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Petrographic characterization and identification of temper sources in local ceramics during the Inca domination and early Spanish colony (Mendoza, west-central Argentina)

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ABSTRACT

This work relies on the potential use of petrography to determine temper provenance and applies it to ceramics of west-central Argentina. Petrography is used to identify the raw materials, production technologies and, for the first time in this region, temper provenance of the Viluco ceramics of mixed Inca type produced by local Mendoza Valley populations during the Inca domination and early Spanish colony (XV–XVII centuries), along the eastern-meridional boundary of both empires. Although the area is geologically complex, being characterized by the Andes Cordillera to the west and the arid plains to the east, isolated outcrops were identified near archaeological sites and comparative petrographic studies of ceramic and geological samples were conducted. The results show that the ceramics were produced with locally available raw materials. The comparative analysis permitted identifying two sources of temper located near the archaeological sites in the Mendoza Valley: the granite stock of Cerro Cacheuta and the volcanic ash (tephra) from El Borbollón. The evidence allows suggesting that the population concentration process that was developed in the short period between the Inca Empire and the early Spanish colony in the Mendoza Valley, required the local production of Viluco ceramics. The use of local tephra inclusions, confirms that this particular tradition related to the Inca expansion and infused with symbolic significance in the marginal southern borders, was developed locally by potters as part of their membership to the Inca Empire.

1. Introduction

The purpose of this paper is to petrographically characterize and study the provenance of the temper of Viluco ceramics of the mixed Inca type. This pottery was made by the local population in west-central Argentina between the 15th and 17th centuries, a short and complex period characterized by the Inca domination and followed by the early Spanish colony. This is the first temper provenance study on the Viluco ceramics from the eastern meridional border of both empires.

It has been proposed that "*petrography is a powerful method for determining pottery provenance based on the composition of rock and mineral inclusions incorporated within the clay body at the time of production*" (Whitbread and Mari, 2014:79). This proves a difficult task because, according to the provenance hypothesis, the variation between potential sources needs to be greater than that within a single source (Wilson and Pollard, 2001). Therefore, using the compositions of rock and mineral inclusions to determine provenance involves demanding requirements because all potential sources should be taken into consideration when identifying (a) whether the pottery at a site was locally produced or imported and (b) if the latter, then identifying its likely origin (Whitbread and Mari, 2014:79). As mentioned, fulfilling these requirements is particularly challenging in geologically complex areas, where similar raw materials may occur in several locations (Whitbread and Mari, 2014). In the north of the Mendoza province, the geology is complex and many outcrops are very widespread. However, there are also isolated outcrops that are well characterized geologically and are located near the archaeological sites of the Mendoza Valley (city of Mendoza) where the Viluco pottery is concentrated. The comparative study was conducted on the petrography of the ceramics from these sites and the geological samples from these isolated outcrops.

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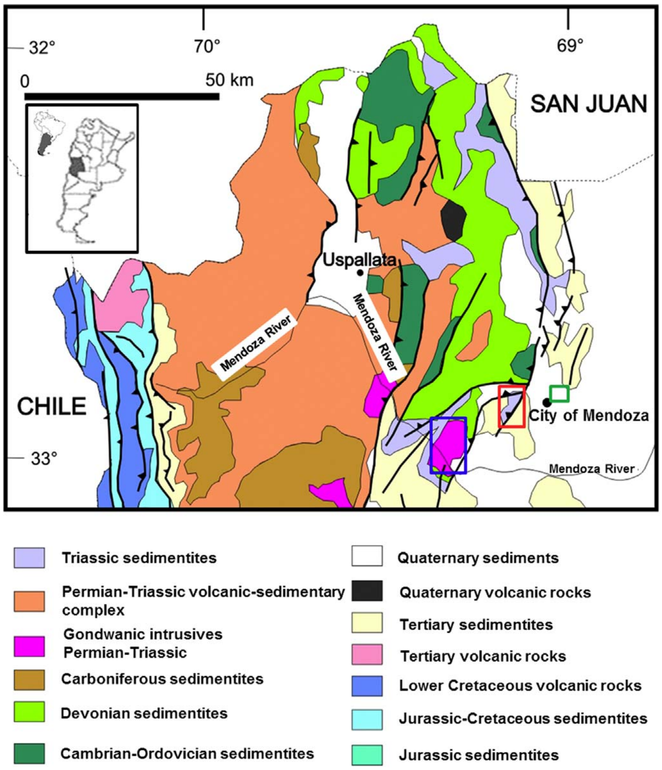

Fig. 1. Geologic sketch of the northern part of the province of Mendoza, with the location of the studied archaeological sites (city of Mendoza) and the sampled geological formations (blue rectangle: Cerro Cacheuta; red rectangle: Divisadero Largo; green rectangle: El Borbollón). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: modified from Spalletti and Veiga (2007).

2. Archaeological background

The study area is located in the northern part of the Mendoza province, west-central Argentina, between 32°06′31.33″ S–68°55′51.23″ W and 33°03′02.37″ S–68°49′42.17″ W (Fig. 1). The area belongs to the South American Arid Diagonal, which is characterized by a large difference in altitude from west to east among the main geomorphological regions: mountains (comprising the Andean Cordillera and the Precordillera), foothills (piedmont) and plains.

The local population that produced Viluco ceramics occupied the southern San Juan province and the northern and central Mendoza province (Lagiglia, 1978; Chiavazza, 2010; Prieto Olavarría, 2012) between the middle of the 15th and 17th centuries. During the Inca domination (between 1470/1480 and 1532/1536 A.D.), they inhabited and worked in Inca *tambos* in the inter-Andean Uspallata Valley under the direct control of imperial administrators. Furthermore, this group settled in the Mendoza Valley (piedmont) as a result of a population concentration process that began during the Inca Empire (Bárcena, 1994) and was continued by the European conquerors (Parisii, 1994) who founded the city of Mendoza there in 1561.

