as Murra (2002) has proposed, the state required and demanded a great quantity of vessels for use in those places where the festivities, ceremonies, and meetings took place, as clearly exposed by Dillehay (2003) in the Andes. According to our investigations, the El Shincal site would have been a meeting place for large reciprocal banquets sponsored by the state. The Pucará de las Lomas Verdes site is in a border region, where meetings for exchange and political negotiation would have required the Inka object paraphernalia to comply with existing protocols. In both sites the decorated pottery, but not the domestic pottery used for cooking, has high frequencies of pyroclastic inclusions in the pastes. The El Shincal site appears to have a large number of objects that were discarded after the popular meetings, highlighting their importance in these contexts.

The inclusions cannot be appreciated on the surface of the ceramic. This characteristic can only be observed when the vessel breaks. The exterior decoration of the pottery shows the rich variety of the Inka designs: Inka mixed, and the Santa María and Belén local designs. Thus it is clear that the inclusions were not a trait to be seen. Thus, the reduction in the vessel weight and the increase in toughness of the vessels with high levels of pumice inclusions represent an advantage for the transportation of items to be used at the sites mentioned. However, it must be emphasized that, as is mentioned by Neupert (1994), the increased strength is appropriate to "extend vessel use life, broaden vessel function, and facilitate the expansion of trade and exchange networks." It is evident that the use of pumice inclusions in the making of ceramics would have led to an improvement in the transportation of vessels carried by a drove of llamas, and would have ensured that the items arrived at their final destination without damage. On the basis of our investigations (Giovannetti et al. 2013), a large number of objects was used in each celebration and ceremony at the El Shincal site, as seen in the excavation of the discard area. Thus, overall, the evidence suggests that the process of pottery manufacturing would have played an important role in the running of the state machinery linked to festive occasions within the Inka Empire.

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