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ORIGINAL PAPER

# Technology, life histories and circulation of gold objects during the Middle Period (AD 400–1000): A perspective from the Atacama Desert, Chile

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**Abstract**
Studies of archaeological goldwork in the Americas are increasingly revealing a rich variety of context-specific ways in which gold items were produced and valued, but research attention has largely focused on visually striking artefacts. However, in the south-central Andes, goldwork is described essentially as a 'sheet technology'—a definition that tends to downplay the potential complexity and cultural significance of this technology in such an extensive and varied region. Here, we employ a life-history approach to explore the existence of particular traditions within this large area. We present chemical and microscopic analyses, using pXRF, SEM–EDS, PIXE and digital microscopy, of 142 gold and silver objects from San Pedro de Atacama (northern Chile), recovered in seven cemeteries dated to the Middle Period (AD 400–1000). Our results reveal a heterogeneous assemblage where compositions, techniques, designs and skill levels vary, suggesting that gold artefacts circulated and were imported from different areas of the south-central Andes, such as Tiwanaku, Cochabamba and northwest Argentina. We also identify for the first time two distinct technological traditions used in San Pedro: small-scale goldwork production, and a tradition of modifying and reusing imported objects by cutting, perforating and separating object parts. Considering the depositional contexts, we propose that the funerary ritual at San Pedro was a key factor in the development of this local goldwork. Our research demonstrates that even small and unimpressive artefacts can be successfully interrogated from archaeological perspectives with integrative approaches that go beyond overly generalising perspectives of gold as an exotic status marker.

**Keywords** Goldwork technology · pXRF · Life histories · Atacama Desert · South-central Andes · Middle Period

## Introduction

The Middle Period ('MP', AD 400–1000) was one of the most thriving and dynamic stages in the history of the south-central Andes ('SCA'; Fig. 1).[1] In this area, which comprises south Peru, eastern Bolivia, northwest Argentina ('NWA') and northern Chile, the MP is characterised by the appearance of artefacts in an artistic style associated with Tiwanaku, thought to represent a shared religious iconography focused on a solar cult that developed in the southern Titicaca Basin (Berenguer 1998; Korpisaari 2006; Bouysse-Cassagne 2017). In this scenario, people, goods and ideas continuously moved between distant places in varied ways: by specialised llama caravans, traders travelling by foot or social visits including political alliances (Dillehay and Núñez 1988; Martínez 1998; Llagostera 2006a; Nielsen 2006, 2013).

Amongst several goods that circulated and were exchanged, gold and silver objects have captured both the scholarly and the public imaginations, especially because of the high value that these metals have in modern western

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[1] For an extended abstract in Spanish, see Online Resource 1.

