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Computed tomography study of snuff trays from San Pedro de Atacama (Northern Chile)

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ABSTRACT

Wooden snuff trays from San Pedro de Atacama (SPA) in northern Chile are objects of particular museological value. Computed tomography (CT), a non-destructive analytical technique useful in the analysis of archaeological objects in which physical tampering is not desirable, was used to study provenience of wood, quality of craftmanship, taphonomic processes and nature of gemstone inlays in a group of snuff trays. While wood used in the manufacture of trays was mostly exogenous to SPA, gemstones used in inlays were likely of local origin. These findings support the active exchange of goods proposed for the south-central Andes region. Several features revealed in the trays support the view that craftsmen producing them were skillful artisans.

1. Introduction

Consumption of hallucinogenic substances by smoking, ingesting, snuffing, chewing or through enemas is a long-standing tradition amongst native peoples of the Americas (Torres and Repke, 2006; Schultes et al., 1998). Smoking pipes, documented in San Pedro de Atacama (SPA) in Northern Chile in contexts before 400 A.D., are gradually replaced by snuffing implements which become predominant during the Middle period (400–1000 A.D.) (Torres, 1999). In fact, prehispanic archaeological sites in SPA show the highest incidence of snuffing implements in the world (Torres, 1999), the most conspicuous of which are wooden snuff trays (Torres, 1987). Many of these artifacts have been optimally preserved by the extreme aridity of the area (Blanchette et al., 1990).

Research on snuff trays has centered mainly on those ascribed to the period when the influence of the Altiplanic Tiwanaku state was strongest. The studies have mainly addressed manufacturing technique and iconography, the most prominent feature in those trays (Llagostera, 1995, 2001, 2006; Llagostera et al., 1988; Núñez, 1963; Tarragó, 1989; Thomas et al., 1984; Torres, 1984, 1986, 1999). The study of non-Tiwanaku trays has received comparatively less attention (Llagostera, 2001; Llagostera et al., 1988; Torres, 1999) until the recent work of Horta Tricallotis (in press-a, in press-b). Among the long debated issues concerning snuff trays from SPA are their assignment to different styles and the correlation of these styles with styles prevailing in other types of archaeological objects – be them from SPA or from elsewhere in the south-central Andes, the relationship between style and cultural period, the societal status of tray users, the diachronic prevalence of tray use within society, the provenience of the materials employed in tray manufacture and of the tray itself, *i.e.*, was it made with local or exogenous raw materials? and was it made by local or foreign artisans? Data pertaining to these issues, particularly the provenience of raw materials, would allow new insights into the circulation of these objects and associated snuffing practices. Given the importance of snuffing and hence snuffing paraphernalia in the

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spiritual realm of prehispanic cultures of the south-central Andes (Torres, 1999), such provenience study seems a timely undertaking.

During the last couple of decades, numerous studies have addressed the provenience of materials used in the manufacture of objects of archaeological significance. An ample variety of physical and chemical analytical techniques have been used to compare features of the material constitutive of the object with those of similar materials from various geographical origins, thus establishing likely candidates as sources. The main conclusions arising from such studies are proposals of patterns of mobility and interaction of ancient human populations. Materials as different as clay (Ma et al., 2012; Neff, 2012), pigments (Beck et al., 2012), textile fibers (Frei et al., 2009), glass (Polikreti et al., 2012), obsidian (Vazquez et al., 2012), metals (Cattin et al., 2011), and wood (Allevato et al., 2010; Rich et al., 2012) have been recently the subject of such studies. Similar studies have also been reported on bioanthropological remains of ancient human populations (Vika, 2009).

Few provenience studies have been performed on archaeological materials from Northern Chile. A study using inductively coupled plasma – mass spectrometry combined with optical emission plasma – mass spectrometry and atomic absorption spectroscopy showed that local andesite was the primary source used in archaeological stone artifacts from the Formative Period of the upper Loa river basin neighboring SPA (Morales et al., 2007; Seelenfreund et al., 2009). Neutron activation analysis as well as scanning electron microscopy and energy dispersive X-ray fluorescence analysis on metal objects from the Middle Period at SPA showed that the origin of alloys employed in them was the Bolivian altipano region (Lechtman and Macfarlane, 2005; Maldonado et al., 2010). More recently, inductively coupled plasma – atomic emission spectrometry confirmed the previous results and further found that two metal objects from Middle Period contexts of SPA were made of unalloyed copper, attributed to local metallurgic activities (Salazar et al., 2011). Chemical, anthropological and cultural markers indicated the provenience of a Late Intermediate Period population from Caspana, in the middle Loa river basin in Northern Chile (Knudson and Torres-Rouff, 2009), and showed that a man from Middle Horizon SPA had lived his early life in the Bolivian altiplano (Torres-Rouff and Knudson, 2007), and that none of a group of individuals from the Middle Period in SPA had lived in the Titicaca basin in their youth (Knudson, 2007).

