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On the provenience of wood used in the manufacture of snuff trays from San Pedro de Atacama (Northern Chile)

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ABSTRACT

The consumption of hallucinogenic substances is a long-standing tradition in the Americas. San Pedro de Atacama (SPA) in Northern Chile is the archaeological zone with the highest incidence of snuffing implements in the world. Snuff trays from SPA have been studied under a variety of prisms but their provenience, in particular that of the wood used in their manufacture, has not yet been addressed. The delicate nature of trays and their excellent state of preservation call for the use of non-invasive analytical methods. Wood density was used to demarcate a possible range of species and hence as a broad provenience marker, and its value determined for 169 trays from the museum at San Pedro de Atacama. The results showed that although some of the SPA snuff trays studied may have been manufactured with local wood, most of them used exogenous wood as raw material. At this point, it is not possible to ascertain the precise origin of such wood, but Bolivia and NWA appear as likely candidates. Three distinct styles have been defined for SPA trays: Tiwanaku, San Pedro, and Circumpuneño (encompassing the area around the Puna de Atacama and including SPA). The effect of style on density points to different sources of wood in Tiwanaku style trays and trays in San Pedro and Circumpuneño styles. As expected from geographically and temporally dynamic patterns of interaction of SPA with neighboring regions, diachronic differences in wood density distributions were found. Tray manufacturing technique was not dependent on wood density, suggesting that the skill of artisans and the quality of their tools allowed them to use any type of wood for their art work, independent of its complexity.

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1. Introduction

The consumption of hallucinogenic substances is a long-standing tradition in the Americas that has continued until present times, particularly among peoples of the Amazonian basin (Schultes et al., 1998). The nature of the resources (and hence chemicals) and paraphernalia employed vary considerably temporally and geographically. Plant-derived hallucinogens have been consumed either by smoking, ingesting, snuffing, chewing or through enemas (Torres and Repke, 2006).

The earliest material evidence for consumption of plant-derived psychotropic substances in the South-central Andean region has been found in North-western Argentina (NWA) (Fernández Distel, 1980) and dates back to ca. 2100 B.C. (Aschero and Yacobaccio, 1994). Ceramic pipes associated with smoking practices appear much later in the oases of San Pedro de Atacama (SPA) in Northern Chile (Torres, 1999). Eventually, pipes disappear from the

archaeological record and wooden trays associated with snuffing practices become frequent. Thermoluminescent and radiocarbon dating of the funerary contexts where the psychotropic paraphernalia has been found (Berenguer et al., 1986; Hubbe and Torres-Rouff, submitted for publication; Hubbe et al., 2012) have provided time limits to the prevalence of snuffing in SPA. The first elements associated with the practice of snuffing in SPA are found in the Sequitor cultural phase (100 B.C.–400 A.D.) (Torres, 1984); during this phase, the first elements of a central altiplanic tradition are also found in SPA (Berenguer et al., 1986). The practice continued in the Circumpuna area for more than a millennium which included the Inka Horizon (Pochettino et al., 1999). Throughout this extensive period, the shape, iconography and manufacturing techniques of snuff trays experienced substantial changes.

In spite of their relatively late appearance as compared to other Andean contexts, it is in archaeological sites around SPA where snuffing implements show the highest incidence in the world (Torres, 1999). The components of the snuffing paraphernalia are restricted to a few elements designed for the preparation, preservation, transport and inhalation of snuff powders, i.e., leather pouch, mortar and pestle, woolen bag, spoon, spatula, snuffing tube

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and snuff tray. In SPA, the most conspicuous of these elements are wooden snuff trays (Torres, 1987). The extreme aridity of the area around SPA has avoided their exposure to water, fungi, bacteria or insects – factors associated to the transformation of archaeological wooden objects (Blanchette et al., 1990) – and has permitted their excellent preservation.