Complex societies, such the Inca state, have made use of different supports to communicate cultural values and determine relationships. The Inca ceramics played an active role in state legitimization and control through the diffusion of designs (shape and decoration) and production technology (D'Altroy et al., 1994; Bray, 2003; Williams et al., 2005). In distant regions from the imperial centre in Cusco, such as northern Mendoza (Prieto Olavarría, 2012), the authority continued in local leaders who were politically and ideologically integrated into the empire and pottery acted as a political tool for the legitimation of power and hospitality (Williams et al., 2005). The imperial Inca ceramic had the highest value among the different ceramic types that circulated through the empire, but it is scarcely represented in the periphery of the state, as is the case in the Southern Andes. In this context, some ceramic types of diverse origins circulated through the provinces while others were produced locally. Many of these local types had imperial legality and their stylistic variety evidences the interaction between different socio-political and ethnic groups, whereby some stylistic elements are associated with ceramic traditions of the governing groups and others with those of the dominated groups (D'Altroy et al., 1994).

The Viluco mixed Inca type analysed in this paper is one of these local types and is represented in funerary (Fig. 2a–b) and domestic contexts of west-central Argentina (Lagiglia, 1978; Novellino et al., 2003; Ots, 2008; Prieto Olavarría, 2012). It is characterized by shapes and decorations made according to parameters of Inca pottery but also inspired by other nearby pottery traditions, such as those of Central Chile, Chilean Norte Chico and traditions of the Southern Andean region like from north-west Argentina (Lagiglia, 1978; Prieto Olavarría and Tobar, 2017). This ceramic type is very abundant in the Mendoza Valley domestic sites (Fig. 2c–d), and in view of the permanent character of the occupations and the population concentration process, it has been proposed that pottery was manufactured in those settlements (Prieto Olavarría, 2012).

Preliminary petrographic studies suggested a close relationship between raw materials and local geology. The non-plastic inclusions are mainly of felsic minerals (quartz and feldspars) and mesosilicic to acid igneous rocks, both volcanic (andesites, dacites and rhyolites) and plutonic (granites and granodiorites). Fragments of low-grade metamorphic rocks (quartzites/metapelites) are scarce and can be correlated to the regional crystalline basement (Prieto Olavarría, 2012).

A group of Viluco vessels containing high percentages of volcanic ash temper (Prieto Olavarría and Castro de Machuca, 2015) is part of an extended tradition present in local ceramic types of north-west Argentina and such a tradition was introduced during the Inca domination (Cremonte, 1994; Páez and Arnosio, 2009). Exploratory petrographic and Scanning Electron Microscope studies indicated that these Viluco ceramics were manufactured locally and it was postulated hypothetically that the raw materials came from pyroclastic deposits (Prieto Olavarría and D'Angelo, 2013).

Fig. 2. Viluco ceramics of the mixed Inca type. a) funerary jar from Beltrán y Liniers (city of Godoy Cruz, Mendoza Valley); b) funerary bowl from Agua Amarga (Tupungato, Uco Valley); c–d) fragments of jar (c) and bowl (d) from Ruinas de San Francisco domestic site (city of Mendoza, Mendoza Valley).

A comparative study of ceramic types containing high percentages of volcanic ash temper recovered from the eastern meridional border of the Inca Empire (Santa María and Inca Local styles from the Tafí Valley, north-west Argentina) and its southernmost limit (Viluco mixed Inca type from the Mendoza Valley, west-central Argentina), indicates that in both areas this was standard practice and they made use of tephra from pyroclastic fall deposits. Furthermore, these vessels have morphological and decorative attributes related to the Inca imperial styles. The results allowed proposing that these ceramics were part of the same tradition associated with the Inca expansion in the marginal southern areas and, according to the historical and archaeological contexts, volcanic ash temper had a symbolic significance and were part of the state strategies of domination in these regions (Prieto Olavarría and Páez, 2015).

Moreover, Viluco dishes were discovered in domestic contexts of the 16th and 17th centuries in the Mendoza Valley. They correspond to a different Viluco ceramic type, known as colonial Viluco type because they mix local indigenous and European pottery traditions (Prieto and Chiavazza, 2009).

3. Ceramic sampling and analytical methods

Forty-one fragments of Viluco ceramics of the mixed Inca type from three nucleated domestic sites located in the main occupation area of the Mendoza Valley (city of Mendoza) were analysed: Ruinas de San Francisco, Alberdi e Ituzaingó and Edificio Plaza Huarpe (Table 1) (Fig. 1). They exemplify the two most represented Viluco shapes in the study area: bowls and jars (Prieto Olavarría, 2012). The selection was based on a previous grouping of fresh cuts under a binocular stereomicroscope (10–60 × magnification).

Petrographic fabric groups were defined by the nature of the dominant inclusions and then were subdivided into fabric classes with more specific compositional and textural characteristics (Whitbread and Mari, 2014). Standard petrographic thin sections were cut vertically through the vessel rims (Whitbread, 1996) or necks. This holistic descriptive approach focuses on the more important aplastic inclusions, the nature of the clay matrix, and permits detecting microstructural and textural evidence in thin sections (Quinn and Burton, 2009, 2016). The matrix-inclusions percentage estimate was based on the visual estimation of percentages technique (Mathew et al., 1991).

4. Geological setting and samples

The geology in the northern area of the Mendoza province is complex. Three main geologic provinces are recognized west of the Mendoza Valley: a) Andean Main Cordillera, b) Andean Frontal Cordillera and c) southwest Precordillera. To the east, the Eastern Plain (Cuyo Plain) is crossed by the Mendoza and Tunuyán Rivers, which are tributaries of the Desaguadero River.

Table 1
Analysed fragments of Viluco ceramics of the mixed Inca type. Samples MDZ003, MDZ004, MDZ005, MDZ006, MDZ007, MDZ 009, MDZ010 were previously published (Prieto Olavarría and Castro de Machuca, 2015).