The provenience of the wood used in the manufacture of snuff trays from SPA was recently addressed by determining wood density, a parameter that can be used to demarcate the range of possible woody species (Niemeyer, 2013). In that study, density was determined as the ratio between the weight of the tray and its volume. This type of measurement may be distorted in trays with gemstone inlays (amounting to one-sixth of the trays at the museum in SPA) because densities of gemstones are normally much higher than those of wood. Hence, an alternative method must be sought for determining densities of gemstone-containing trays, the subject of the present study.

X-ray computed tomography (CT) is a non-destructive analytical technique particularly suited to the analysis of sensitive archaeological objects in which physical tampering should be minimized (van Kaick and Delorme, 2005). It provides values of X-ray absorption by volume elements in the object analyzed which, upon suitable calibration, can be transformed into density data. In the present case, CT has the distinct advantages of simultaneously providing the densities of the two main raw materials of snuff trays, *i.e.* wood and gemstones, and also providing insights into the craftmanship techniques employed in the manufacture of the trays. In this study, we address the question whether CT can be used to study provenience of wood, quality of craftmanship, taphonomic processes and nature of gemstone inlays in a group of snuff trays from SPA.

2. Materials and methods

2.1. Objects and samples studied

At the time this study was initiated (November 2010), the Instituto de Investigaciones Arqueológicas y Museo at San Pedro de Atacama had included in its database 416 snuff trays in different states of preservation, 411 of which were made of wood, two of bone and three of stone; of the wooden trays, 69 had gemstones inlayed. In the present study, nine snuff trays were chosen which upon macroscopic examination were well preserved, with smooth surfaces and well-defined contours (Table 1, Fig. 1): six of the trays chosen contained a large number of inlayed gemstones while three others, used for comparison of conventional and CT methods for determining density, contained no gemstones. At the museum at SPA, trays are stored under low humidity conditions (*ca.* 10% RH), comparable to standard conditions for reporting wood densities (Chave et al., 2006; Lindgren, 1991a).

Reference wood samples for calibration purposes were obtained of native trees from SPA ($N = 3$, representing all tree species growing in the area), and from areas of western and southern Bolivia and northwestern Argentina with direct cultural links with

Table 1
Characteristics of the snuff trays studied.

IIAM number[a]	Mummy number	Site	Cultural phase[b]	Density (g/cm^3)	Distance between rings (mm)	Angle (°)[e]	Manufacturing technique[g]
4	5383	Coyo Oriente	Quitor/Coyo	1.13	2.0	2	HR
19	4040	Coyo Oriente	Quitor/Coyo	1.10	1.1	2	VC
75	2264–2267	Quitor 5	Quitor	0.41	3.0	nd[f]	VC
101	2145	Quitor 5	na[c]	0.48	nr[d]	3	WD
231	3935	Coyo Oriente	na[c]	0.57	3.0	10	VC
272	5369	Coyo Oriente	na[c]	0.69	2.4	2	LI
283	1483	Yaye 2	Yaye/Solor	0.96	1.1	0	WD
324	2702	Quitor 6	Sequitor/Quitor	0.73	10	6	VC
392	4850	Tchilimoya	Quitor/Coyo	0.86	1.4	nd[f]	VC

[a] Catalog number at the Instituto de Investigaciones Arqueológicas y Museo at San Pedro de Atacama.
[b] See text for references. More than one cultural phase is given when the context did not allow specific assignment.
[c] Not available: the archaeological context of the mummy did not allow its assignment to a cultural phase.
[d] No rings were observed in this tray (see text for possible explanations).
[e] Mean angle between the direction of wood fibers and main axes of sagittal and coronal planes as depicted in Fig. 2.
[f] Accurate measurements could not be taken due to the curved nature of the tray.
[g] Manufacturing technique employed: HR = high reliefs on a planar tray appendix; VC = volumetrically carved appendix; WD = appendix without decoration; LI = linear incisions on the appendix.

Fig. 1. Snuff trays studied. IIAM catalog numbers are shown below the trays. Photographs reprinted with the permission of the museum.

SPA during prehispanic times ($N = 24$, representing less than 20% of tree species growing in the areas). The wood blocks (ranging from *ca*. 50 to *ca*. 100 cm^3) were dried in an oven at 80 °C until their weight was stable. Residual water under these conditions is estimated to be around 10%. Reference samples of gemstones for calibration purposes were obtained from a commercial source.

2.2. Measurements

In a multi-slice CT system, the X-ray tube rotates 360° continuously around the object (X–Y plane) and simultaneously moves orthonormally (Z direction) producing volumetric information amenable to reconstruction algorithms (Radon and Fourier transforms, and back projection). Data is displayed in a matrix of 2D pixels whose values, the CT numbers (measured in Hounsfield units – HU), represent the X-ray absorption of the structure, and 3D matrices where the volume element, called voxel, includes the pixel and a third dimension given by slice thickness. CT numbers, when properly normalized, are linearly related to the density of the corresponding voxels (Freyburger et al., 2009; Lindgren, 1991a,b; Wei et al., 2011).

