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A diachronic study of pre-Hispanic vessels from the middle basin of Paraná River (South America) using a petrographic approach

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ABSTRACT

This paper presents a petrographic study of pre-Hispanic vessels from archaeological sites located in the middle basin of the Paraná River, a geographical area where this analytical technique still has very limited application in ceramic studies. Within this framework, a first approach to the chronological variability of pottery through the analysis of 58 ceramic thin sections is carried out. The samples correspond to vessels made by complex hunter-gatherer groups between 625 ± 46 and 1.380 ± 100 ^{14}C years BP. The pottery was recovered from three archaeological sites: Arroyo Arenal 1, Arroyo Largo I, and La Palmera II (Entre Rios Province, northeastern Argentina), which are linked to an archaeological unit locally called Goya-Malabrigo. The results show, among other chronological variations, an increasing trend in the use of grog temper over time. These data allow the expansion of knowledge about the ceramic technology of human groups who occupied the area of the Paraná River during the Late Holocene.

1. Introduction

This paper focuses on the ceramic technology of the pre-Hispanic human groups that occupied the middle basin of the Paraná River during the pre-Hispanic period. Unlike the upper Paraná basin, where human occupation has been detected from the Early Holocene, in the middle Paraná basin it has only been recorded from the Late Holocene. Most of the archaeological sites registered in this area are associated with the archaeological unit generically called Goya-Malabrigo, which is identified in South America over the entire middle basin of the Paraná River and on a part of the lower river (Ceruti, 2003). The regional presence of these groups has been apparent on the archaeological record since 2050 ± 60 years BP (Echegoy, 1994) until the European contact period. However, it is considered that their occupation of this area became more intense during the last millennium before present (Ceruti, 2000), a time from which the number of Goya-Malabrigo sites increased significantly on the regional archaeological record.

The carbon and nitrogen levels obtained from the human bones of Goya-Malabrigo individuals show a mostly carnivorous diet, based on depleted $\delta^{13}C$ proteins linked to the C_3 photosynthetic pathway, which is in turn consistent with the isotopic values detected in the main food sources of these human groups: freshwater fish and continental mammals (Ottalagano and Loponte, 2016). Freshwater fish such as *Pterodoras granulosus* and *Pimelodus* sp. were an important part of their diet. Their subsistence also included the exploitation of rodents (mainly *Myocastor coypus*) and some deer such as *Blastocerus dichotomus* and *Mazama gouazoubira* (e.g. Ceruti and González, 2007; Nóbile, 1993; Ottalagano et al., 2015a; Santiago, 2004; Tonni et al., 1985). Their diet was probably supplemented with some minor intake of C_3 plants (Ottalagano and Loponte 2016) such as *Cucurbita* sp., *Prosopis* sp., *Phaseolus* sp., *Ipomea* sp., and various grasses, whose micro-remains have been reported in ceramic and lithic artifacts of these groups (e.g. Bonomo et al., 2011; Colobig and Ottalagano, 2015; Cornero and Rangone, 2015; Sánchez et al., 2013).

Ceramics played an important role in their subsistence. Their use was strongly associated with processing and cooking food, also including the case of decorated vessels, which usually record traces of use, such as soot and fatty acids, as well as plant micro-remains (Colobig and Ottalagano, 2015; Ottalagano, 2013a). Predominately hemispherical shapes with simple contours are a common feature of pots, bowls, and dishes. The most usual decorative techniques are incising and painting (generally red, but in some cases white), but the main diagnostic feature of the Goya-Malabrigo style is the presence of pottery with zoomorphic appendages, usually representing parrots (Caggiano, 1984; Ceruti et al., 1980; Ottalagano et al., 2015b; Serrano, 1950). These modeled ceramic figures may have constituted symbols of group identity within a context of growing social complexity (Ottalagano, 2013a).

At the regional level, an important continuity in the morphology of the vessels and in the decorative style of the Goya-Malabrigo ceramics can be observed over time. In particular in the archaeological sites considered in this work, where technological, morphological, and stylistic studies have been carried out in detail, has been identified a generally stable pattern of the decorative, technical, and formal attributes of

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potteries in the temporary block of the 1380–625 years BP (Ottalagano, 2013a). However, little is known so far with respect to the microscopic characteristics of these ceramics, and even less about the aspects of their chronological variability. Ceramic technology related to the archaeological Goya-Malabrigo contexts has been studied extensively based on macroscopic studies (Caggiano, 1984; Ceruti et al., 1980; Ottalagano et al., 2015b; Ottalagano, 2013a; Píccoli and Barboza, 2013; Serrano, 1950, among others), but generally it lacks a systematic microscopic analysis. Petrography, which is currently considered one of the essential analytical techniques of archaeological ceramic studies (Peterson, 2009), has begun to be applied to the analysis of pottery from the lower Paraná in relation to Guarani horticulturists and hunter-gatherer groups (Capdepont and Bonomo, 2010–2011; Loponte, 2008; Pérez et al., 2009; Pérez, 2010; Tapia, et al., 2013), and very rarely in relation to human occupations clearly regarded as being Goya-Malabrigo (Ottalagano, 2013b, 2015).

This study is based on the analysis of ceramic samples from archaeological and environmental contexts that are very similar to each other. They come from Goya-Malabrigo sites located within the same ecoregion, which includes the floodplain of the Paraná river: a sector with azonal features, where the many existing water courses generate conditions of high humidity as well as reduced levels of daily and seasonal temperature variations, aspects that facilitate the development of flora and fauna typical to the subtropical areas of northeastern Argentina (Burkart et al., 1999). This paper proposes focusing on the application of a scientific method, such as petrographic analysis, for the purpose of increasing the knowledge about the ceramic technology of the Paraná River basin, and trying to begin to establish regional temporal trends as a basis for new research questions.

2. Materials and methods

This paper includes the information generated from the analysis of 58 ceramic samples recovered from three archaeological sites located along the middle Paraná River basin (Entre Rios Province) (Tables 1 and 2, Fig. 1). The vessel fragments from Arroyo Largo I and Arroyo Arenal I sites were recovered by Ceruti (1989), while those from La Palmera II site were excavated by Ottalagano et al. (2015a). The Arroyo Arenal I (AAI from here on) and Arroyo Largo I (ALI from here on) sites are located very close together, separated by the Paraná River course. The La Palmera II site (LPII from here on) is located ca. 70 km to the south of both sites (Fig. 1).