Shape	Samples of archaeological sites		
	Ruinas de San Francisco	Edificio Plaza Huarpe	Alberdi e Ituzaingó
Bowl	MDZ006/MDZ007/12DOC 3613DOC/13DOC/15DOC 16DOC/14DOC/22DOC/ 17/24/1177/5145DOC	MDZ005/ 451DOC/44DOC	MDZ008/MDZ009/ MDZ010/10DOC
Jar	27DOC/33DOC/35DOC/ 3DOC/523/1302/ 1356DOC/38ADOC/ 38BDOC/5518DOC/4	MDZ003/ MDZ004/ 41DOC/42DOC	5DOC/36DOC/ 39DOC 2443DOC/ 5415DOC/43DOC

Bearing in mind the variety and great extension of plutonic, volcanic and sedimentary outcrops in the area, attention was focused on the geological formations that outcrop close to the main area of indigenous settlements in the Mendoza Valley. The exposed rocks represent most of the stratigraphic chart, except for Precambrian, Upper Jurassic and Cretaceous strata (Fig. 1). The Mendoza River crosses the entire lithological sequence from west to east for 273 km.

To compare with the ceramic thin sections, nine samples of isolated outcrops near the archaeological sites were collected and also examined petrographically in thin sections: the Cerro Cacheuta granitic stock, mafic dykes and sands from terraces of the Mendoza River near the Cacheuta Stock, sedimentary rocks and corresponding sands from the Papagayos and Mariño formations (Divisadero Largo) and samples from the El Borbollón tephra (Fig. 1). In addition, five samples of sands from the Divisadero Largo creek and Mendoza River were analysed.

The Cacheuta Stock granite (≈ 33° S–69°7′ W) is situated in the Precordillera, 20 km west of the city of the Mendoza (Fig. 1). It lies in a NNE/SSW trending basin of mainly acidic volcanic rocks of the Choiyoi Group (Lower Triassic) and syn- and post-rift sedimentary rocks of Upper Triassic age (Cingolani et al., 2012). This stock has an ellipsoidal outcrop pattern with a NNE-SSW trending long axis, and its area is approximately 70 km^2. The Cacheuta granite can be subdivided into two discrete facies: 1) rapakivi granite and 2) 'normal' granite containing coarse K-feldspar, quartz, plagioclase, biotite flakes and occasional euhedral hornblende. Dykes of more mafic composition cut the outcrop.

The Choiyoi Group of Permian-Triassic age (Gondwanic magmatism) is dominant in the Frontal Cordillera and covers a large area of the Precordillera. The upper part of this igneous sequence is composed of huge volumes of sub-volcanic, volcanic and pyroclastic rocks that are mainly rhyolitic in composition, while the lower sequence is composed of mesosilicic to basic rocks (andesites and basalts). In the study area, the Choiyoi Group is represented by the Tambillos Formation (welded tuffs, rhyolites and calcarenites) and Mal País Formation (andesites, dacites, tuffs and volcanic breccias), which surround the Cacheuta Stock (Cortés et al., 1997, in Folguera et al., 2003).

Cenozoic outcrops are found in the Divisadero Largo area located 8 km west of the city of Mendoza (Fig. 1). Simpson et al. (1962) recognized the basal Papagayos Formation (conglomerate, sandstones and siltstones) and the Divisadero Largo Formation. The latter is characterized by clashing siltstones and claystones as well as yellowish grey medium- and fine-grained sandstones with fossiliferous (mammalian) content interbedded with gypsum/anhydrite levels. The sequence is overlaid by the Mariño Formation, a continental clastic sequence that reaches a thickness of 1900 m (Cerdeño et al., 2006).

The El Borbollón anticline is an active growing structure located 5 km northeast of the city of Mendoza. Its outcrops are small and isolated and are practically unrecorded in the geological literature. They are homogeneous in nature, consist mainly of cineritic layers of essentially white ash-fall tuffs of Late Quaternary age (Olgiati and Ramos, 2003) and are derived from the active volcanic arc in the southwest of the Mendoza province and south of the Tupungato volcano.

5. Results of the petrographic studies

Three ceramic petrographic fabric groups were defined: Granitic, Volcanic and Sedimentary. Each group was subdivided into fabric classes (Table 2) based on more specific compositional and textural characteristics (Table 3).

5.1. Granitic fabric group

5.1.1. Coarse granite fabric class (Fig. 3a, c)

In this fabric class, all of the inclusions were found in granitic rocks. The dominant crystal clasts are of strongly argillitized microperthitic K-feldspar occasionally with tartan twinning, quartz-rich fluid inclusions and twinned oligoclase with slight sericitic alteration. The mafic

Table 2
Petrographic fabric groups and fabric classes of the mixed Inca-type Viluco ceramic samples. The plus minus sign (±) indicated the presence, in greater or lesser quantity in each sample, of crystal clasts and lithoclasts from different origins in the fabric classes.

Fabric group	Granitic					Volcanic						Sedimentary
Fabric class	Coarse granite	Coarse granite ± volcanic ± sedimentary	Coarse granite ± claystone	Fine granite ± claystone	Fine granite ± limestone	Coarse volcanic-rich	Fine volcanic-rich	Coarse volcanic ± sedimentary ± granite ± metamorphic	Fine volcanic ± sedimentary ± granite ± metamorphic	Coarse pumice-rich	Fine pumice-rich	Coarse sedimentary ± volcanic
Samples	5DOC 12DOC 27DOC 33DOC 35DOC 41DOC 42DOC 1356DOC 3613DOC	13DOC 38ADOC 38BDOC 4	MDZ008	15DOC	16DOC	MDZ003 MDZ004	3DOC 14DOC 451DOC	MDZ005 MDZ006 22DOC 2443DOC 5415DOC	36DOC 39DOC	MDZ009 MDZ010 17 24 523 1177 1302	MDZ007 43DOC	10DOC 44DOC 5145DOC 5518DOC

Table 3
Attributes of the inclusions found in the mixed Inca-type Viluco ceramics, according to fabric class.