A 64-channel multi-slice Siemens Somaton Sensation medical scanner was used to study different features of snuff trays. Optimization of instrumental parameters for the observation of wood samples was achieved by sequentially changing the value of acquisition parameters and having a panel of four naïve and independent observers judge the quality of images in terms of rendering wood structural details. After five cycles of parameter changes optimization was achieved with the following values: u75 (type of filter), 120 kV (tube voltage), 200 mAs (current intensity), 0.45 (pitch), 0.6 mm (scan width) and 0.3 mm (overlap between successive scans). Under these conditions, the voxel size, a measure of instrumental resolution, was $0.35 \times 0.35 \times 0.6$ mm. Optimization was also performed for the observation of gemstones inlayed. Given the high density of these materials and hence the important attenuation that the X-ray beam experiences (Bushong, 2000), the most relevant factor to consider is tube voltage; lower values correspond to fewer penetrating photons which may produce higher image noise (Goldman, 2007a, 2007b, 2008). The optimization criteria employed were the standard deviation of data obtained from different volumes within homogeneous materials (aluminum and titanium) and signal-to-noise ratio, *i.e.* quality of image. The optimum value for tube voltage was 120 kV.

Raw data was analyzed using different algorithms of the Syngo software which are part of multi-planar reformation (MPR) and volume rendering (VRT) techniques. TheMPR algorithms were used to evaluate planar sections in different orientations and to determine spatial relationships within the objects, in particular the orientation of wood fibers within the tray, *i.e.* the angles between the direction of wood fibers and the main axes within sagittal and coronal planes of the tray (Fig. 2). VRT was used to obtain 3D graphical representations of the different levels of density. The density histogram of each tray was analyzed, trapezoidal volumes were created which encompassed different and discrete density values, and each of these volumes was assigned a certain value of RGB color, brightness and opacity to obtain a representative 3D colored digital reconstruction of the tray. Image J 1.44p was used to determine the number of growth rings in the trays, by creating the density profile along lines bisecting representative (free of cracks or blemishes) transverse sections; growth rings can be accurately discerned from such profiles (Fig. 2).

Digital imaging techniques allow the selection of areas or volumes of the tray to be analyzed and also the exclusion from the analysis of portions of the tray with CT numbers below or above a certain threshold value. Thus, mean CT numbers were determined: i) for the whole tray after digitally excluding volumes corresponding to gemstones inlayed or volumes showing superficial degradation processes (when determining wood density), ii) for certain wood volumes (when exploring distance between growth rings and densities in certain regions of the tray) and iii) for gemstone inlays (when determining their density).

CT numbers were calibrated using two series of materials, wood and gemstone samples, whose bulk density was determined by conventional volume and mass measurements. Two different calibration lines were obtained for the two density ranges explored (Saw et al., 2005), *i.e.*, one for wood and another for gemstones (Fig. 3). Mean density values for snuff tray wood and for gemstone inlays were extrapolated from the corresponding calibration lines.

Wood is a heterogeneous material; hence, densities differ when measured at different places of a wood piece (Schweingruber, 1996). A corollary of this is that if wood pieces examined are too small, the density determined may not reflect the mean density of