AAI and LPII were considered unicomponent sites, where multiple activities were performed (Ceruti, 1989, 2003; Ottalagano et al., 2015a). AAI has an AMS dating on human remains indicating a late occupation, close to the time of European contact (Table 1). Two radiocarbon datings have been obtained from the LPII site: 1056 ± 47 years BP on human remains and the other 1032 ± 47 years BP based on *Myocastor coypus* (Ottalagano et al., 2015a). ALI is also a multipurpose site, but bicomponent. Two Goya-Malabrigo occupations are recorded, which were dated, respectively, at 900 ± 120 years BP and 1380 ± 100 years BP, based on the carbon remains (Ceruti, 1989, 2003). The later occupation of ALI, considering the standard deviation indicated by the datings, could become *cuasi* contemporary to the occupation of LPII. However, in this work it was decided to conduct an independent analysis of samples from both sites to assess any possible spatial differences of the ceramics, given the distances between the two sites and the location of ALI on an island. If we consider that the time lapse between the earlier occupation and the more recent ones is 600 to 900 years (considering the standard deviation of the datings), we can assume that several dozens of generations of artisans were involved in ceramic production, being able to generate continuities or variability on the features of the vessels.

The selected ceramics samples come from the same sectors and levels where the dated materials were recovered to ensure their association with the datings available for each site. The samples correspond to horizontal thin sections, that is to say they were cut parallel to the rims of the vessels (Woods, 1985). Macroscopic characteristics of samples from the AAI and ALI sites are presented in Table 2. Those from the LPII site were analyzed and published in Ottalagano (2015), and correspond to: plain vessels ($n = 14$), decorated vessels with red paint ($n = 9$), with incisions ($n = 8$), with red paint and incisions (n = 1), and with zoomorphic appendages ($n = 2$). It should be noted that the petrographic analysis carried out previously identified technological similarities between plain and decorated vessels; for this reason it was decided to group them into the same data set. On the contrary, the samples corresponding to the “coarse potteries” from LPII (locally known as *alfarerías gruesas* or *campanas*) are not considered in this analysis (samples 15, 16, 17 in Ottalagano, 2015), since these devices have pastes with specific characteristics (see also Loponte, 2008; Ottalagano and Pérez, 2013; Ottalagano, 2015; Pérez, 2010).

Thin sections were studied at magnifications of ×40, ×100, and ×400 using a petrographic microscope, with both polarized and nonpolarized transmitted light illumination. The petrographic analysis included aspects related to: (a) the matrix: percentage breakdown of the components of the paste; (b) the inclusions: type, frequency, sorting, orientation, shape, and size; and (c) voids: frequency, shape, size, and orientation. The Udden-Wentworth's granulometric scale was used to categorize the size of the inclusions (Adams et al., 1984), and Barraclough's graphics (1992) to determine their degree of sphericity and roundness, as well as their level of sorting. The density charts provided by Prehistoric Ceramic Research Group (PCRG) (2010) were used to calculate the frequencies of the various components identified. The real frequency of an element refers to their proportion in the paste, which is identified through the visual field of the microscope, while the relative frequency refers to the proportion of one particular type of inclusion in relation to the total nonplastic materials observed in a sample.

3. Results and discussion

The petrographic study of the selected samples established that the ceramics were characterized by pastes where the clay matrix was highly predominant in relation to inclusions and pores, except in few cases

Table 1
Samples considered in this study.

Samples	*N*	Site	Lab. code	^{14}C year BP (context)	cal AD age (1 sigma)	cal AD age (2 sigma)	Source
AAI-1 to AAI-10	10	Arroyo Arenal I (AAI)	AA102684	625 ± 46	1346–1393 ($p = 0.62$)	1284–1406 ($p = 1$)	This paper
ALI-1 to ALI-7	7	Arroyo Largo I (ALI)	INGEIS n/d	900 ± 120	1024–1224 ($p = 0.98$)	889–1299 ($p = 0.99$)	This paper
LPII-1 to LPII-14 and LPII-18 to LPII-37	34	La Palmera II (LPII)	AA102682/AA102683	1032 ± 47 1056 ± 47	966–1037 ($p = 0.91$) 961–1023 ($p = 0.82$)	893–1050 ($p = 0.88$) 882–1045 ($p = 0.97$)	Ottalagano (2015)
ALI-8 to ALI-14	7	Arroyo Largo I (ALI)	INGEIS n/d	1380 ± 100	563–724 ($p = 0.87$)	527–882 ($p = 0.92$)	This paper
Total	58						

Note: The radiocarbon dates for the Arroyo Largo I site was taken from Ceruti (2003). n/d = no data available with respect to the laboratory code.

Table 2
Macroscopic features of ceramic samples from the AAI and ALI sites.

Sample	Decoration	Surface treatment	Vessel form	Thickness wall	Mouth diameter	Matrix color
AAI-1	No	Smoothed	Indet.	6 mm	indet.	Black/yellow orange
AAI-2	No	Smoothed	Open form	5 mm	18–22 cm	Black
AAI-3	No	Smoothed	Indet.	6 mm	18–30 cm	Brownish black
AAI-4	No	Smoothed	Open form	5 mm	Indet.	Brownish black
AAI-5	No	Smoothed	Indet.	6 mm	Indet.	Black/yellow orange
AAI-6	No	Polished	Closed form (with Hole for suspension)	6 mm	16–22 cm	Brown
AAI-7	No	Smoothed	Closed form	7 mm	>28 cm	Black
AA1–8	Red paint	Smoothed	Indet.	7 mm	22–30 cm	Brownish black
AA1–9	No	Smoothed	Closed form (with Hole for suspension)	6 mm	22–24 cm	Black
AA1–10	No	Smoothed	Indet.	5 mm	Indet.	Brownish black/yellow orange
ALI-1	No	Smoothed	Open form	5 mm	22–30 cm	Black
ALI-2	No	Smoothed	Closed form	5 mm	26 cm	Black
ALI-3	No	Smoothed	Indet.	6 mm	Indet.	Brownish black
ALI-4	No	Smoothed	Open form	5 mm	22–34 cm	Brown
ALI-5	No	Smoothed	Indet.	6 mm	Indet.	Black/yellow orange
ALI-6	No	Smoothed	Indet.	8 mm	Indet.	Black
ALI-7	No	Smoothed	Open form	5 mm	26–30 cm	Black
ALI-8	No	Smoothed	Indet.	7 mm	Indet.	Brown
ALI-9	No	Smoothed	Closed form	5 mm	22–30 cm	Black
ALI-10	No	Smoothed	Indet.	8 mm	indet.	Light yellow
ALI-11	Incised lip	Smoothed	Open form	9 mm	>30 cm	Brownish black
ALI-12	Incised lip	Smoothed	Closed form	5 mm	18–22 cm	Brownish black
ALI-13	Red paint	Smoothed	Open form	7 mm	>26 cm	Brownish black
ALI-14	No	Smoothed	Indet.	6 mm	>30 cm	Olive black