Since the pioneering studies of Uhle (1913, 1915), several researchers have analyzed the snuff trays found in SPA under a variety of prisms (Horta, in press-a, in press-b, in press-c; Llagostera, 1995, 2006; Llagostera et al., 1988; Núñez, 1963; Tarragó, 1989; Thomas et al., 1984; Torres, 1984, 1986). The studies have mostly referred to trays assigned to the period during which Tiwanaku influence at SPA was strongest, and in which iconographic elements in the trays – corresponding to a wide range of religious and mythical representations – are associated with those found in the megalithic structures present in Tiwanaku sites (Llagostera, 1995, 2006; Llagostera et al., 1988; Núñez, 1963; Torres, 1984, 1986). The study of non-Tiwanaku trays has received less attention (Llagostera, 2001; Llagostera et al., 1988; Torres, 1999) until the recent work of Horta (in press-a, in press-b, in press-c). Different styles have been defined for snuff trays which include, aside from a Tiwanaku style, a local San Pedro style and a Circumpuneño style prevailing in the area around the Puna de Atacama, which includes the coast of Atacama, the river Loa basin, the Salar de Atacama, the Jujuy puna and the Humahuaca valley, and other areas of NWA (Horta, in press-a, in press-b, in press-c). A question that has not yet been addressed is the provenience of the trays found in SPA, in particular the wood used in their manufacture.

The identification of wood species used in the manufacture of trays constitutes a relevant line of evidence to solve questions on the origin and circulation of these objects and on associated snuffing practices. The traditional method for wood identification involves the mechanical cleansing of the wood surface and the extraction of thin (ca. 20–40 μm) transverse, tangential and radial sections from a ca. 10 mm^2 area. The sections are chemically treated for decoloration, dehydration, staining and fixation, and are then observed under the microscope (Wheeler and Baas, 1998). Several extraction trials may be necessary before a suitable section is obtained; hence, the process may involve a substantial tampering of the object. The method has been applied to archaeological wood in a wide variety of states, including dessicated (Rodríguez, 2008), charred (Rodríguez, 2004), and fossilized wood (Estrada-Ruiz et al., 2007). However, given the delicate nature, excellent state of preservation and exceptional museological value of most snuff trays, use of non-invasive analytical methods is desirable. Recently, wood structural details have been revealed by using non-invasive techniques such as high resolution X-ray computed tomography and X-ray synchrotron tomographic microscopy (Smith et al., 2009; Steppe et al., 2004), leading to the identification of the wood species. Although these techniques show great promise in the study of sensitive archaeological objects, their massive application to snuff trays is at present beyond consideration given the cost and risk of transporting the trays to the laboratories in possession of such instruments.

Density is an important trait of wood which reflects its structure and hence its identity (Chave et al., 2006; Swenson and Enquist, 2007). Provided that wood is in a good state of conservation, as is the case of many snuff trays from SPA, this parameter, although not species-specific, can be used to demarcate the range of possible species and thus provide a first approach to the origin and circulation of the raw material used to manufacture snuff trays. Furthermore, it can be determined non-invasively through traditional independent mass and volume measurements. In this paper, wood density was determined in a set of snuff trays from the museum at San Pedro de Atacama chosen on the basis of their preservation state and lack of metallic and stone inlays.

2. Materials and methods

2.1. Archaeological material

Snuff trays available at the Instituto de Investigaciones y Museo R.P. Gustavo Le Paige de San Pedro de Atacama were examined macroscopically and classified according to their preservation status into three classes: class 1 corresponded to well preserved complete trays with smooth surface, well defined contours and absence of lithic or metallic inlays; class 2 included distorted, deformed, incomplete, fragmented (but essentially reconstituted) and worn out trays with eroded or roughened surfaces; and class 3 included very low quality tray fragments. Trays studied belonged only to class 1. Of the total of 411 trays which had been catalogued by the Museum at the time this study was undertaken (November 2010), 169 snuff trays fell within this class.

Trays are stored in the museum under low humidity conditions (ca. 10% RH); hence, they can be considered to be essentially at the standard condition for reporting wood densities (Chave et al., 2006).

2.2. Reference wood samples and measurement of wood density

Wood samples to be used as reference material were collected from the three native tree species growing in the oases of SPA (Rodríguez et al., 1984); they were oven-dried at 60° until their weight was stable. Samples were also obtained from wood from native trees growing in ecoregions of Bolivia and NWA with demonstrated direct cultural connections to SPA in pre-hispanic times; these samples were obtained in the dry state (ca. 8–16% moisture content).

Volumes were determined using metallic spheres (diameter = 1.96 ± 0.098 mm, weight = 44.7 ± 4.9 mg, $N = 20$) and a metacrylate rectangular container (thickness = 5 mm; internal length, width and height = 14.3, 4.7 and 21.4 cm, respectively; approximate volume = 1.4 l). The container was first filled to maximum capacity with spheres. Thereafter, the container was almost emptied and the spheres withdrawn set aside; a snuff tray or a wood sample was introduced and then the container was filled again to maximum capacity with spheres from the group previously set aside. The weight of the remaining spheres was determined. The volume of those spheres, corresponding to the volume of the snuff tray or wood sample, was read from a calibration line made as described above with objects of known volume. Weights were determined with a Shimadzu Libror EB-2800 balance (± 0.1 g).