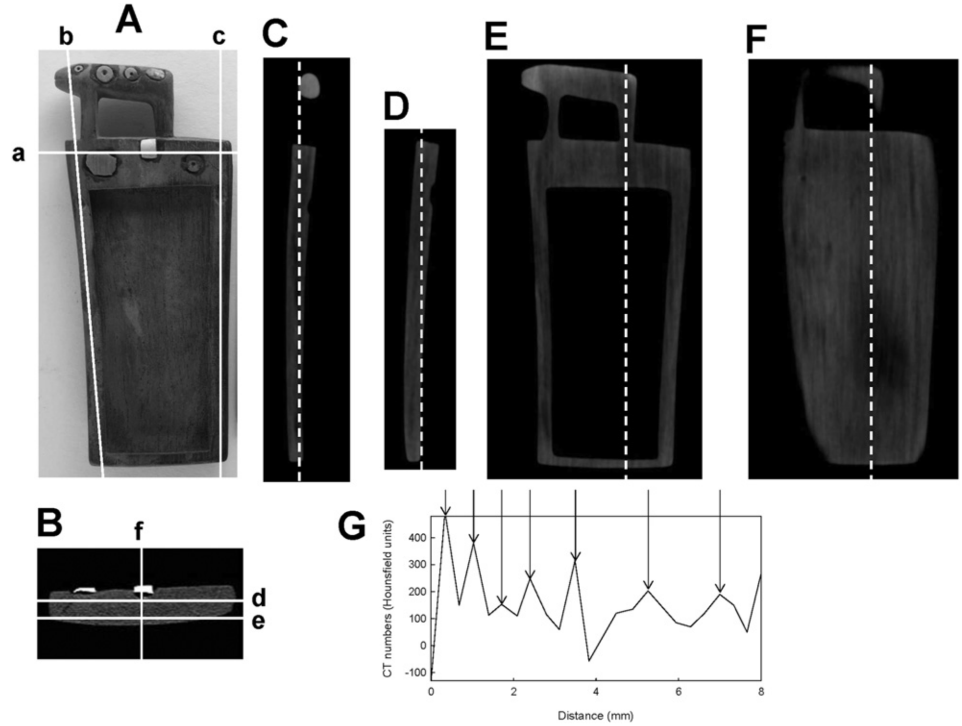

Fig. 2. Measurements performed on a representative snuff tray. A: Frontal view indicating three of the planes studied; B: CT image of transverse plane **a**, showing further planes studied; C: CT image of the lateral sagittal plane **b**; D: CT image of the lateral sagittal plane **c**; E: CT image through coronal plane **d** passing through the receptacle of the tray. F. CT image through coronal plane **e** passing below the receptacle. Lines shown in panels C, D, E and F were used as reference for determining the angle of the wood fibers. G. Density measurements along line **f** of panel B: the distance between two consecutive arrows corresponds to the distance between two annual growth rings.

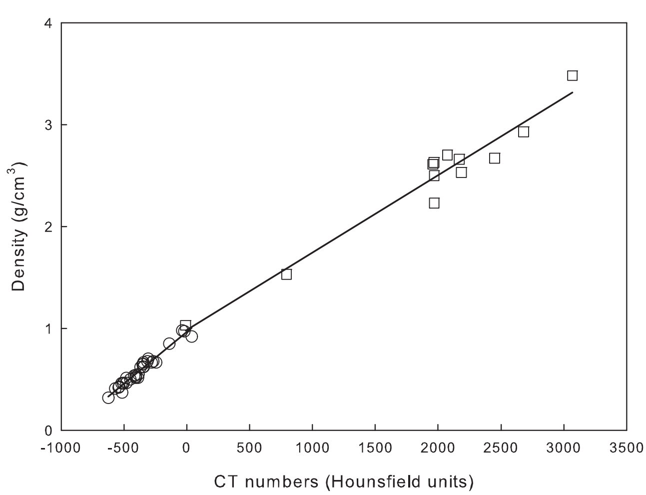

Fig. 3. Calibration lines for the two density ranges explored (left: wood; right: minerals). Wood reference samples (circles) corresponded to the following botanical species: *Amburana cearensis* (Fabaceae), *Apuleia mollaris* (Fabaceae), *Astronium graveolens* (Anacardiaceae), *Calophyllum brasiliense* (Clusiaceae), *Cariniana estrellensis* (Lecythidaceae), *Cedrela odorata* (Meliaceae), *Cedrelinga catenaeformis* (Fabaceae), *Ceiba pentandra* (Malvaceae), *Centrolobium ochroxylum* (Fabaceae), *Centrolobium tomentosum* (Fabaceae), *Cinnamomum porphyrium* (Lauraceae), *Dipteryx odorata* (Fabaceae), *Erisma uncinatum* (Vochysiaceae), *Geoffroea decorticans* (Fabaceae), *Haplorhus peruvianus* (Anacardiaceae), *Hura crepitans* (Euphorbiaceae), *Juglans australis* (Juglandaceae), *Juglans olanchana* (Juglandaceae), *Myrica pavonis* (Myricaceae), *Myroxylon balsamum* (Fabaceae), *Platymiscium ulei* (Fabaceae), *Polylepis rugulosa* (Rosaceae), *Polylepis tarapacana* (Rosaceae), *Prosopis alba* (Fabaceae), *Prosopis tamarugo* (Fabaceae), *Qualea paraensis* (*Vochysiaceae*), *Schinus molle* (Anacardiaceae), *Swietenia macrophylla* (Meliaceae), *Tabebuia impetiginosa* (Bignoniaceae), *Terminalia amazonia* (Combretaceae), *Tetragastris altissima* (Burseraceae), and *Virola sebifera* (Myristicaceae). Gemstone reference samples (squares) corresponded to amber, amethyst, chrysocolla, chrysoprase, jadeite, jasper, lapis lazuli, malachite, obsidian, quartz, tourmaline and ulexite. Linear regression analysis for wood: $Y = 0.964 + 0.001101\ X$, $r^2 = 0.955$; for gemstones: $Y = 0.987 + 0.000759\ X$, $r^2 = 0.952$.

a larger piece of the same wood (Lindgren, 1991b; Freyburger et al., 2009). In the present case, the volumes of snuff trays were all sufficiently large (Fig. 1) as to avoid this "small volume effect".

Distance between growth rings, although to a certain extent a function of the environmental conditions under which the tree grew (Schweingruber, 1996), remains a characteristic property of wood species (Chave et al., 2006). It may be visualized by determining mean CT number of voxels along lines bisecting transverse sections of the tray (Fig. 2B): density peaks along the gradients (Fig. 2G) correspond to slow-growing denser wood deposited during dry periods (Panshin and de Zeeuw, 1980; Wilson and White, 1986). Distance between pairs of adjacent rings was measured and averaged along the gradients.