Note: All samples correspond to rims.

where the percentage of matrix is <50% (samples AAI-1, AAI-3, AAI-7, ALI-1, ALI-4, ALI-6) (Tables 3 and 4). These last samples are especially associated with the temporary block of the 900–625 years BP. The pastes analyzed do not show signs of having reached the vitrification stage in no case. The clay-sized matrix varies slightly in terms of color (Table 2). The widespread predominance of dark-colored matrix in freshly fractured sherds indicates the existence of an oxygen reduced firing atmosphere.

The samples analyzed present a homogeneous mineralogical composition. Grains of quartz predominate, and feldspar grains are observed in lower proportions (potassic feldspar and plagioclase). The sizes of quartz and feldspar grains are generally very fine (<0.1 mm) and fine

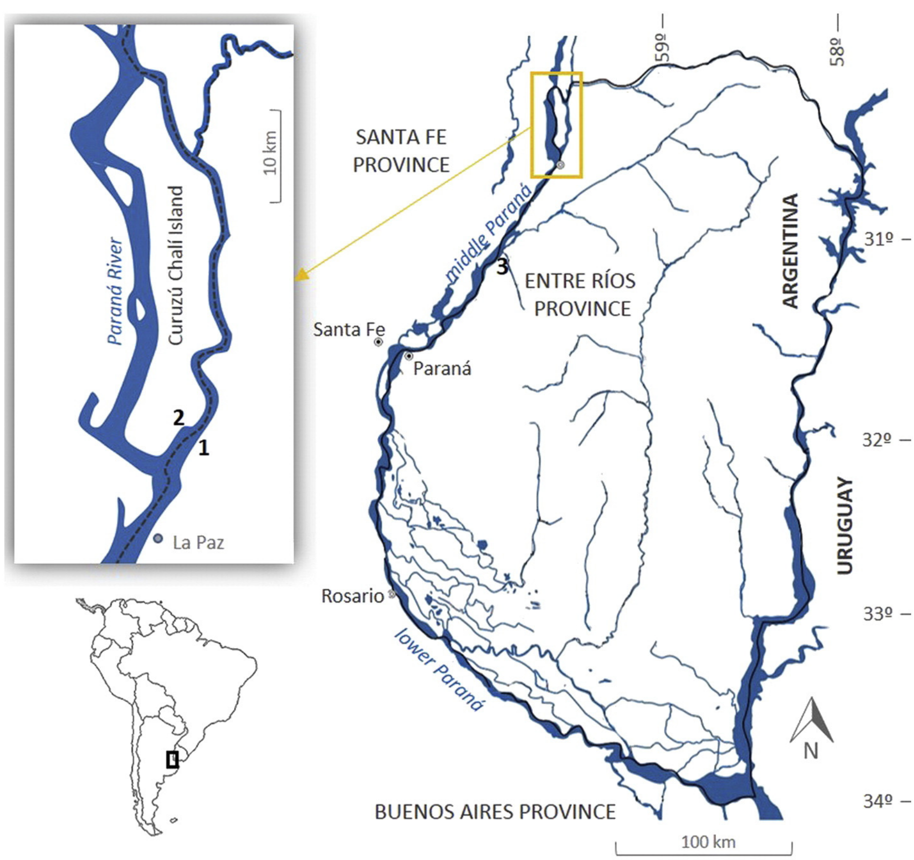

Fig. 1. Location of the archaeological sites included in this study: 1) Arroyo Arenal I; 2) Arroyo Largo I, 3) La Palmera II.

Table 3
Petrographic features of ceramic samples.

^{14}C year BP (context)	Sample	Percentage relationships of the paste components			Relative percentage of the major groups of inclusions				
		Matrix	Inclusions	Pores/voids	Mineal grains	Nodules (oxides)	Crushed sherds	Bioclast	Others
625 ± 46	AAI-1	43	50	7*	57	29	13.5	<1	<1
	AAI-2	40	30	30	60.5	21.5	15	0	3
	AAI-3	45	50	5	59	19.5	19.5	0	2
	AAI-4	60	30	10	50	33	16.5	<1	<1
	AAI-5	63	30	7	47	22	22	6	3
	AAI-6	43	50	7	61	30.5	6	2	<1
	AAI-7	45	25	30	28	40	28	0	4
	AAI-8	77	20	3	40	40	8	8	4
	AAI-9	60	25	15	18.5	26	55.5	0	<1
	AAI-10	65	20	15	25	25	50	0	<1
900 ± 120	ALI-1	47	50	3*	64	14	20	0	2
	ALI-2	60	25	15	27	38	27	7.5	<1
	ALI-3	53	40	7	62.5	7.5	25	0	5
	ALI-4	49	50	1	50	40	0	10	<1
	ALI-5	63	35	2	42.5	43	8.5	3	3
	ALI-6	45	40	15*	62	12.5	25	<1	<1
	ALI-7	60	30	10	47	31	15.5	6	<1
1032–1056 ± 47	LPII-1	59	40	1	65	30	0	0	5
	LPII-2	68	25	7	49	46	1	1	3
	LPII-3	65	25	10	40	49	7	0	4
	LPII-4	59	40	1	59	39	1	0	1
	LPII-5	73	20	7	12	70	15	0	3
	LPII-6	57	40	3	47	32	20	1	0
	LPII-7	84	15	1	48	47	3	<1	1.5
	LPII-8	72	25	3	62	30	5	0	3
	LPII-9	55	20	25	50	47	0	0	3
	LPII-10	60	30	10	52	47	0	0	1
	LPII-11	50	30	20	30	55	12	1	2
	LPII-12	65	25	10	40	43	10	<1	6.5
	LPII-13	78	15	7	30	65	0	0	5
	LPII-14	80	15	5	43	45	7	0	5
	LPII-18	70	25	5	43	41	15	<1	<1
	LPII-19	50	40	10	61	35	2	0	2
	LPII-20	65	20	15	33	40	20	1	6
	LPII-21	70	20	10	51	40	3	1	5
	LPII-22	60	25	15	45	52	0	0	3
	LPII-23	60	30	10	54	40	5	1	0
	LPII-24	75	15	10	41	51	1	0	7
	LPII-25	60	20	20	25	68	1	0	6
	LPII-26	65	20	15	12	64	20	<1	3.3
	LPII-27	60	25	15	60	29	1	0	10
	LPII-28	53	40	7	52	15	30	0	3
	LPII-29	70	20	10*	54	30	15	0	1
	LPII-30	60	20	20	37	43	15	0	5
	LPII-31	60	30	10	22	70	5	<1	2.5
	LPII-32	60	25	15*	15	81	3	0	1
	LPII-33	65	30	5	60	39	0	0	1
	LPII-34	77	20	3	46	45	7	1	1
	LPII-35	60	25	15	27	57	12	0	4
	LPII-36	82	15	3	27	70	2	0	1
	LPII-37	59	40	1	78	21	0	0	1
1380 ± 100	ALI-8	63	30	7	44	44	12	0	<1
	ALI-9	70	15	15*	19	62.5	12.5	6	<1
	ALI-10	75	20	5	22.5	32	0	45	<1
	ALI-11	68	25	7	37	37	3.5	18.5	4
	ALI-12	70	20	10	23	45	23	4.5	4.5
	ALI-13	68	25	7	20	40	8	28	4
	ALI-14	63	30	7	45.5	30	9	15	<1