Temper and textural attributes	Granitic fabric classes					Volcanic fabric classes						Sedimentary fabric class
	Coarse granite	Coarse granite ± volcanic ± sedimentary	Coarse granite ± claystone	Fine granite ± claystone	Fine granite ± limestone	Coarse volcanic-rich	Fine volcanic-rich	Coarse volcanic ± sedimentary ± granite ± metamorphic	Fine volcanic ± sedimentary ± granite ± metamorphic	Coarse pumice-rich	Fine pumice-rich	Coarse sedimentary ± volcanic
Shape	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular	Angular to subangular
Size	Crystal clasts ≤ 0.1 mm Lithoclasts 0.2 mm to 1 mm	Crystal clasts and lithoclasts ≤ 0.1 mm to 2 mm	Crystal clasts ≤ 0.1 mm Crystal clasts and lithoclasts 0.25 mm to 1 mm	Crystal clasts and lithoclasts 0.2 mm to 0.5 mm	Lithoclasts up to 0.3 mm	Small crystal clasts and lithoclasts ≤ 0.1 mm to 0.25 mm Large crystal clasts and lithoclasts 0.75 mm to 1.25 mm	Small crystal clasts and lithoclasts ≤ 0.1 mm Large crystal clasts and lithoclasts 0.25 mm to 0.5 mm	Small crystal clasts and lithoclasts ≤ 0.1 mm Large crystal clasts and lithoclasts 0.25 mm to 1.5 mm	Small crystal clasts and lithoclasts ≤ 0.1 mm Large clasts and lithoclasts 0.25 mm to 0.5 mm	Crystal clasts ≤ 0.1 mm Lithoclasts 0.25 mm to 1 mm	Crystal clasts ≤ 0.1 mm Lithoclasts 0.25 mm to 0.5 mm	Small crystal clasts and lithoclasts ≤ 0.1 Large lithoclasts 0.25 mm to 0.75 mm
Size distribution	Bimodal or homogeneous	Bimodal	Bimodal	Bimodal	Bimodal	Bimodal	Bimodal	Bimodal or homogeneous	Homogeneous	Bimodal	Bimodal	Bimodal
Percentage of total volume	15% to 20%	10% to 20%	30%	20%	15% to 30%	10% to 20%	20% to 30%	20%	20%	20% to 30%	20%	15% to 20%
Orientation	Non oriented	Non oriented	Preferential orientation	Preferential orientation	Preferential orientation	Preferential orientation	Preferential orientation	Preferential orientation	Non oriented	Preferential orientation	Preferential orientation	Preferential orientation

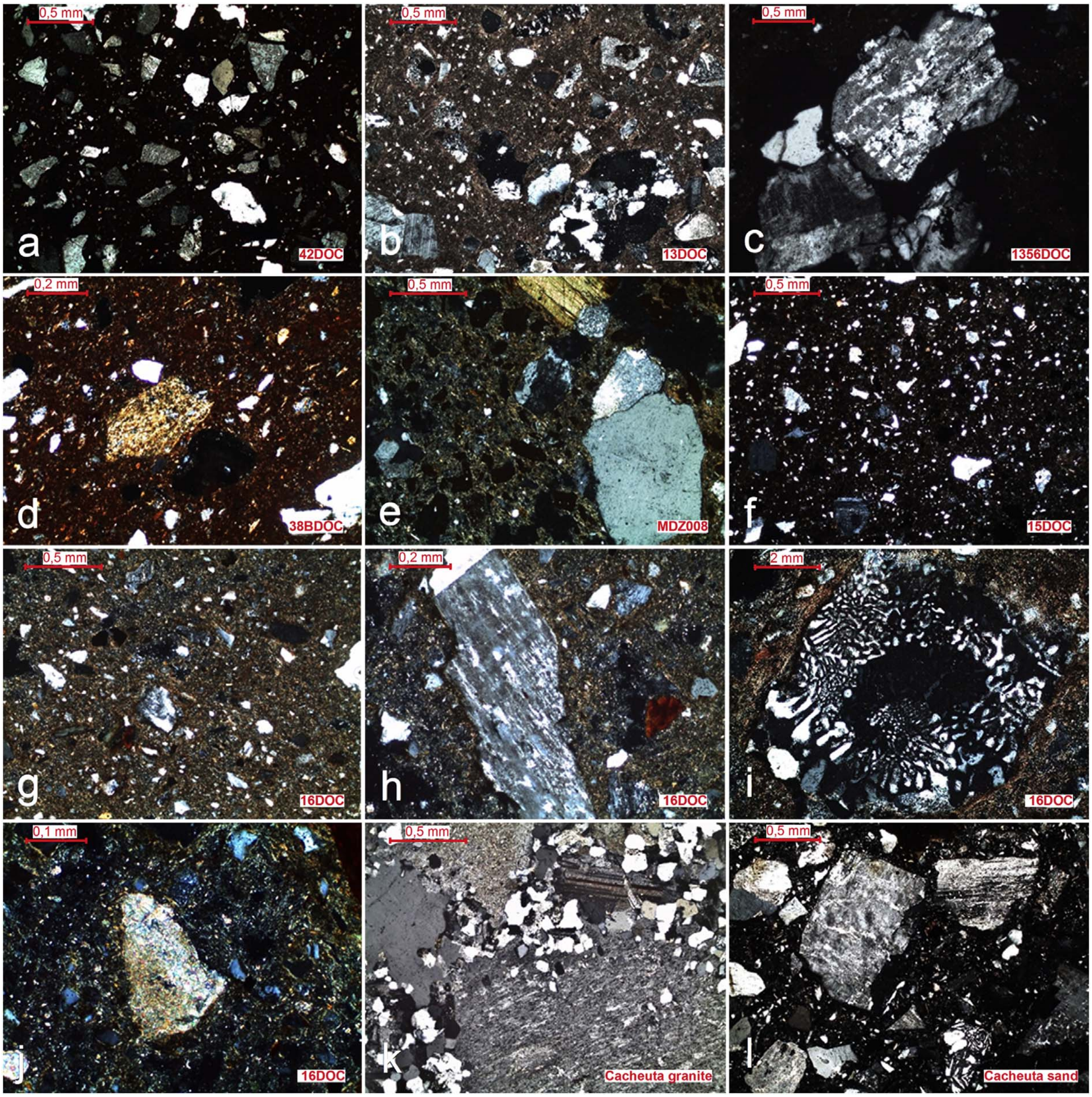

Fig. 3. Photomicrographs of the Granitic fabric group of the mixed Inca-type Viluco ceramics: a–e) coarse-textured samples, with randomly distributed angular to subangular inclusions of granite; c) detail of microperthitic K-feldspar and quartz crystal clasts derived from the granite; d) slightly oriented crystal clasts and siltstone inclusion; e) K-feldspar, biotite and oriented fine-grained inclusions of claystone; f–j) fine-textured sample; h) microperthite crystal clast with slight argillic alteration and biotite flake; i) graphic intergrowth of alkali feldspar and quartz (granophyric texture); j) micrite limestone inclusion; k–l) Cacheuta granite composed of microperthitic K-feldspar, twinned plagioclase and interstitial quartz and its corresponding sand (l) showing a clast with granophyric texture. All the photomicrographs were taken under cross-polarised light.