Finally, density is a characteristic property of gemstones. Gemstones are found in nature as heterogeneous substances on account of different quality and quantity of impurities in them; hence, the density of a gemstone is normally a function of the individual sample studied and its dimensions, its value falling within a range which reflects different states of purity. Preliminary identification of a gemstone through density values can be achieved by comparison with reference gemstones.

Fig. 2 illustrates the types of measurements performed for the analysis of one of the snuff trays (IIAM19), including the angles between the direction of wood fibers and the main axis of the tray, and the density profile along a cross-section of the tray allowing the determination of mean distance between growth rings. Similar analyses were performed for all trays.

3. Results

3.1. Nature of wood species

The differences between conventionally determined densities of trays IIAM4, IIAM75 and IIAM272 (1.05, 0.43 and 0.68 g/cm^3, respectively) and of trays IIAM19 and IIAM392 (1.15 and 0.88 g/cm^3, respectively) and the corresponding CT-determined values (Table 1), fall within the errors involved in CT density determinations (estimated at *ca*. 10%: see Freyburger et al., 2009) and in conventionally determined densities (estimated at 5%: see Lindgren, 1991a, and at 2–4%: see Niemeyer, 2013), thus showing that both methods are applicable to trays with few and small inlayed gemstones, or without them.

Fig. 4 shows CT-determined mean densities values of the snuff trays and of wood from species native to SPA and to neighboring areas. Data shows that most trays have mean densities that do not correspond to densities for species native to SPA. The fact that some tray densities fall outside the range for woods collected from western and southern Bolivia and northwestern Argentina stems from having studied a relatively small sample of the tree species in those areas: analysis of literature data on density of woods from those areas shows a near continuum ranging from 0.24 to 1.35 g/cm^3 (Atencia, 2003; Gutiérrez and Sandoval, 2008).

Previous work showed that wood with density equal to or below 0.46 and equal to or above 0.73 g/cm^3 could be safely assumed to correspond to species exogenous to SPA, and wood with densities between 0.46 and 0.73 g/cm^3 was undetermined with respect to provenience: it could correspond to species native to SPA but also to species exogenous to SPA (Niemeyer, 2013). Trays IIAM101, IIAM231, IIAM272 and IIAM324 show densities which could correspond to species native to SPA. Based only on wood density values, Niemeyer (2013) determined that about half of the 169 snuff trays studied were manufactured with wood exogenous to SPA; consistently, in the present study density values of five of the nine trays point to wood exogenous to SPA.

The study on densities was complemented by a study of distances between growth rings. Data in Fig. 5 and Table 1 shows that mean distance between growth rings of most snuff trays differ from corresponding values for species native to SPA, although trays IIAM4, IIAM75 and IIAM231 show values close to those of local woods. Taken together, density and growth ring studies suggest that tray IIAM231 is the only one among those studied that could have been manufactured from local wood (algarrobo, *Prosopis alba*). It is interesting to note that algarrobo exhibits an ample distribution, being found throughout northern Argentina and Chile and southern Paraguay (Burkart, 1987; Degen and Mereles, 1996). Hence, tray IIAM231 could have been manufactured from wood from an algarrobo tree growing in areas distant from SPA.

It should be mentioned that no rings were detected in snuff tray IIAM101. In this case, the woody species may correspond to a tropical species in which annual growth rings may not be visible (Kipfmueller and Swetnam, 2005; Panshin and de Zeeuw, 1980; Wilson and White, 1986), or its growth rings be too close to each other to be measured given the instrument's resolution (Brüchert et al., 2008; Lindgren et al., 1992; Okochi et al., 2007), or too distant from each other so that the tray was made from an intergrowth ring area.

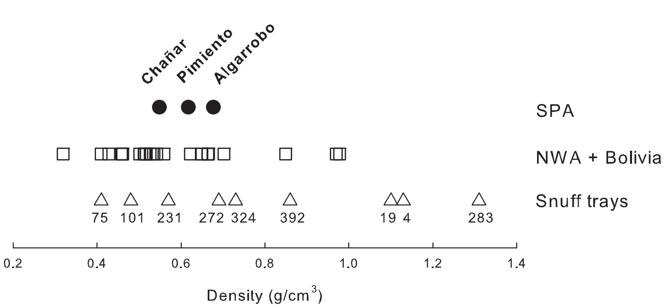

Fig. 4. Density of snuff trays and of wood species from SPA [pimiento: *Schinus molle* (Anacardiaceae), chañar: *Geoffroea decorticans* (Fabaceae), and algarrobo, *Prosopis alba* (Fabaceae)], and northwestern Argentina and western and southern Bolivia (see legend to Fig. 3 for species used). Numbers below the triangles correspond to snuff trays IIAM numbers (see Table 1 and Fig. 1).