Note: * = large and amorphous voids are detected in a high proportion (equal to or higher than the pore).

(0.1–0.25 mm), and in a few cases they are of medium size (0.25–0.5 mm) (Figs. 2a-b and 3). Also very common are nodules of ferric oxides that correspond mainly to hematite, usually with very coarse sizes (>1 mm) (Figs. 2c and 3). The nodules are spherical units that do not consist of isolated grains. They also tend to be amorphous and impregnate the ceramic paste (Aguilar et al., 1998; Bullock et al., 1986). Additionally, opaque minerals grains such as magnetite with very fine (<0.1 mm) and fine (0.1–0.25 mm) sizes are distinguished. Moreover, very scarce grains with very fine sizes (<0.1 mm) that presented interference colors under the microscope were observed; they can be identified primarily as micas. All these mineral inclusions are typical of local sedimentary banks, where the sand is composed of up to 99% quartz, as well as including some feldspars and opaque minerals, among other scarce elements (Iriondo and Rodríguez, 1973). Micas also occur naturally in the clays of the region Brunetto et al. (2013) and Herbst (2000) also mention the presence of ferruginous elements in the mineralogy of the Ituzaingó Formation, which is a local sedimentary formation of fluvial origin.

Quartz, which is the most abundant mineral inclusion in virtually all the samples, shows variable levels of wear. However, spherical quartz

Table 4
Average values of the samples grouped according to the chronology of their archaeological context.

^{14}C year BP (context)	cal AD age (1 sigma)	cal AD age (2 sigma)	N	Percentage relationships of the paste components			Relative percentage of the major groups of inclusions				
				Matrix	Inclusions	Pores/voids	Mineral grains	Nodules (oxides)	Crushed sherds	Bioclast	Others
625 ± 46	1346–1393 ($p = 0.62$)	1284–1406 ($p = 1$)	10	54.1	33	12.9	44.6	28.6	23.4	2	1.4
900 ± 120	1024–1224 ($p = 0.98$)	889–1299 ($p = 0.99$)	7	53.8	38.6	7.6	50.7	26.5	17.2	4.4	1.7
1032 ± 47	966–1037 ($p = 0.91$)	893–1050 ($p = 0.88$)	34	64.9	25.6	9.5	43.2	46.3	7	0.5	3
1056 ± 47	961–1023 ($p = 0.82$)	882–1045 ($p = 0.97$)									
1380 ± 100	563–724 ($p = 0.87$)	527–882 ($p = 0.92$)	7	68.1	23.6	8.3	30.1	41.5	9.7	16.7	2

grains often predominate with sub-rounded corners, and sometimes rounded and well-rounded, which would be associated with their sedimentary origin (Fig. 2a) (Aguilar et al., 1998). The proportion of mineral grains in the paste, and particularly quartz, is essentially high in all the cases, except for the samples whose context has the earlier chronology of 1380 ± 100 years BP, where a marked decrease in the real frequency is observed in these mineral inclusions (Fig. 4d). By contrast, the samples associated with the more recent chronology of 625 ± 46 and 900 ± 120 years BP, exhibit the highest frequencies of these nonplastic inclusions (Fig. 4d).

The identification of quartz and feldspar grains suggests the presence of sand in the clayey mixtures. In general, grain size and the relative abundance of nonplastic inclusions can serve as indicators to determine whether or not inclusions were added by the potters intentionally (PCRG, 2010; Shepard, 1956). Quartz and feldspar grains tend to have a well-sorted distribution in most of the samples, reflecting a high degree of uniformity in the size of these nonplastic materials