2.3. Adscription of snuff trays to cultural periods, styles, and manufacturing technique employed

In the absence of direct dates for snuff trays excavated from SPA oases, their chronology was determined through the study of contextual elements in the individual tomb where each tray was found. Trays were assigned to cultural phases mainly through association to co-occurring pottery styles (Berenguer et al., 1986; Tarragó, 1989). Cultural phases represented in the trays were: Toconao (Middle Formative Period), Sequitor (Late Formative Period), Quitor and Coyo (Middle Period), Yaye (initial Late Intermediate Period), Solor (final Late Intermediate Period) and Catarpe (Late Period – Inka). Assignments could only be made in 103 trays due to the lack of contextual information for the other trays.

Several studies have addressed the iconography of snuff trays found in SPA (e.g.: Llagostera, 1995, 2006; Torres, 1984, 1986, 1987, 2004), with emphasis on Tiwanaku-style trays. Additionally, a thorough study of trays available at several museums worldwide was undertaken by Horta (in press-a, in press-b, in press-c) and

gave rise to the definition of Circumpuneño (Horta, in press-a, in press-b) and San Pedro (Horta, in press-c) styles.

Snuff trays, consisting of a receptacle and an appendix, were grouped according to the manufacturing technique employed: group A included trays without decoration ($N = 99$); group B included trays with linear incisions on the appendix ($N = 20$); group C included trays with high reliefs on a planar appendix ($N = 6$); and group D included trays with a volumetrically carved appendix ($N = 44$). Fig. 1 schematically illustrates some of the trays studied showing different manufacturing techniques as well as styles.

3. Results

3.1. Measurement of density

The weight of metal spheres displaced by objects of known volume correlated significantly with such volumes (Spearman correlation: $r_s = 0.978$, $N = 14$, $P < 0.001$). A linear regression passing through the origin produced the equation: Weight (g) = $7.291 \times$ Volume (cm^3). This equation was used to determine the volume of trays and of pieces of wood from the weight of the metallic spheres they displaced; these values, together with the weight of trays and wood samples were used to determine their density.

Reproducibility of density determinations was assessed by replicating 10 times the determination of density in 15 snuff trays which encompassed a wide range of density (0.36 – 1.09 g/cm^3 ; mean density: 0.70 g/cm^3) and volume (14.9 – 98.6 cm^3 ; mean volume: 46.3 cm^3). The standard deviations of measurements ranged from 0.010 to 0.041 g/cm^3 , with a mean value of 0.020 g/cm^3 .

Accuracy of density measurements was assessed by studying wood from 26 species of known densities from Chile, Bolivia and Argentina covering a wide density range (0.23 – 1.21 g/cm^3). Experimental values correlated significantly with those reported in the literature (Zanne et al., 2009): Spearman correlation: $r_s = 0.841$, $N = 26$, $P < 0.001$; linear regression passing through the origin: $d_{\text{experimental}} (g/cm^3) = 1.025 \times d_{\text{literature}} (g/cm^3)$.

Wood density has been shown to vary not only between species but also between and within individual trees; additionally, densities may be reported at different wood moisture contents and calculated in relation to moist or dry sample volume (Chave et al., 2006). However, variations within a species, when reported within a small humidity interval, mostly fall within a 5% range (Nogueira et al., 2005). The value of density as species character was assessed by determining the effect on wood density of log diameter and log age (as judged by the number of growth rings), of duramen vs. alburnum, and of the individual tree. The wood of *Acacia caven* (Fabaceae), a native tree growing in Chile from 27° to

$37^\circ S$ latitude, was used as model for these studies. These data provided an experimental estimate of wood density variations within a species. Density was not correlated with log diameter or age (Spearman correlation for log diameter: $r_s = -0.345$, $N = 11$, $P = 0.283$, diameter range 4 – 12 cm; Spearman correlation for log age: $r_s = -0.096$, $N = 11$, $P = 0.755$, age range 12 – 33 years), densities of duramen and alburnum were not significantly different (ANOVA: $F = 0.0126$; $df = 42$; $P = 0.911$), and inter-individual variations were not significant (ANOVA: $F = 0.516$; $df = 14$; $P = 0.759$, 4 – 5 -cm diameter logs from 6 individuals). These data showed that intra- and inter-individual variations are indeed small and support wood density as a useful marker for examining wood provenience.