minerals are subordinated and, among them biotite with incipient chloritization predominates. Few hornblende, rare to very rare zircon and tourmaline and abundant opaques (Fe oxides) are seen. The groundmass is mostly homogeneous and microgranular. It also contains hornblende instead of biotite, which suggests that the raw material possibly corresponds to a differentiated facies (tonalite) of the Cacheuta Stock. All samples were fired under an oxidizing atmosphere.

5.1.2. Coarse granite ± volcanic ± sedimentary fabric class (Fig. 3b, d)

The dominant and larger antiplastic inclusions correspond to granitic rocks and minerals derived from them. Crystal clasts > lithoclasts: microperthitic K-feldspar and argillitized plagioclase are most frequently found, followed by lesser amounts of slightly chloritized biotite, hornblende, epidote and opaques. Variable but always subordinate amounts of mesosilicic to acid volcanic rocks (andesite to rhyolite), microdiorites, hornfels, claystones, iron-cemented sandstones and even pumice material are sometimes observed. Angular to subrounded fragments of microdiorites and sporadic crystal clasts of pyroxene (augite) would correspond to mafic dykes intruding the granite outcrops of Cerro Cacheuta. The groundmass is microgranular. All samples were fired under an oxidizing atmosphere.

5.1.3. Coarse granite ± claystone fabric class (Fig. 3e) and fine granite ± claystone fabric class (Fig. 3f)

In these fabric classes, the inclusions of granitic rocks and crystal clasts derived from them are largely dominant. The latter include quartz, microperthitic K-feldspar, slightly argillitized plagioclase, biotite and rare tourmaline and muscovite. In addition, variable amounts of clay inclusions are present. The larger clasts are granitic. The groundmass is very fine-grained microgranular. All samples were fired under an oxidizing atmosphere.

5.1.4. Fine granite ± limestone fabric class (Fig. 3g, h, i, j).

The dominant antiplastics are of granite s. str., and very subordinate proportions of micrite limestones are also present. Rare microvughs are sometimes seen. The groundmass is micaceous. All samples were fired under an oxidizing atmosphere.

Samples of the Cerro Cacheuta granite (Fig. 3k) have holocrystalline hipidiomorphic textures and are composed of orthoclase, quartz, oligoclase and biotite and green or brown hornblende is very rarely seen. The orthoclase occurs as subhedral to euhedral twinned microperthitic crystals. Accessory minerals such as opaques, zircon and apatite were identified. Myrmekites and graphic intergrowths are frequent. The feldspars show incipient sericitic and/or clay alteration, and the biotite is somewhat chloritized. The mafic dykes have inequigranular hipidiomorphic textures and are composed of oligoclase-andesine crystals that often show a divergent habit, green hornblende, opaques and scarce quartz. The accessory minerals are apatite, sphene and in some cases augite or biotite. The coarse sand from Cacheuta (Fig. 3l) has heterogeneous grain sizes and is almost exclusively composed of granite-derived fragments with abundant quartz, microperthitic K-feldspar with variable argillic alteration and biotite. Fragments with myrmekites and micrographic textures are also abundant. Clasts of microdiorites that correspond to mafic dykes cutting the Cacheuta Stock and quartz sandstones are sporadically seen. The fragments are sometimes stained by Fe-oxides.