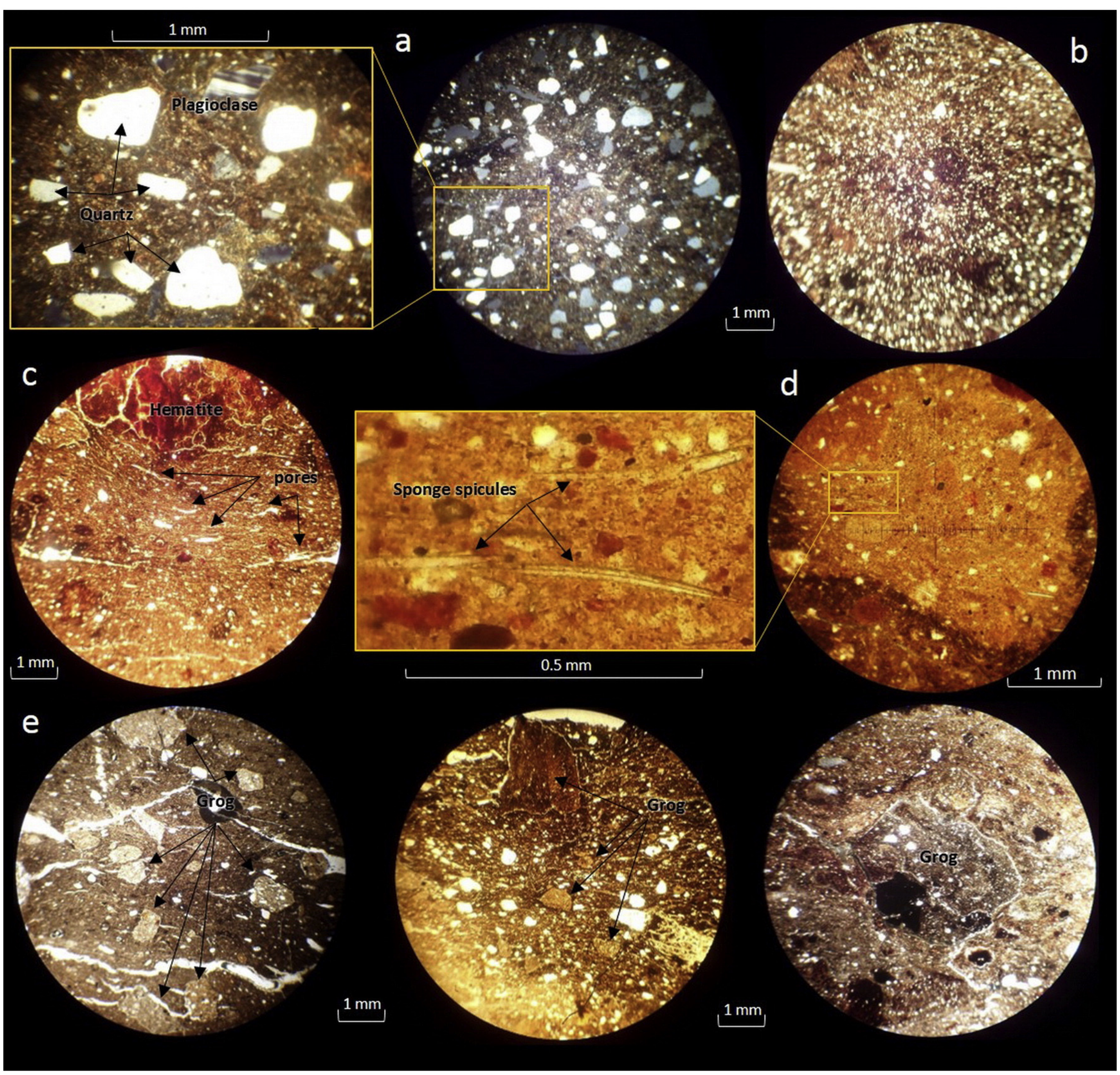

Fig. 2. Photomicrograph of ceramic thin sections by petrographic microscope (a and b under crossed nicols, c-e under parallel nicols): a) grains of poorly sorted quartz and feldspar (sample AAI-3), b) grains of very well sorted quartz and feldspar (sample ALI-1), c) hematite nodules (a parallel arrangement of pores and inclusions is observed) (sample AAI-4), d) sponge spicules (sample ALI-10), e) crushed sherds (grog temper), from right to left: samples AAI-9, ALI-3, and ALI-8.

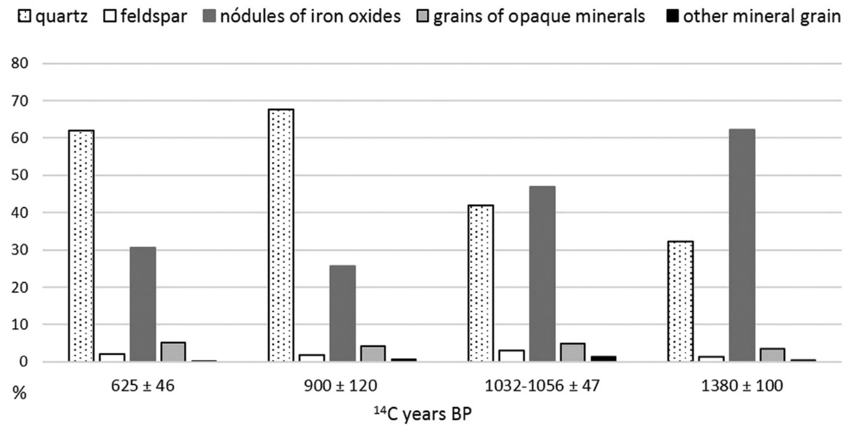

Fig. 3. Mineralogical composition of ceramics, grouped according to their chronology. The percentages refer to the relative frequency of these inclusions in relation to the total mineral elements present in the samples.

(Figs. 2b and 5). Although quartz appears in relatively large amounts in some of the samples analyzed, little variation is apparent in the texture. This suggests that the quartz (and also the feldspars) occurring naturally in the clay used to produce most of the ceramics analyzed here. However, on the contrary, a few samples recorded abundant mineral grains that were poorly sorted (samples AAI-2, AAI-3, AAI-6, ALI-4,