3.2. Distribution of snuff trays and snuff tray densities

Fig. 2 shows the frequency distribution of density values of the snuff trays studied. Also shown in the figure are the densities of the wood species native to SPA and native to ecoregions of Bolivia and NWA with demonstrated direct interactions with SPA during prehispanic times. While trays with density equal to or below 0.46 and equal to or above 0.73 g/cm^3 can be safely assumed to have been manufactured with woody species exogenous to SPA, wood with densities between 0.46 and 0.73 may be from species native to SPA but also from species exogenous to SPA given that: i) the three native tree species present in SPA are also naturally distributed throughout the Circumpuna area (*Goeffroea decorticans*: Ireland and Pennington, 1999; *Prosopis alba*: Burkart, 1987; *Schinus molle*: Barkley, 1957), and ii) other species from the Circumpuna area may have densities similar to those of the three species native to SPA (Chave et al., 2006).

Fig. 3 shows the distribution of snuff trays within each of the three broad density classes described above, according to cultural phase, style and manufacturing technique; within each group, at least half of the trays were manufactured with wood exogenous to SPA. The interaction of cultural phase with style was explored in Fig. 4; while Tiwanaku and San Pedro style trays were found in all cultural phases, Circumpuneño style trays were only found in the Yaye/Solor phase. The interaction of cultural phase with manufacturing technique is shown in Fig. 4; type C trays with high reliefs on a planar appendix were not found in all cultural phases, most likely on account of their low occurrence (only 6 trays exist with this style within the group studied), while other types were represented in all cultural phases.

Independent one-way ANOVAs were performed to assess variation in tray density as a function of cultural phase, style and manufacturing technique. Cultural phase had a significant effect on density (Kruskal–Wallis ANOVA: $H = 12.957$, $df = 4$, $P = 0.011$);

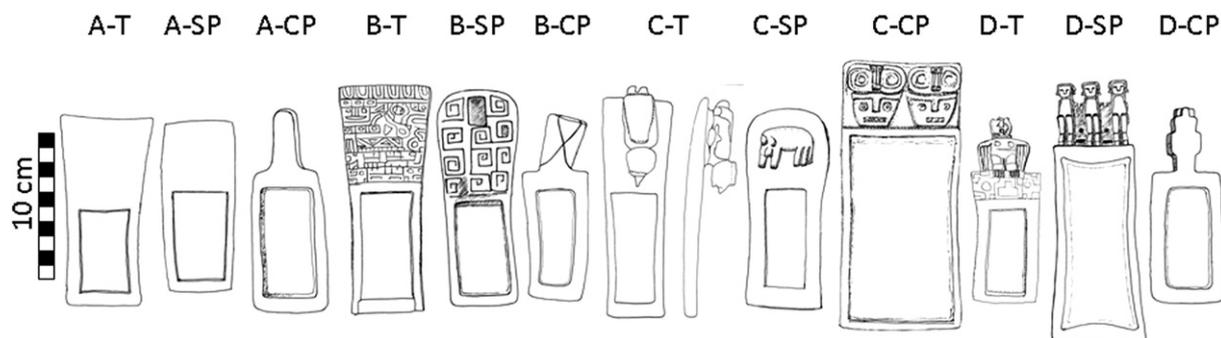


Fig. 1. Schematic illustrations of snuff trays showing different types according to the manufacturing technique employed and style: trays without decoration (A), with linear incisions (B), with high reliefs on a planar appendix (C) and with a volumetrically carved appendix (D). Abbreviations refer to styles: T = Tiwanaku; SP = San Pedro, and CP = Circumpuneño. Museum catalog numbers (IIAM numbers) of the trays shown are as follows (from left to right): 368, 129, 309, 280, 68, 326, 400, 258, 371, 364, 1 and 310.