5.2. Volcanic fabric group

5.2.1. Coarse volcanic-rich fabric class (Fig. 4b) and fine volcanic-rich fabric class (Fig. 4f, j)

Ceramics from these fabric classes are mostly composed of litho-

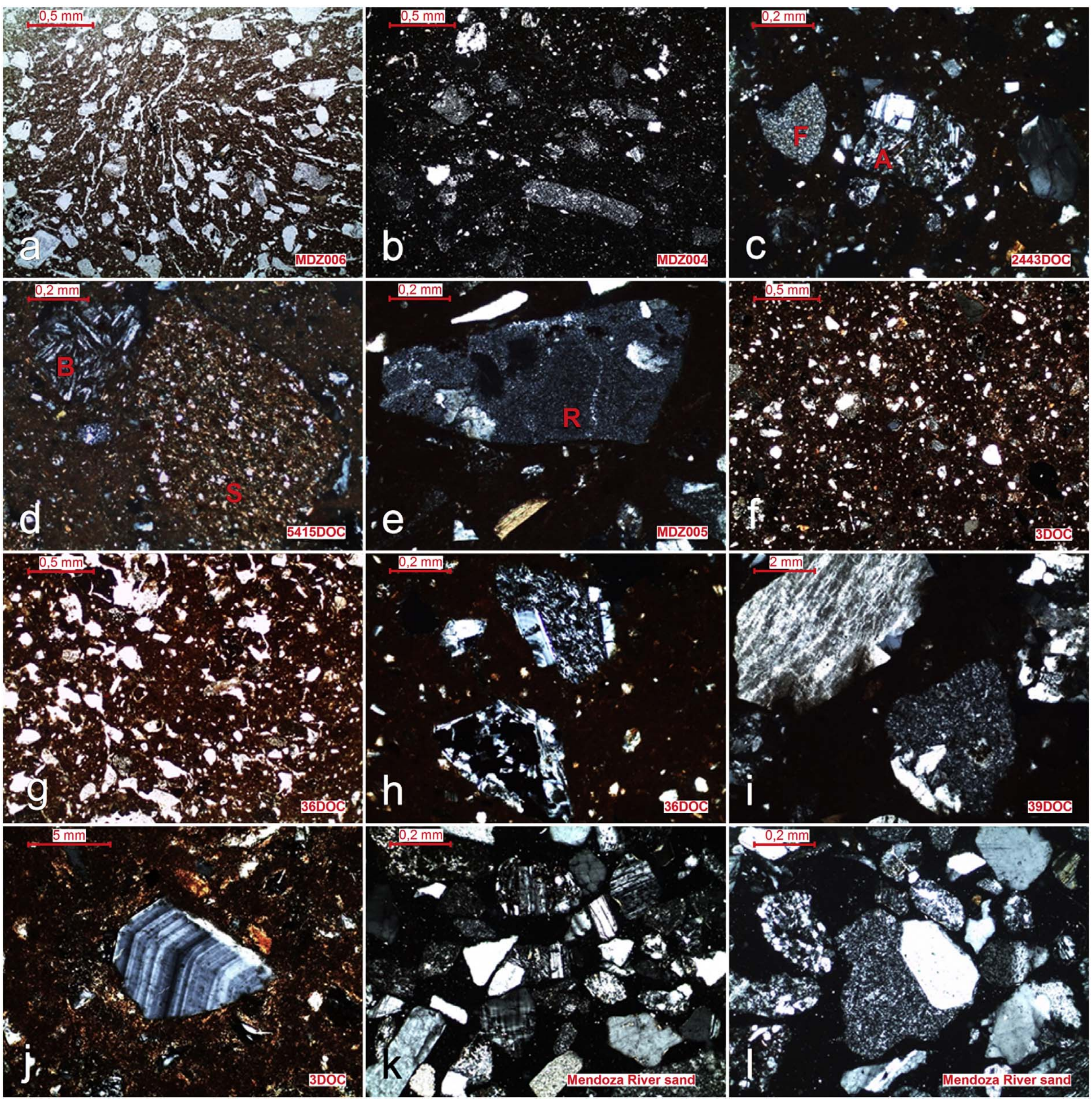

Fig. 4. Photomicrographs of the Volcanic fabric group of the mixed Inca-type Viluco ceramics: a–e) coarse-textured samples; c–e) inclusions of felsite (F), andesite (A), basaltic andesite (B), devitrified rhyolite (R) and sandstone (S) lithoclasts; f–j) fine-textured samples; h–j) angular to sub-angular fragments of intermediate to acid volcanic rocks in a fine-grained groundmass; i) microperthitic K-feldspar and volcanic clasts; j) detail of the strongly zoned plagioclase; k–l) sands from the Mendoza River showing angular to sub-rounded clasts of mostly volcanic rocks with felsitic and porphyritic textures, quartz, twinned plagioclase and also a microcline. The photomicrographs (a) and (g) were taken under plane-polarised light and the remainder using cross-polarised light.

clasts, which are usually fresh and consist of intermediate to acid volcanic and pyroclastic rocks. They mainly include fragments of andesite, dacite and rhyolite and crystal clasts derived from them. Rhyolite and rhyolite tuffs with typical devitrification/recrystallization textures (spherulites, flow banding and micropoikilitic) are very conspicuous. Moreover, porphyritic rocks with plagioclase phenocrysts set in a microgranular devitrified groundmass are very common. The dominant crystal clasts are plagioclase with polysynthetic twins and marked zonal structure, quartz and biotite flakes, while hornblende, apatite and microperthitic K-feldspar are subordinated. Fragments of metamorphic rocks (iron-stained metaquartzites, slates, phyllites and quartz-mica schists), polycrystalline quartz and granites are sporadically seen. Some samples show calcite infilling cavities and/or in veinlets. The groundmass is very fine-grained microgranular. All samples were fired under an oxidizing atmosphere.

5.2.2. Coarse volcanic ± sedimentary ± granite ± metamorphic fabric class (Fig. 4a, c, d, e) and fine volcanic ± sedimentary ± granite ± metamorphic fabric class (Fig. 4g, h, i)

They are compositionally heterogeneous fabric classes which consist mainly of clasts of intermediate to acid volcanic rocks and tuffs (basaltic andesite, andesite, dacite and rhyolite) as well as quartz and twinned and zoned plagioclase crystal clasts. The rhyolite lithoclasts show devitrification/recrystallization textures (spherulites, flow banding and micropoikilitic) and variable argillic alteration. Minor proportions of sedimentary rocks (claystones, iron-cemented quartz sandstones and limestones), granites and metamorphic rocks (phyllites, crenulated quartz-mica schists, metaquartzites and hornfels) are observed. Subordinated inclusions of biotite, microperthitic K-feldspar, microcline, hornblende and very rare epidote are present, occasionally with calcite patches. The groundmass is micaceous or microgranular. All samples were fired under an oxidizing atmosphere.

Given that the volcanic outcrops are very extended in the study area, two sand samples from the Mendoza River were analysed for comparative purposes. Both are fine grained and have uniform granulometry. The dominant components (lithic ≫ crystals) are of volcanic origin and are mainly angular to subangular and variable argillitized. Volcanic rocks (basaltic andesites to rhyolites) with microgranular, spherulitic, micropoikilitic and porphyritic textures as well as devitrified tuffs and subordinated pumice are the most common. The sand samples also contain lithoclasts of sedimentary rocks (sandstones, siltstones, claystones and minor limestones). The observed crystal clasts, in decreasing order of abundance, are twinned plagioclase, quartz, clinopyroxene (augite), hornblende, biotite and, exceptionally, chalcedony quartz (Fig. 4k–l).

5.2.3. Fine pumice-rich fabric class (Fig. 5a) and coarse pumice-rich fabric class (Fig. 5b)

In these fabric classes, the essential components (≥ 95%) are pumice fragments and to a lesser extent glass shards that are usually fresh or with incipient alteration/devitrification and are well oriented. Scarce small crystal clasts of twinned and zoned plagioclase, quartz, hornblende, biotite, apatite, epidote and opaques are also seen. There are few fragments of intermediate to acid volcanic rocks (mainly andesites and dacites), claystones and granite. Vughs are scarce and are occasionally infilled by calcite. The groundmass is fine to very fine-grained microgranular. All samples were fired under an oxidizing atmosphere.