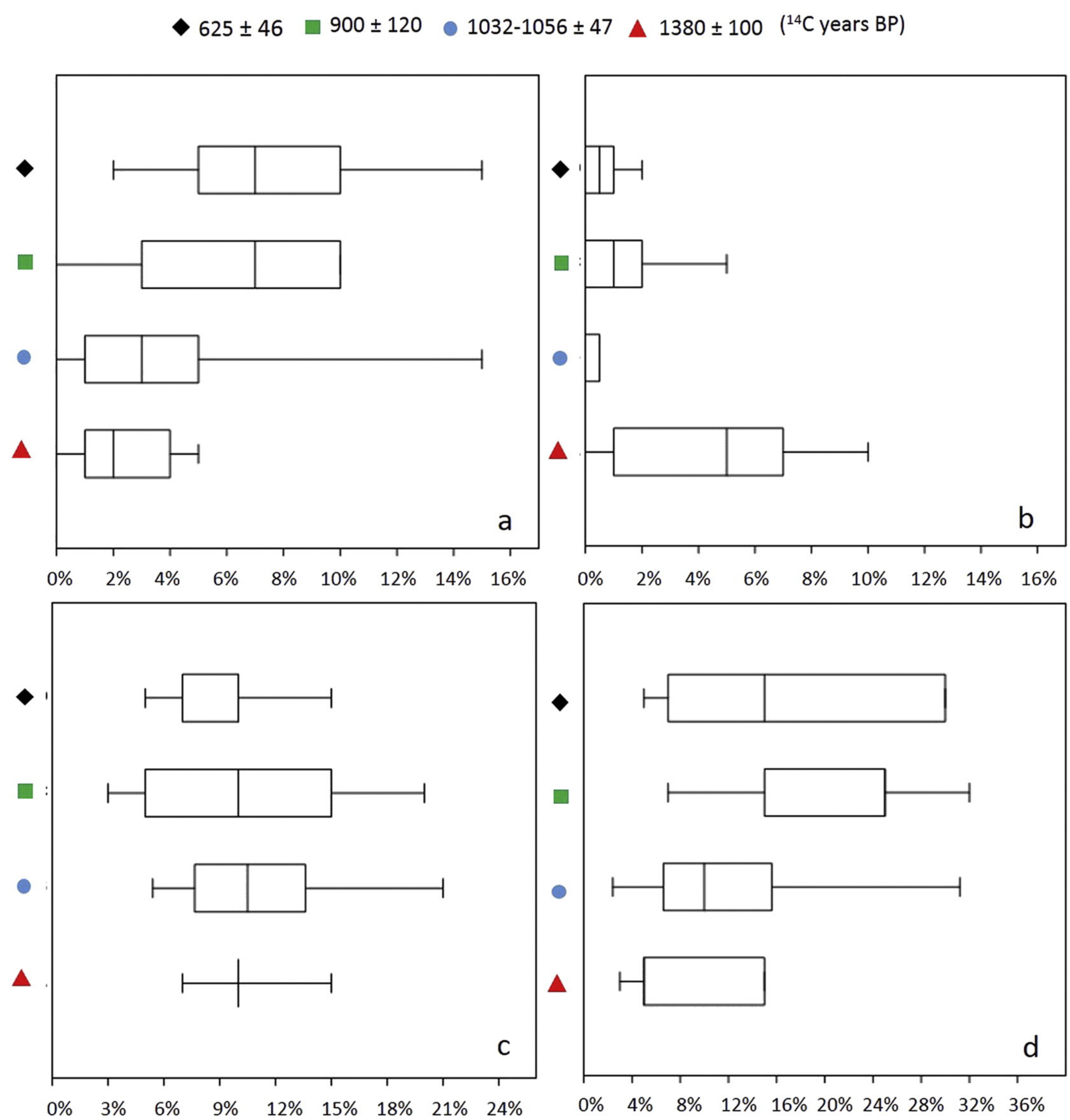

Fig. 4. Real frequency of different groups of inclusions in the samples grouped according to their chronology: a) crushed sherds, b) bioclast (mainly sponge spicules), c) nodules of iron oxides, d) mineral grains (principally quartz, accessorily feldspars and opaque minerals, and micas in very small proportions).

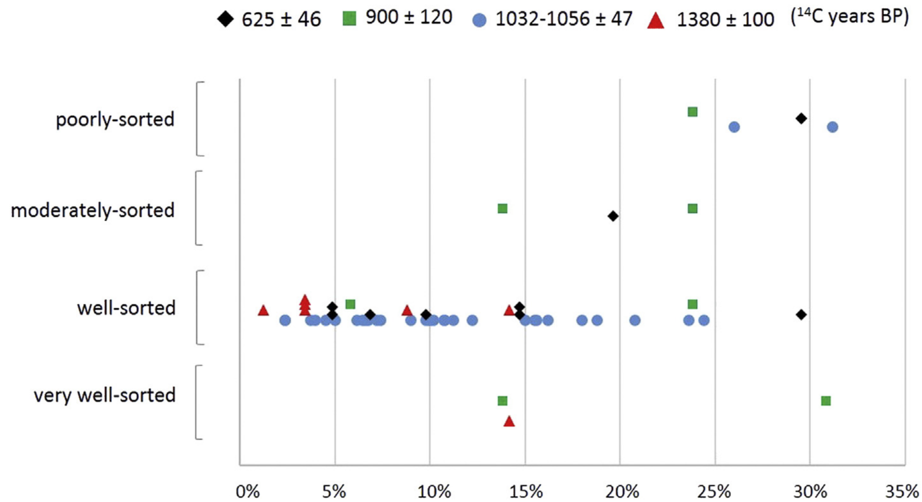

Fig. 5. Real frequency and sorting of quartz and feldspar grains in the samples grouped according to their chronology.

ALI-6, 1 and 37 LPII) (Figs. 2a and 5), which might be related in particular to the intentional addition of sand to the ceramic paste. It should be noted that the high frequency of poorly sorted quartz and feldspar grains, which could be indicative of the deliberate addition of sand, was not observed in the samples belonging to vessels with an earlier chronology (Fig. 5).

Nodules of iron oxides (hematite) were recorded mainly in low to moderate frequencies (sensu PCRG, 2010), with an average real frequency of around 10% in all the chronological groups, which would seem to indicate an unintentional incorporation into the paste. Only two ceramic thin sections show a higher rate of iron oxides of around the 20% (Fig. 4c). Although in these two cases the greater presence of these nonplastic inclusions might suggest an intentional incorporation, the possibility of determining between materials added by potters or naturally occurring in clays is one of the most complex aspects of identification (Cremonte and Bugliani, 2006–2009; PCRG, 2010). Iron oxides in ceramic pastes (particularly hematite nodules), which function as an optimal element that reduces the plasticity of clays, have also been reported for many pre-Hispanic sites located in the lower Paraná basin (Loponte, 2008; Ottalagano and Pérez, 2013; Pérez, 2010; Tapia et al., 2013), where it has been proposed that the potters possibly selected the clay banks that naturally contained these nodules (Loponte, 2008; Pérez, 2010).

Crushed sherds or grog are the only materials that can be considered an intentional aggregate by the potters. Grog temper was identified in variable amounts in 84.5% ($n = 49$) of the samples, with sizes that tended to be coarse (0.5–1 mm) and very coarse (> 1 mm) (Table 3, Fig. 2e). The addition of grog is a recognized technological option destined to optimize the manufacturing process because it has effects on the plasticity of clay and on the resistance to the vessels during drying (Rye, 1981; Shepard, 1956). In some ethnographical cases, its incorporation into the paste has also been linked to symbolic motivations (Gosselain and Livingstone-Smith, 2005).