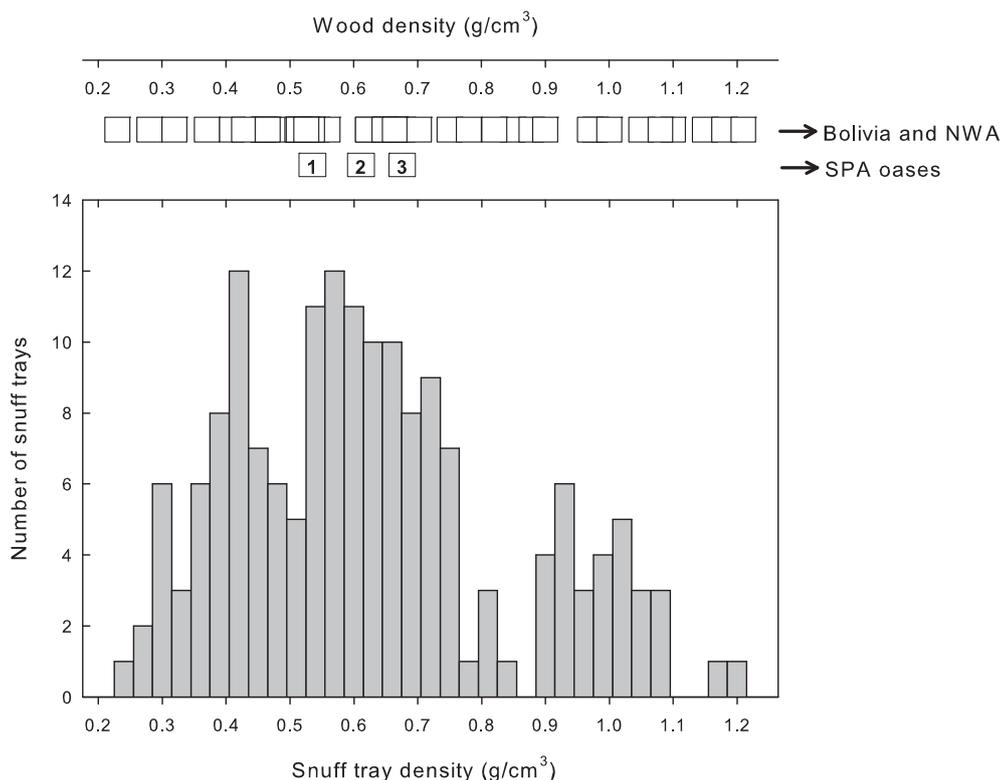


Fig. 2. Distribution of densities of snuff trays ($N = 169$). The density interval of each bar corresponds to 1.5 times the mean standard deviation of density determinations of trays (1.5×0.020); the width of the squares of known wood samples correspond to 1.5 times the mean standard deviation of density determinations of *A. caven* wood samples (1.5×0.020 – see text). Native woody species naturally growing in SPA correspond to 1: *Geoffroea decorticans* (Fabaceae); 2: *Schinus molle* (Anacardiaceae) and 3: *Prosopis alba* (Fabaceae). Native woody species from Bolivia and Northwestern Argentina ($N = 26$) encompassed a wide range of densities.

a posteriori Dunn's tests showed a significant difference in density between trays belonging to Quito and Yaye/Solor cultural phases ($Q = 3.319$, $P < 0.05$) (Fig. 5). Tray density was also significantly affected by style (ANOVA: $F = 3.196$, $df = 2$, $P = 0.045$); a posteriori Holm–Sidak tests showed a significant difference between Tiwanaku style and both San Pedro and Circumpuneño styles ($t = 2.301$,

$P = 0.024$; $t = 2.482$, $P = 0.015$, respectively) but not between the latter two styles ($t = 0.797$, $P = 0.427$) (Fig. 6). Manufacturing technique was not significantly affected by density (Kruskal–Wallis ANOVA: $H = 3.544$, $df = 3$, $P = 0.315$).