Tephra from El Borbollón consists essentially of pumice material (Fig. 5c, d). It is entirely composed of pumice fragments and subordinated glass shards agglutinated by fine-grained calcite. Scarce angular crystal clasts of polysynthetic twinned plagioclase, biotite and minor quartz and Fe-oxides are sometimes present.

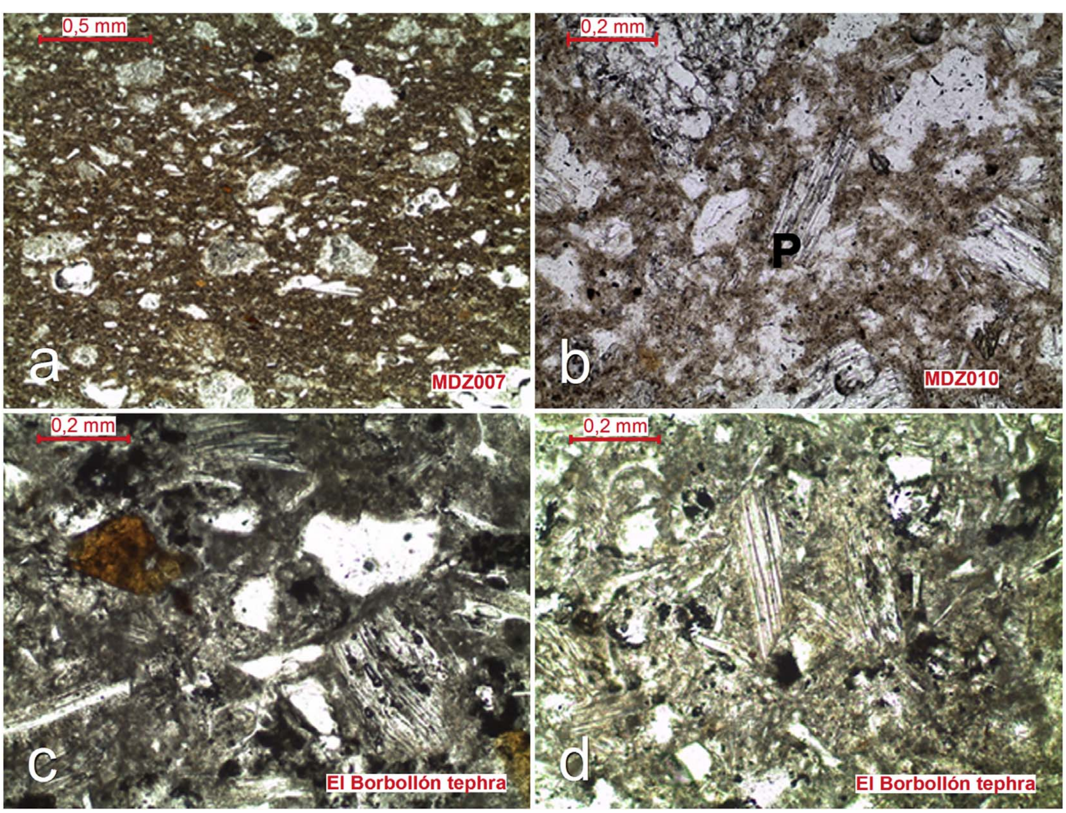

Fig. 5. a–b) Photomicrographs of the Pumice-rich fabric class of the mixed Inca-type Viluco ceramics: a) fine texture, b) coarse texture. Both images show unflattened tube pumice vesicles with fibrous, laminar internal textures (P). c–d) Tube pumice and biotite flakes in the El Borbollón tephra. The photomicrographs were taken with plane-polarised light.

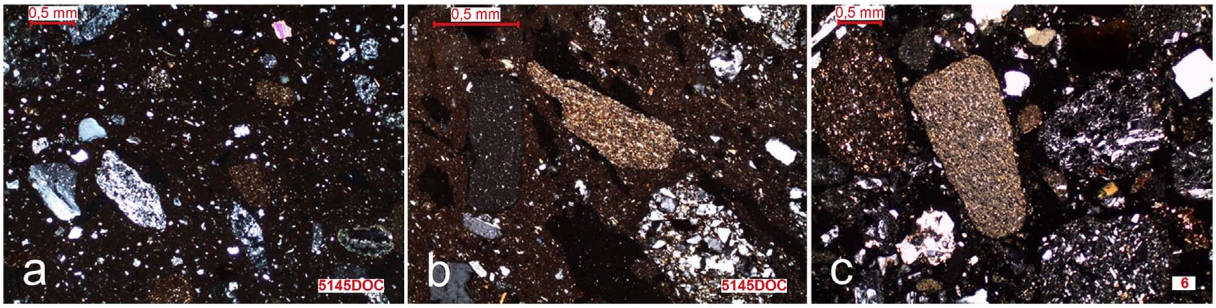

Fig. 6. a–b) Photomicrographs of the Sedimentary fabric group of the mixed Inca-type Viluco ceramics. Oriented fragments of siltstones, claystones, quartz-feldspar sandstones and minor volcanic rocks in a microgranular groundmass. Vugh partly infilled by calcite. c) Sand from Divisadero Largo creek showing clasts of siltstones, fine-grained sandstones and volcanic rocks. The photomicrographs were taken under cross-polarised light.

5.3. Sedimentary fabric group

5.3.1. Coarse sedimentary ± volcanic rocks fabric class (Fig. 6a–b)

It is a compositionally heterogeneous fabric class dominated by lithoclasts derived from sedimentary rocks; however, volcanic lithoclasts are also very abundant. Among the former, there are siltstones, claystones and iron-cemented quartz-mica sandstones in a decreasing order of abundance. The volcanic lithoclasts are represented by rocks of intermediate to acid composition (andesite, dacite and rhyolite). Crystal clasts are scarce and they include mainly zoned and twinned plagioclase, light green pyroxene, quartz, hornblende, microperthitic K-feldspar and biotite in a decreasing order of abundance. Phyllites and polycrystalline quartz fragments are occasionally present. The larger clasts correspond to sedimentary rocks. The groundmass is microgranular or micaceous. All samples were fired under an oxidizing atmosphere.