As plotted in Fig. 4a, the vessels associated with the chronology of 1380 ± 100 years BP show the lowest grog frequencies, which are in the order of 1–5%, and with an average of 2.4%. The real frequency of grog in ceramic pastes seems to follow an increasing trend over time (Fig. 4a). In the ceramics related to the chronological lapse of 1032–1056 BP ± 47 years BP, the average is 3.6%. In these sets, although the rate of grog is mostly between 1 and 5%, some samples reach a frequency of 10–15% (Ottalagano, 2015). Meanwhile, the samples related to the chronology of 900 ± 120 years BP showed frequencies of 3–10% with an average of 6.4%. Finally, grog temper was incorporated into all the vessels associated with the chronology of 625 ± 46. In these cases, the frequencies are in the order of 2–15%, with an average of 7.1% (Fig. 4a). In some samples in this chronological set in particular (AAI-9 and AAI-10), the crushed sherds cover about half of the nonplastic materials identified in the vessel pastes (Table 3), indicating that the potters chose to add a larger amount of grog to the clay mixture, at the expense of other inclusions.

The presence of grog temper in the paste has also been reported from hunter-gatherer sites located in the southern areas of the Paraná River (e.g. Capdepont and Bonomo, 2010–2011; Loponte, 2008; Ottalagano and Pérez, 2013; Pérez, 2010; Tapia et al., 2013), with low real frequencies in the order of 3–5% (Ottalagano and Pérez, 2013), and in samples associated with contexts dated between 680 ± 80 and 1640 ± 70 years BP (Loponte, 2008). This same frequency of grog has also been found in a Goya-Malabrigo site from the lower Paraná basin, although no chronological data for this archaeological context are available yet (Ottalagano, 2013b). On the other hand, the presence of crushed sherds was observed with percentages above 15% in ceramics from sites located in the lower Paraná, but related to Guarani occupations and with chronologies between 405 ± 35 and 690 ± 70 years BP (Capdepont and Bonomo, 2010–2011; Pérez et al., 2009; Pérez, 2010). Referring to Goya-Malabrigo ceramics, Caggiano (1984:35) had already noted that "… there is an evolutionary trend in the use of sand temper toward grog temper" (the translation is mine). However, in the absence of petrographic techniques that can provide accurate data, this trend was hard to confirm and quantify. While the observations expressed herein tend to support a possible temporary increase regarding the use of grog, they do not report sufficient data to argue a decrease in the use of sand as a nonplastic material, if not perhaps the opposite.

In some samples, the absence or scarcity of grog temper in the ceramic pastes coincides with a greater presence of bioclasts: freshwater sponge spicules in particular, and secondarily diatoms (samples ALI-10, ALI-11, ALI-13) (Fig. 2d). By selecting clays that naturally contain sponge spicules, potters might not have had to add other types of nonplastic inclusions, such as crushed sherds. Bioclasts are most frequently recorded in samples associated with earlier chronologies (Fig. 4b). These inclusions of organic origin are usually found as a natural component of the sediments of the Paraná River basin (Patterer et al., 2013), and its siliceous structures function as optimal antiplastics to balance the plasticity of the paste and to prevent shrinkage and crack propagation during drying, firing, and cooking (Natalio et al., 2015; Shepard, 1956). The presence of bioclasts is markedly higher at the Arroyo Largo I site, which could be related to the characteristics of the clays available for the potters; however, this should be confirmed in the future with a detailed sedimentological analysis of the potential sources of clays for this site. Nevertheless, a decrease can be observed in sponge spicule frequency in the ceramics related to the occupation located chronologically at 900 ± 120 years BP, with respect to earlier occupations at the same site, located at 1380 ± 100 years BP (Fig. 4b).

The identification of freshwater sponge spicules has also been reported in pre-Hispanic ceramics from the lower Paraná, especially in the so-called "tubular potteries" (sensu Vignati, 1942) that appear in particularly high quantities (Pérez, 2010). They have also been observed in ceramic vessels manufactured by hunter-gatherer groups between 1640 ± 70 and 680 ± 80, as well as by Guarani horticulturists groups between 405 ± 35 and 690 ± 70 years BP (Capdepont and Bonomo, 2010–2011; Loponte, 2008), opening up the debate regarding its intentional incorporation into the paste. The use of sponge spicules as a temper was very widespread throughout Amazonia in pre-Columbian occupations, for example (e.g. Costa et al., 2004; Lima and Neves, 2011). In this study case, it is possible that potters selected sedimentary banks that naturally contained these bio-siliceous inclusions, rather than their deliberate incorporation. It must be considered that only one sample shows sponge spicules in moderate proportions of about 10% real frequency (sample ALI-10), and in very high relative frequencies (Table 3, Fig. 4b), while in the remaining samples much lower values are observed.

Table 4 shows the frequency of pores in the samples, which follows a similar trend to that found in several pre-Hispanic archaeological sites located in the lower Paraná, where analogous average values of voids in ceramic thin sections were recorded (Ottalagano and Pérez, 2013). As can be seen in Fig. 2c, the pores generally have elongated shapes, with a tendency to a parallel arrangement. Many other pores surround the inclusions, due to the contraction of the clay during the drying and firing stages (Gibson and Woods, 1997). For their part, large and amorphous voids are rare in general, although in some of the samples they were identified in larger amounts (Table 3). These cavities are typical of inadequate kneading of the pastes, and have much larger sizes than the pores, reaching several millimeters in width and length (Rye, 1981; Shepard, 1956). Excluding samples with excessive cavities ($n = 6$), the following proportions of pores were observed in the vessel pastes: very low porosity (frequencies of 1–3%) ($n = 11$), low porosity (frequencies of 5–7%) ($n = 16$), moderate porosity (frequencies of 10–15%) ($n = 19$), high porosity (frequencies of 20–25%) ($n = 4$), and very high porosity (frequencies of 30%) ($n = 2$). In contrast to the large and amorphous voids, many of the pores originated when appropriate kneading of the raw materials was carried out, which can be considered a positive feature, since it increases the thermal shock resistance by preventing cracks in the vessel walls. High porosity, however, can contribute to inefficiency in heating (Arnold, 1985; Rye, 1981; Shepard, 1956). Therefore, around two-thirds of the pastes analyzed present adequate pore proportions, not too low or too high, so as to allow improved performance of the vessels during cooking activities.