4. Discussion

This work used wood density as a marker of wood provenience by comparing the density of snuff trays from SPA with the density of wood from species native to SPA and to areas with demonstrated direct interactions with SPA during pre-hispanic times, i.e., Bolivia and NWA. The results in Fig. 2 show that although some of the SPA snuff trays studied may have been manufactured with local wood, most of them used wood exogenous to SPA as raw material. At this point, it is not possible to ascertain the precise provenience of such exogenous wood. However, based on various hypotheses on the interactions of SPA with neighboring areas, e.g., SPA as a key node of pre-hispanic trade networks (Llagostera, 1996; Núñez, 1992, 1996; Torres and Conklin, 1995), as a participant in the Algarrobo multi-ethnic cultural system (Martínez, 1990, 2000), and as an element in the South-central Andes social field *sensu* (Terrell, 2001; Stovel, 2008), provenience from Bolivia and NWA appears as likely. Trade between both sides of the Andes has been shown to include a wide range of raw materials and goods such as gemstones, minerals, metals, ceramics, basketry, textiles and engraved gourds (e.g.: Agüero, 2000; Agüero et al., 1997; Castro et al., 1979, 1984; Latcham, 1938; Lechtman and Macfarlane, 2005; Llagostera, 1996; Núñez and Dillehay, 1979; Uhle, 1913; Uribe, 1997; Uribe and Agüero, 2001; Uribe et al., 2004). Fig. 3 shows that the exchange of wood, either as raw material or as a finished object, occurred throughout the Formative, Intermediate and Late Intermediate periods.

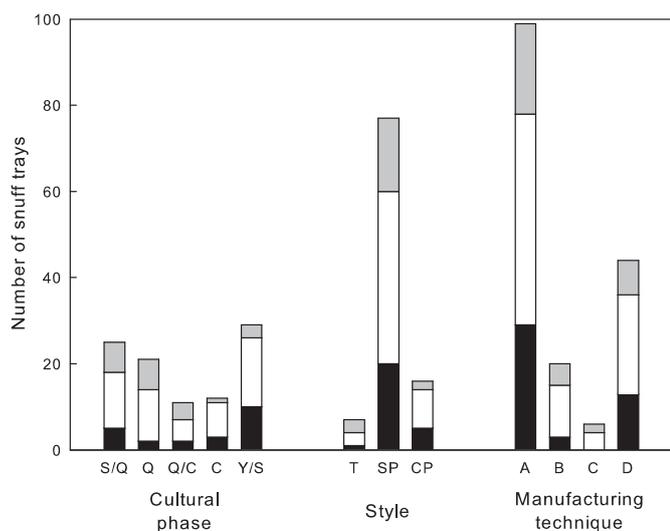


Fig. 3. Distribution of snuff trays according to cultural phase ($N = 98$), style ($N = 100$) and manufacturing technique ($N = 169$). Whole bars: all trays. Trays were manufactured with: low-density wood exogenous to SPA (black section), intermediate-density local wood or wood exogenous to SPA (white section), or high-density wood exogenous to SPA (gray section).

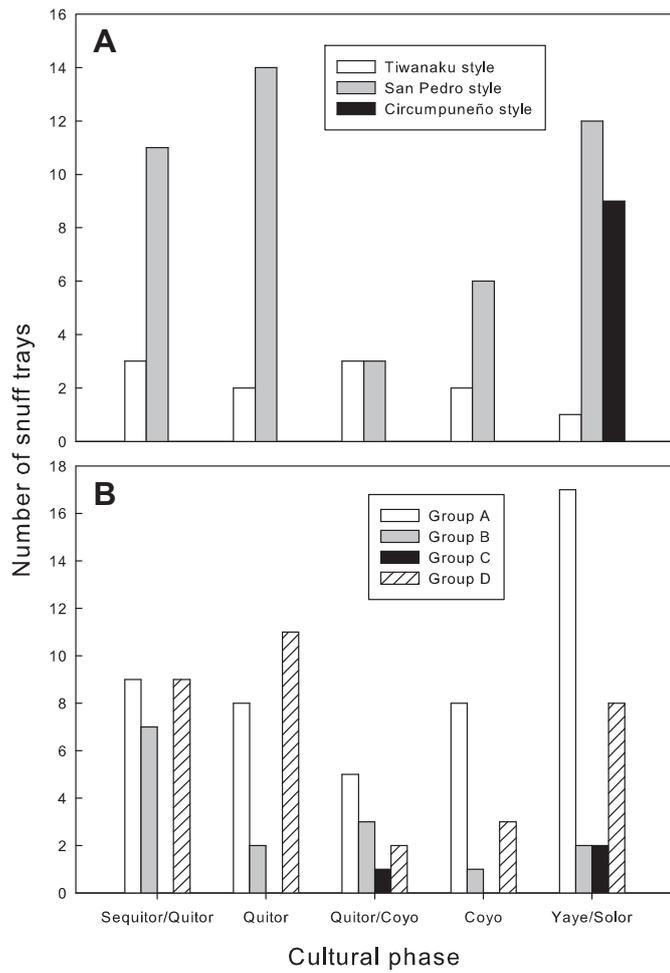


Fig. 4. Interaction of cultural phase with: A, style ($N = 56$); B, manufacturing technique ($N = 98$) of snuff trays.