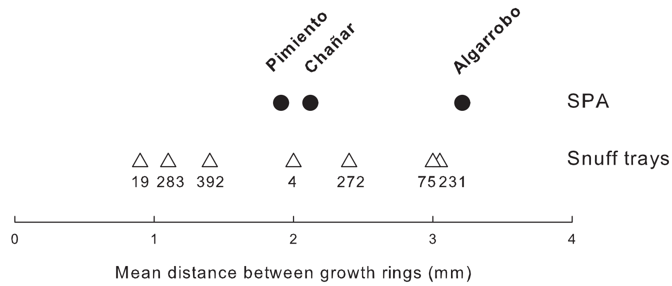

Fig. 5. Distance between growth rings in snuff trays and in woody species from SPA (see legend to Fig. 4 for species used). Numbers below the triangles correspond to snuff trays IIAM numbers (see Table 1 and Fig. 1).

3.2. Craftmanship

Craftmanship was judged as the capacity of the artisan to select the piece of wood in such way that a particular pre-conceived design would take advantage of the mechanical properties and aesthetical features of the piece of wood selected. Thus, wood shows different mechanical resistance depending on the direction of forces applied (Forest Products Laboratory, 2010). A longitudinal object such as a snuff tray is best positioned within a block of wood with its longitudinal axis parallel (angle = 0°) to the direction of wood fibers. Values of such angles for the snuff trays studied were determined and ranged from 0 to 10° (mean ± standard error: 3.6 ± 1.9°), showing an adequate choice of tray orientation in most cases (Table 1).

Table 1 also shows the high quality of craftmanship in the sense that volumetric carving, the most difficult type of decoration among those found in SPA trays, was achieved with wood of a wide range of densities, including one of the hardest obtainable from forests of the south-central Andes (Atencia, 2003; Gutiérrez and Sandoval, 2008).

As a tree ages, its wood often shows two distinct zones: a generally harder and darker interior zone called the heartwood and an exterior one, generally softer and lighter, called the sapwood (Panshin and de Zeeuw, 1980; Wilson and White, 1986). In tray IIAM75 with an appendix (trays generally have a receptacle where snuffing powders were deposited and an appendix which presumably was used as a holder) carved in the round it was found that the mechanically most sensitive part of the tray, *i.e.*, that containing the thin feet of the animal, was placed by the artisan within the limits of the heartwood (Fig. 6), a wise choice from the mechanical resistance point of view but also one that involves carving the most delicate parts of the tray in the densest part of the wood. Another interesting example is tray IIAM392, in which the head of the bird resting on the tray appendix was located within the hardwood while the rest of the tray was carved out of the sapwood (Fig. 7). The color contrast between the two types of wood must have provided an attractive visual effect.

3.3. Taphonomic processes

Although cemeteries in SPA are situated in an extremely dry desert area, occasional summer rains may occur as a result of the altiplanic rainy season (Servant and Servant-Vildary, 2003). If such a phenomenon had occurred during the burial or soon thereafter, some bacterial or fungal decay may be expected in snuff trays

Fig. 6. Study of craftmanship in snuff tray IIAM75. A,B: front and lateral views of tray; C: CT image of sagittal plane, the arrows showing the areas of comparatively higher density corresponding to the duramen of the original log; D: VRT reformation of the tray in lateral view, brownish color indicating areas of higher density. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

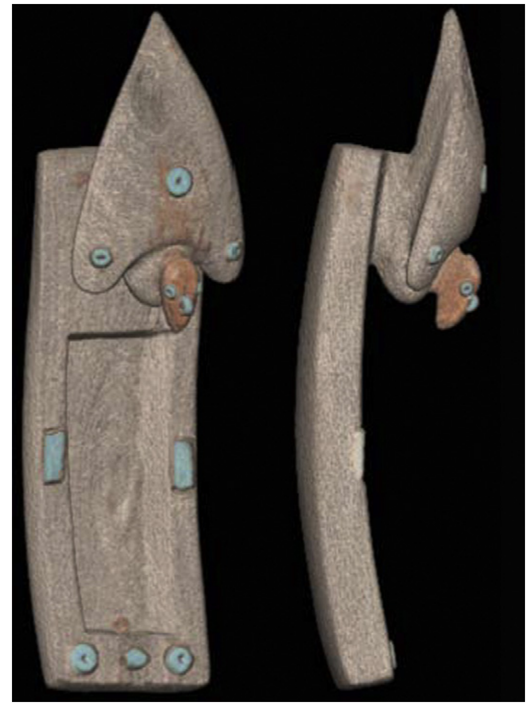

Fig. 7. Study of craftmanship in snuff tray IIAM392 showing VRT reformatting in two views, brownish color indicating areas of higher density. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

included in the burial; such processes lead to a decrease in wood density (Forest Products Laboratory, 2010). This may be the case in tray IIAM283 (Fig. 8), which shows an all-around lower density layer. It should be mentioned that this low-density layer was excluded for the determination of the mean wood density of the tray (see Methods).