The higher values of porosity are recorded in the ceramic assemblage associated with the 625 ± 46 years BP (Tables 3 and 4). In addition, this assemblage shows a greater fluctuation in the pore rates of its samples (9.8 of standard deviation). By contrast, the variation in the pore levels of the samples associated with the chronology of 1380 ± 100 is significantly lower (3.3 of standard deviation). Pérez (2010) provided a temporal analysis of porosity in ceramics corresponding to hunter-gatherer occupations from the lower Paraná, where, as opposed to the case study, she observed a decrease in the pore rates over time, specifically reporting for the ceramics of the Bellaca 2 site (dated from 680 ± 80 years BP) an average porosity value of 6%, while for the Túmulo de Campana 2 site (dated from 1640 ± 70) an average of 15% was observed, with intermediate gradients in the samples recovered from sites with chronologies between 1.110 ± 70 and 940 ± 60 years BP. It should be noted, however, that the porosity of a vessel is determined by several factors, not only by the kneading intensity, but also by the kind of clays used, the types of inclusions, and the firing temperatures, among others (Shepard, 1956), thus it is a complex attribute to evaluate comparatively.

In particular, the form and arrangement of the pores are related to the manufacturing techniques (Livingstone-Smith, 2007; Peterson, 2009; Pierret, 1994; Rye, 1981). In vessels that were manufactured by coiling techniques, for example, the orientation of the pores and fine inclusions became aligned and tended to follow a pattern parallel to the rim of the vessel, according to the direction in which the coil was kneaded (Gibson and Woods, 1997). This pattern is dominant in the samples corresponding to the different chronological groups (Fig. 6), suggesting manufacturing techniques based on the superposition of clay coils, a widely applied technique in the region (Capdepont and Bonomo, 2010–2011; Ceruti et al., 1980; Loponte, 2008; Ottalagano et al., 2015b; Pérez, 2010; Serrano, 1958). Only one of the samples exhibited a random arrangement of the paste components (Fig. 6), which could indicate discontinuous pressure on the clay mass, as occurred, for example, in the modeling techniques (Livingstone-Smith, 2007; Shepard, 1956). In some samples no orientation pattern was identified, possibly because of the low percentage of pores.

4. Conclusions

The vessels analyzed show a very homogeneous mineralogical composition, with the presence of mineral inclusions that are naturally present in the local riverbank clay deposits, such as quartz, feldspar, and iron oxides, thus supporting the idea of the local manufacturing of ceramics. Small masses of fired clay recovered during the excavations (Ceruti, 1989; Ottalagano et al., 2015a) also indicate that pottery was locally manufactured at the sites. The samples showed in general variable proportions of pores and inclusions. However, those associated with the earlier dating of 1380 ± 100 years BP have some peculiarities. For example, they were characterized by pastes where the clay matrix was highly predominant in relation to the pores and inclusions. These ceramics presented the lowest inclusion levels, and in particular the quartz proportions were markedly lower than those detected in the rest of the ceramic assemblages. Especially remarkable in this ceramic set is the absence of poorly-sorted quartz grains, an attribute that in conjunction with their abundance in ceramic pastes usually indicates the intentional addition of sand to the clay mixture. Moreover, the random arrangement of the components of the paste detected in one of the samples in this chronological set suggests that in this case the modeling technique was implemented to make the vessel. These data contrast with the parallel arrangement of the pores and inclusions observed in the rest of the samples analyzed, a pattern linked with the coiling technique. Modeling technique has been particularly recorded in the "coarse potteries" of the region (locally known as alfarerías gruesas or campanas) (see Loponte, 2008; Ottalagano and Pérez, 2013;

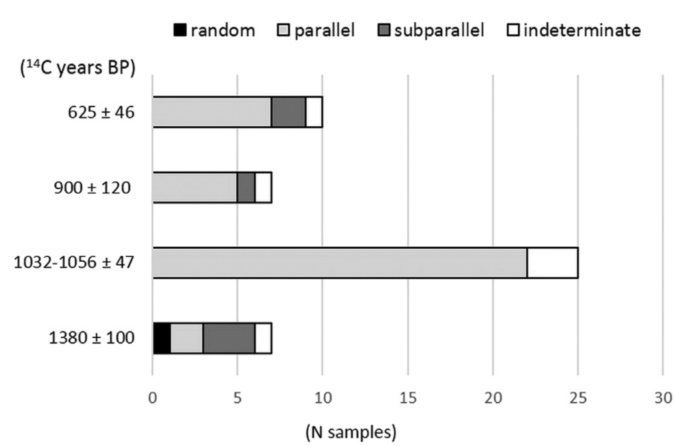

Fig. 6. Orientation of the pores and inclusions in the samples corresponding to horizontal thin sections grouped according to their chronology (to reinforce the comparative effects of the graphic, the samples corresponding to the vertical thin sections of the LPII site were discarded).

Ottalagano, 2015; Pérez, 2010), but is difficult to detect macroscopically in the rest of the ceramic artifacts from the sites considered in this work, where the coiling technique has primarily been observed (Ottalagano et al., 2015b).

At the other extreme, the samples associated with the chronology of 625 ± 46 years BP show, on average, a greater porosity than the rest of the ceramics studied here, although this cannot be considered too significant a difference. The most important contrast observed between the more recent vessels and those from earlier on, is related to the proportions of crushed sherds that were incorporated into the ceramic pastes. An increase was detected in the incorporation of grog over time, which is reflected in the increase in both the real and relative frequencies of this inclusion in the pastes. In all the ceramic thin sections related to the chronology of 625 ± 46 years BP grog temper was observed, with relative frequencies of over 50% in some cases. For their part, the vessels whose context date from 1380 ± 100 years BP, showed the lowest levels of crushed sherds. At the same time, they present higher levels of sponge spicules, especially in those samples where very low-to-null proportions of grog were observed. The incorporation of bioclasts, probably by selecting clays that naturally contained them, could have rendered unnecessary the addition of a larger amount of crushed sherds in these cases.

If the observed differences between the earlier and the later vessels are a reflection of variations in the technological behaviors of human groups over time (or if on the contrary, they are the result of random factors or product of the natural variability of the raw materials used), this is something that only from now on can we begin to assess in this area, given the historical absence of petrographic data available, especially for the middle Paraná River basin, and in reference to the Goya-Malabrigo occupations. Because of the small number of samples analyzed (especially for AAI and ALI sites), the results of the petrographic study described here must be considered mainly as preliminary. However, this study sought to expand the available information with which to begin to establish regional temporal trends regarding the ceramic technology of the pre-Hispanic human groups that occupied the Paraná River area during the Late Holocene.

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