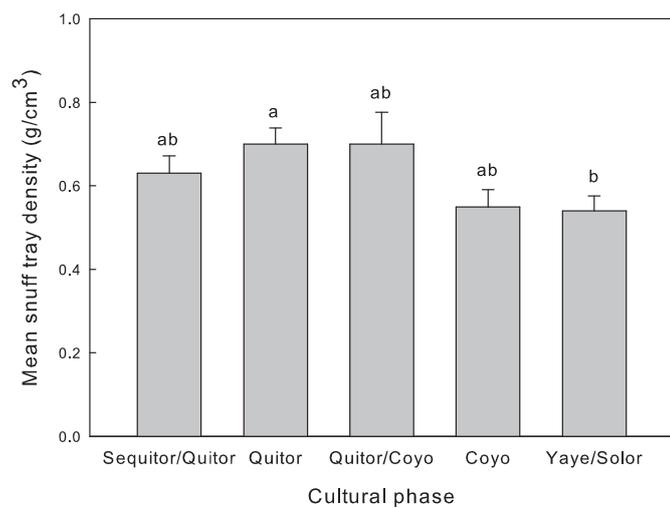


Fig. 5. Mean densities (\pm SEM) of snuff trays found in funerary contexts belonging to different cultural phases of SPA. Different letters above the bars indicate significant differences at $P < 0.05$. Only cultural phases represented by more than two trays were considered in the analysis; hence, five trays were excluded which were assigned to the following cultural phases: Toconao/Sequitur (1), Sequitur (2), Yaye (1) and Catarpe (1). The snuff trays included in the analysis were assigned the following cultural phases: Sequitur/Quitor (25), Quitor (21), Quitor/Coyo (11), Coyo (12) and Yaye/Solor (29).

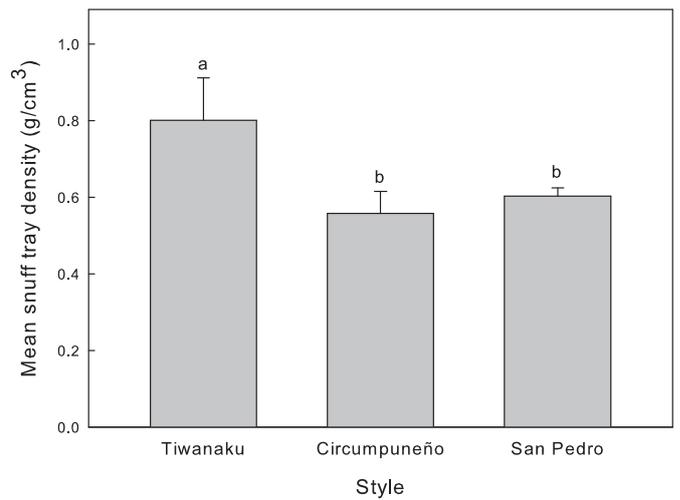


Fig. 6. Mean densities (\pm SEM) of snuff trays ascribed to different styles. Different letters above the bars indicate significant differences at $P < 0.05$. The numbers of snuff trays within the sample studied which could be assigned to styles are as follows: Tiwanaku (6), Circumpuneño (15) and San Pedro (79).

Having established that most snuff trays from SPA were made with wood from neighboring areas, the question remains whether the object itself or just the raw material were imported to SPA. There is no direct evidence to support either of these possibilities. SPA has been proposed as a center for artistic and religious activities within the South-central Andes, particularly in relation to the use of psychedelic substances (Torres, 1999). Given the sacred connotation of snuff trays and their character of portable temples, it is likely that during Tiwanaku influence on SPA, Tiwanaku style snuff trays were imported ready-made as vehicles for ideological proselitism (Berenguer, 1998; Llagostera, 2006). The simultaneous presence in SPA of San Pedro style trays with Tiwanaku style trays suggests that the SPA society is developing its own religious symbols concomitant with Tiwanaku influence, as has been found in other markers of the period (e.g.: Stovel, 2005; Torres-Rouff, 2008), or that trays of different styles may have been manufactured for individuals of different social standing in the society (Llagostera et al., 1988; Torres-Rouff, 2011).