3.4. Identification of gemstone inlays

Most gemstones inlayed in the trays studied ($N = 82$) ranged in color from blue to green, suggesting copper-based minerals. Their mean densities are compared in Fig. 9 with the density ranges of chrysocolla and turquoise (Schumann, 2000), two gemstones frequently found in copper ores of the south-central Andes. Other gemstones also present in such copper ores have much higher densities (RRUFF Project, University of Arizona; http://rruff.geo.arizona.edu/doclib/hom), e.g. atacamite (3.75 g/cm^3), brochantite (3.97 g/cm^3), olivenite (4.45 g/cm^3), and pseudomalachite (4.15–4.35 g/cm^3). The comparison points to the preferential use of turquoise and, to a lesser extent, chrysocolla as inlays. Of the 82 gemstones analyzed, 62 were tentatively identified as turquoise and 4 as chrysocolla; 14 gemstones had densities which could be adscribed to either turquoise or chrysocolla, and 2 corresponded to a different low-density gemstone which could not be identified.

4. Discussion

The data in Figs. 4 and 5 and in Table 1 shows that, with the possible exception of tray IIAM231, snuff trays studied were manufactured using wood exogenous to SPA as raw material, independently of the cultural phase when they were manufactured. A chronology for the atacameño region based on the extensive ceramic funerary record at SPA has been proposed (Berenguer et al., 1986; Tarragó, 1976; Uribe, 2002). Along the cultural phases defined, patterns of interactions with neighboring areas have varied at the geographical scale (Llagostera, 1996; Núñez, 1992, 1996; Stovel, 2008; Torres and Conklin, 1995). Thus, while during the Sequitor phase (AD 100–400) SPA interacted mainly with northwestern Argentina, during the Quitor and Coyo phases (AD 400–1000), interactions also occurred with the region around lake Titicaca in Bolivia (*i.e.*, Tiwanaku influence) and with southern and western Bolivia; later on, during the Yaye and Solor phases (AD 1000–1470), prevalent interactions occurred with northwestern Argentina, the highland plateau between southern Bolivia and northern Argentina, and the Loa river basin. Southern and western Bolivia and northwestern Argentina appear as the most likely source areas of wood exogenous to SPA on the basis of the patterns of interactions described above and the fact that biodiverse forests in these areas represent a rich source of woody species; thus, while only three native woody species grow in the area of SPA (Rodríguez et al., 1983), over 200 native woody species grow, at comparatively higher abundance, in neighboring forests of Bolivia and Argentina (Ibish and Mérida, 2003; Navarro and Maldonado, 2002; Tortorelli, 2009). The differential availability of trees between these areas and the notion that the sparsely distributed trees in SPA had to be used for essential activities such as dwelling construction and cooking (Núñez Atencio, 1991) must have encouraged the use of foreign wood for snuff tray manufacture. Furthermore, snuffing, an activity pursued by few and selected members of society (Llagostera, 2006), would be further segregated socially through use of exotic wood. Along a similar vein, metal objects made with exogenous raw materials have been proposed to be part of a prestige economy in SPA (Salazar et al., 2011), and internal social differences in society have been found to be reflected in the distribution of foreign goods in SPA cemeteries, at least during the Middle Period (Hubbe et al.,

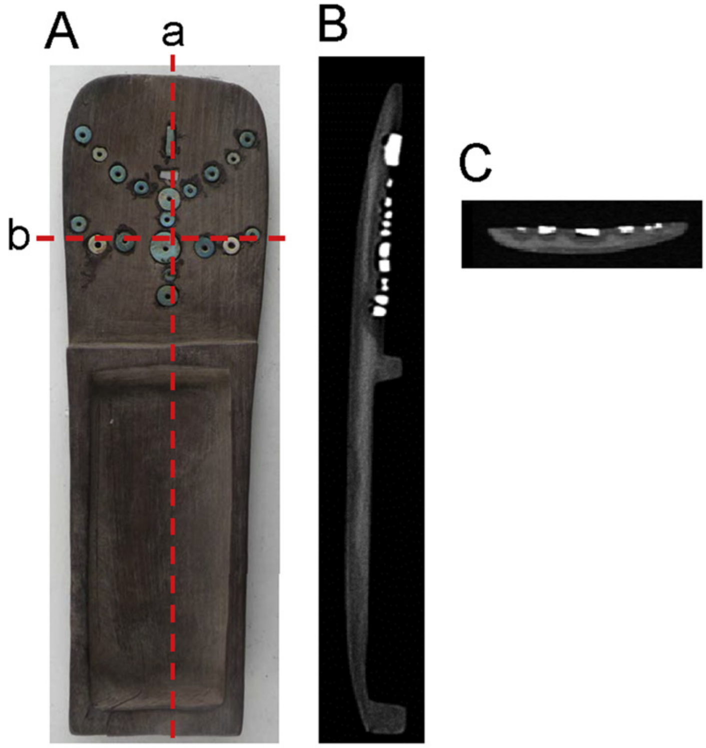

Fig. 8. Taphonomic processes in snuff tray IIAM283. The frontal photograph shows cross-sections studied. A: CT image of sagittal plane; B: CT image of transverse plane.

2012; Rivera, 2008; Torres-Rouff, 2008, 2011). The use of exogenous raw materials for the manufacture of prestige objects is consistent with the thesis that during the Middle Period a local hierarchy was being consolidated at SPA (Berenguer, 2004; Berenguer and Dauelsberg, 1989; Berenguer et al., 1980; Llagostera, 1996, 2004, 2006).