The coarse sand from Divisadero Largo creek, which flows through the homonymous formation, contains abundant sub-angular to sub-rounded lithic fragments. In order of decreasing abundance, there are fine-grained sedimentary rocks (siltstones > claystones), quartz-feldspar sandstones, phyllites, mesosilicic and acid volcanic rocks (basaltic andesite to rhyolite) and subordinate welded tuffs. Among the crystal clasts, there are plagioclase, quartz and pyroxene in a decreasing order of abundance. Calcite is present as cement material in some of the sandstone fragments (Fig. 6c). Sand from the Mariño Formation is composed of sedimentary and basic to mesosilicic volcanic rock clasts, with a predominance of the former. Material from the Papagayos Formation is comprised entirely of fragments of very fine-grained sedimentary rocks (siltstones and claystones).

6. Discussion

Thin-section petrography enabled the characterization of diverse aspects of the Viluco ceramics. It defined the geological origin of the temper used for its manufacture, as well as texture and microstructure attributes, which in turn allowed characterizing fabric groups and their respective classes. The detailed petrographic analysis of the temper of the Viluco ceramics and its comparison with thin sections of distinct lithologies, indicate that the sources of the raw materials occur within the regional geology of the northern Mendoza province. In two cases, the sources could be clearly ascribed to outcrops located near the archaeological sites: the Cacheuta Stock (Granite fabric group) and the El Borbollón tephra (Pumice-rich fabric classes).

The temper inclusions from the Granitic fabric group are almost entirely derived from granitic rocks (granite to tonalite) and are compositionally the same as the mineralogy of the Cacheuta Stock and its corresponding sand. The microdiorite inclusions found in several samples can be attributed to mafic dykes cutting the granitic bodies, which strengthens the correlation. In some samples, there were clay inclusions, limestones and acidic volcanic rocks, which have allowed the subdivision into classes. However, in all cases, the dominant and larger antiplastics came from granitic rocks. The combination of granitic rocks, microdiorites, hornfels, volcanic and low-grade metasedimentary rock inclusions is consistent with the geology in and around the Cacheuta Stock and supports the idea that the raw materials could have been derived from that lithology. In the Coarse Granite fabric class, 100% of the antiplastics came from granites s. str., which suggests a close relationship with granite bodies. In the coarse granite ± claystone fabric class and fine granite ± claystone fabric class, the abundance of clay inclusions suggests that they were incorporated within the clay.

The comparative analysis of the samples from the Coarse and Fine Pumice-rich fabric classes and the white ash-fall tuffs of Late Quaternary age from El Borbollón indicates that their compositions are basically the same. Both contain ash material (mostly pumice fragments, glass shards and subordinated perlitic glass) with similar textural features (size, vesicularity and fragmental morphology). Moreover, the scarce crystal clasts observed in both cases share the same mineralogy, which consists of angular fragments of polysynthetic twinned plagioclase and fresh biotite and lesser amounts of hornblende, quartz and iron oxides. The few claystone inclusions in the ceramics could have been incorporated within the clay. The pumice fragments used as temper in the Viluco ceramics show high vesicularity, are slightly flattened and exhibit tubular as well as spherical morphologies. A similar morphology of tube pumice vesicles can be seen in the El Borbollón tephra. The similarity in fragment size (maximum length ≈ 0.4 mm) is also remarkable.

Regarding the other fabric classes from the Volcanic fabric group, it is difficult to accurately establish their temper provenances due to their wide distribution in the studied area (outcrops and riversides of the Mendoza River and its tributaries). However, the raw materials could be attributed to drag material from the various tributaries descending from the Cordillera and Precordillera and converging in the Mendoza River. Most of the inclusions contained in the analysed sands correspond unequivocally to the volcanic formations which outcrop in the Cordillera and Precordillera and are grouped collectively as the Choiyoi Group. It is highly probable that the Choiyoi Group was the source of the volcanic materials found in these ceramic samples considering that the lithic fragments identified in the Volcanic fabric group could be correlated with formations of the Choiyoi Group surrounding the Cacheuta Stock at the Potrerillos locality as well as upstream of the Mendoza River. In the fine and coarse volcanic ± sedimentary ± granite ± metamorphic fabric classes, the inclusions of andesite and basaltic andesite are slightly more common than the more acidic volcanic rocks. There is also an increase in the relative amounts of lithoclasts derived from metasedimentary/sedimentary and granitic rocks, which suggests that the source of the raw materials is probably located much closer to the Cacheuta Stock and the surrounding sedimentary formations, downstream of the Mendoza River.

In addition, the petrographic analysis revealed certain similarities between the sedimentary and volcanic inclusions of the Viluco ceramics and the sands collected at Divisadero Largo creek. However, it is not possible to assign with certainty such a source of raw materials to the coarse sedimentary ± volcanic fabric class.

7. Conclusions

Positive results were obtained from the application of a comparative petrographic analysis of thin sections of ceramics and geological samples. This work, applied to a case of the southern Andean area, evidences the method's good potential for defining the provenance of tempers used in ceramics manufacture. It was possible, for the first time in west central Argentina, to characterize in detail the temper provenance of the pottery produced by local potters during the Inca domination and early Spanish colonial period in the eastern-meridional boundary of both empires.

By determining that the Viluco ceramics of mixed Inca type was produced with raw materials available in the outcrops near the Mendoza valley, it can be stated that the ceramic production was carried out locally. This practice was part of the usual domination strategies developed in the empire provinces, in which there was little circulation of ceramic types connoting imperial legality.

Granite and tephra used as temper came from isolated outcrops in the area, from which it is inferred that the Viluco production technology involved a selection of these raw materials. Specifically, the exploitation of volcanic tephra from the El Borbollón anticline, confirms that this particular tradition related to the Inca expansion and infused with symbolic significance in the marginal southern borders, was developed locally by potters as part of their membership to the Inca Empire.

The evidence allows suggesting that the population concentration process that was developed in the short period between the Inca Empire and the early Spanish colony in the Mendoza Valley, required the local production of Viluco ceramics of mixed Inca type, just as it occurred in other regions of the empire, possibly due to the increasing demand of vessels used by the local hierarchies in contexts of hospitality and legitimation of the power.

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