The effect of style on density (Fig. 6) suggests that sources of wood were different for Tiwanaku style trays and for trays made in San Pedro style. It seems likely that wood used in Tiwanaku style trays came from forests easily accessible from lake Titicaca, the center of the Tiwanaku culture, although the extensive network of interactions of Tiwanaku at the time of strongest influence on SPA point to some of Tiwanaku's provincial centers such as Cochabamba (Uribe and Agüero, 2004) as potential wood sources. Having established that wood used in San Pedro style trays came from sources different from the above, likely candidates are the San Pedro oases and even the forests at the other side of the Andes in NWA. An interesting question to address is why such great proportion of trays with SP style were made with wood exogenous to SPA. Two lines of arguments may be advanced: i) trees were scarce in SPA compared to neighboring areas and they had to provide logs for dwelling construction and fuel for heating and cooking purposes; and ii) the social segregation of the snuffing practice within the SPA society (Llagostera, 2006), as mentioned above, would be further enhanced through use of exotic raw materials.

The question still remains whether trays with San Pedro style were made locally. While this can not be confidently ascertained, indirect evidence exists to support the presence in SPA of wood



Fig. 7. Examples of repaired (A, C) and incomplete (E, F) trays at the museum in San Pedro de Atacama. Also shown are trays with appendixes including zones which resemble the missing parts of trays A (tray C) and C (tray D). Museum catalog numbers (IIAM numbers) of the trays shown are as follows (from left to right): 262, 232, 394, 344, 412 and 209. Photographs reprinted with the permission of the museum.

artisans who could have been involved in their manufacture: i) axes, awls and chisels found in SPA funerary contexts could have been used to fell trees and work their wood; and ii) unfinished and repaired snuff trays have been found in SPA funerary contexts (Fig. 7); interestingly, the densities of the unfinished trays (Fig. 7E and F: 0.48 and 0.69 g/cm³, respectively) fall within the range corresponding to local woody species (see Fig. 2).

Since the patterns of interaction of SPA with various cultures in neighboring regions were geographically and temporally dynamic (Stovel, 2008), diachronic differences in the use of raw materials – wood in particular – may be expected. This was partly shown by data in Fig. 6; however, the trends are rendered imprecise on three accounts: data distribution between cultural phases is quite unbalanced, cultural phases could not be unequivocally defined for many trays, and identification of wood at the species level is not yet available. The first problem can only be solved through further excavations, an activity which is presently forbidden in the SPA area. Dating of the snuff trays themselves would be desirable and would partly solve the second problem stated; highly sensitive techniques such as AMS radiocarbon dating are presently available which might be worthwhile applying to a selected group of trays. Identification of species used in the manufacture of trays is clearly a natural continuation of this study. The results of the present work can help prioritize and limit the snuff trays to be tampered with for wood identification purposes; thus, it seems of greater interest to study: i) trays whose densities fall within the 0.49–0.73 g/cm³ range, i.e., those which can not be assigned to the local or exogenous groups on the basis of their density, ii) trays with San Pedro and Circumpuneño styles, since it is more likely that those with Tiwanaku style were manufactured in Tiwanaku with local wood, and iii) trays which can be confidently assigned to a cultural phase, so that diachronic changes in patterns of interaction and mobility of goods in the area may be assessed; in particular, it would be of special interest to study trays from the cultural phases prior to the main expansive influence of Tiwanaku.

Finally, it may be argued that different manufacturing techniques of the snuff trays might have made use of different types of wood; for example, hard woods in the simple undecorated trays, softer wood in trays with linear incisions or low reliefs and softest wood in trays with carving on the round. This was not brought forward by the analysis, which showed no significant effect of manufacturing technique on tray density. Apparently the

skill of the artisans and the quality of their tools allowed them to use any type of wood for their art work, independently of its complexity.

In conclusion, the wood density determinations presented in this work have shown that most snuff trays found in SPA were manufactured with wood exogenous to SPA. Data suggests that most Tiwanaku style trays were imported ready-made from Tiwanaku or neighboring areas, whereas San Pedro and Circumpuneño style trays could have been manufactured in SPA using local or exogenous wood. This work adds a new dimension to studies on patterns of exchange of goods and raw materials among South-central Andean societies by addressing wood as materiality. Given the spiritual importance of snuff trays in the region, it would be worthwhile to follow-up this work by studies on the identification of wood species employed in the manufacture of snuff trays, coupled with further insights into their style and additional data on their chronology.

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