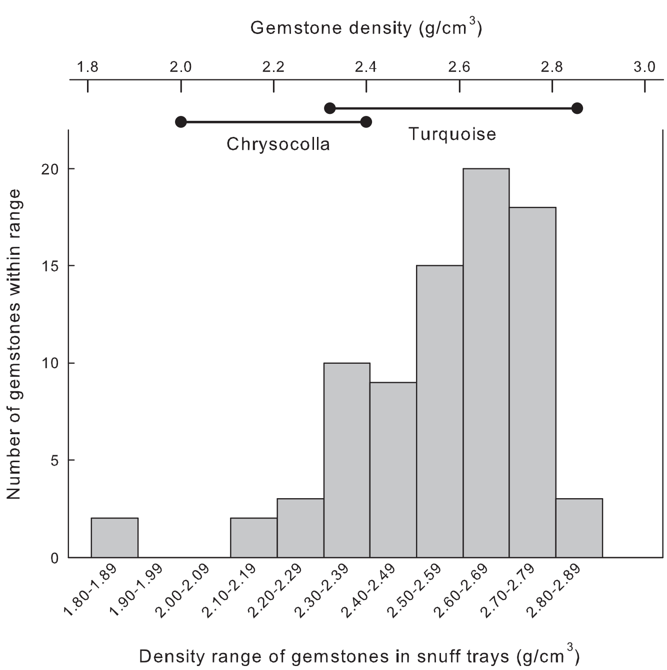

Fig. 9. Comparison of densities of mineral inlays of snuff trays with density ranges reported for turquoise and chrysocolla.

The densities determined of the gemstones inlayed in the snuff trays (Fig. 9), are consistent with their identification as turquoise and chrysocolla, a so-called "cultural turquoise" on account of its resemblance to turquoise (Weigand et al., 1977). These gemstones have been used to adorn objects since ancient times. They occur in a limited number of places around the world. In the Americas, they are found notably in western North America, and were intensively used by prehispanic peoples in the American Southwest as well as in Mesoamerica (Hull et al., 2008; Weigand and Harbottle, 1993). In the south-central Andes, the Circumpuna region, particularly the upper Loa river area not far from SPA, has been a rich source of both gemstones since the Formative Period (Salazar, 2008). These gemstones were used by native cultures of the area to decorate ritual objects and to mark social differences in hierarchical societies (Núñez, 1987). Snuff trays, being prestige objects with a sacred significance through which ideology was disseminated (Berenguer, 1998; Llagostera, 2006), had the social and spiritual value which justified the incorporation in them of valued gemstones.

The place of manufacture of snuff trays made with wood exogenous to SPA cannot be reliably ascertained: they may have been imported to SPA as such or they may have been locally produced using imported wood. During the period of Tiwanaku influence on SPA, it is likely that snuff trays were imported as such from Tiwanaku to SPA as part of the intense exchange of goods within the extensive network of caravan trails (Berenguer, 2000; Kolata, 1993), particularly being goods involved in the dissemination of Tiwanaku ideology (Berenguer, 1998; Llagostera, 2006). The multiple trade nodes between Tiwanaku and SPA during the Middle Period (Berenguer, 2000; Kolata, 1993) suggest a multigeographical origin of trays, supported to a certain extent by their remarkable formal diversity. Alternatively, local artisans may have been involved in their manufacture using exogenous wood, after seeing the general motifs found in Tiwanaku stone temples (e.g., tray IIAM231) while traveling to Tiwanaku (Orellana Rodríguez, 1985), or after seeing the motifs on other supporting materials in SPA (Oakland, 1984) or during their travels (Agüero, 2007). A possible way to discern between these possibilities is to explore wood manufacturing traditions in the region in terms of, for example, manufacturing traces in the trays and tools used in their manufacture. Similar questions on provenience of raw materials and place of manufacture of the object have been answered through such an approach with other materials, e.g., textiles (Oakland Rodman, 1992; Agüero, 2003), ceramics (Stovel, 2008), and metallurgy (Lechtman, 1991). On the other hand, gemstones may have been inlayed at the place of origin of the tray or, more likely, at SPA, which was nearer to the site of extraction of gemstones (Horta Tricallotis, in press-a).

In summary, several interesting features of snuff trays could be studied with computed tomography without physical intervention and modification of the tray. The quality of craftmanship, the nature of gemstone inlays, the provenience of wood and gemstones, and taphonomic processes in wood have been addressed. While wood used in the manufacture of trays was mostly exogenous to SPA, gemstones used in inlays were mostly of local origin; these findings support the active exchange of goods proposed for the south-central Andes. Recently, X-ray computed microtomography and synchrotron tomographic microscopy have been used in detailed structural studies of small wooden objects (Smith et al., 2009; Steppe et al., 2004), leading to the identification of the wood species. Applied to snuff trays from SPA, this technique will indicate the particular ecosystem where the wood was brought from and hence provide a more detailed view of the exchange of goods during prehispanic times in the south-central Andes.

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