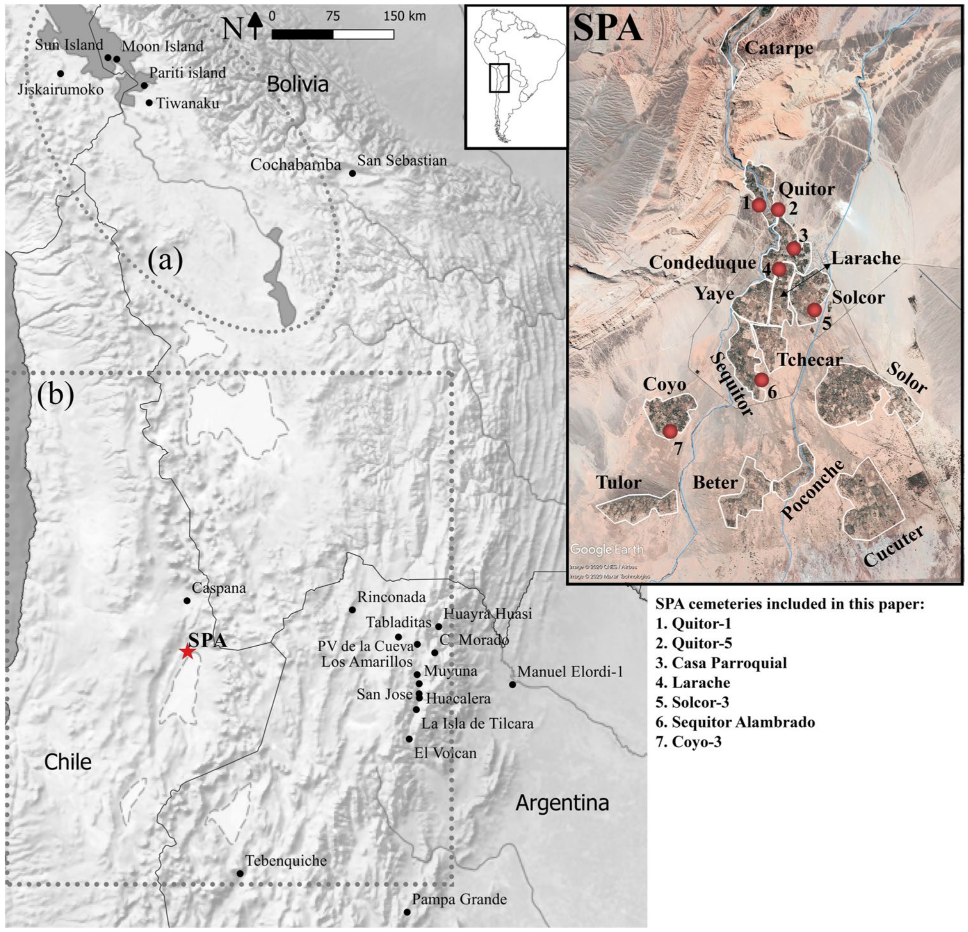


**Fig. 1** Map of the south-central Andes ('SCA') showing (**a**) the Titicaca Basin and central Altiplano, (**b**) the Circumpuna and the archaeological sites mentioned in the text. The inset corresponds to SPA, the 14 *ayllus* and the 7 cemeteries with metals included in this study (red circles 1–7). DMS coordinates of the sites were omitted in compliance with Convention 169 of the International Labor Organization on Indigenous and Tribal Peoples

society. Gold was the first metal to be worked in the Andes. There are few early finds, most dated around 1500 BC. These are tubular beads associated with a hunter-gatherer's burial at Jiskairumoko, Peru (Aldenderfer et al. 2008), gold processing evidence at Putushio, Ecuador (Rehren and Temme 1994), gold foils and a metalworker's kit at Waywaka, Peru (Grossman 1972, 1978, 2013), and the gold foils from Mina Perdida, Peru (Burger and Gordon 1998). However, it was with the expansion of Chavin religious imagery during the Early Horizon (900 BC–AD 1) that goldwork spread in the central and south-central Andes (Shimada et al. 2000; Lechtman 2014; Vetter and Bazán 2021).

Technologically speaking, gold in the SCA was used mainly in its native state or alloyed with silver, whereas the production of copper–gold or copper-silver alloys was rare (as opposed to north coastal Peruvian traditions based on gilding and silvering copper–gold or copper-silver alloys). Gold and silver were hammered and annealed, and most objects were two-dimensional ornaments decorated by embossing, chasing and cut-out; some examples have inlays of semi-precious stones (Root 1949; Money 1991; McEwan and Haeberli 2000; Schlosser et al. 2009). More complex examples of this so-called sheet technology include larger objects where three-dimensional shapes are obtained by deforming single sheets (e.g. by raising) or by soldering, although the latter is uncommon (Lechtman 1991a; Schlosser et al. 2009). Regarding silver, researchers have recovered in Puno Bay (Lake Titicaca) the earliest evidence of silver production ca. AD 60–120, already using complex smelting processes (e.g. cupellation) at least until the Tiwanaku period AD 400–1000 (Schultze et al. 2009, 2016; Schultze 2013), but direct evidence for the manufacture of objects is virtually absent.

Gold and silver were used in most of the SCA during the MP, including areas under Wari and Tiwanaku influence, northern Chile and NWA (Le Paige 1961; Chávez 1985; González 2003; Téllez and Murphy 2007; Goretti 2012). Nevertheless, these objects are not abundant.[2] Most gold finds concentrate a significant number of artefacts in

[2] Many objects have been looted and melted between the conquest and the present. Nevertheless, the amount of gold reported in the SCA appears to be much less than the abundant finds associated with Moche and Sicán on the north coast of Peru, also from the Middle Period (e.g. Shimada 1996; Shimada et al. 2000; Shimada and Griffin 2005).

specific burials or offerings such as those from La Isla de Tilcara (Tarragó et al. 2010) and Huacalera (Pelissero 2014) in NWA, the finds near Pikillaqta in Peru (Chávez 1985), the San Sebastián treasure in Cochabamba (Money 1991), the three individuals in the Kalasasaya Temple in Tiwanaku (Korpisaari 2006; Korpisaari et al. 2011), or the offerings of the Pariti Island (Bennett 1936; Korpisaari et al. 2012) and Lake Titicaca in general (Reinhard 1992; Young-Sánchez 2004). Although colonial chronicles point to the important Inca temples and shrines dedicated to the sun on the islands of the Sun and the Moon in Lake Titicaca, some authors, based on written sources and archaeological data, place solar worship in earlier times as a central element of the Tiwanaku culture and, consequently, the ritual dimension of gold and gold mines (Bouysse-Cassagne 2004, 2005, 2017; Korpisaari et al. 2012). Therefore, considering the high symbolic value of metals, together with this 'scattered' distribution pattern, gold and silver are usually interpreted as items that accompanied important individuals (Money 1991; e.g. Korpisaari 2006; Tarragó et al. 2010), and expressed cultural affiliation to the Tiwanaku polity (Benavente et al. 1986; Barón 2004; Tamblay 2004; Salazar et al. 2014)(*cf* Stovel 2001).

To date, there have been limited attempts to properly characterise this gold and silver 'sheet technology' and explore the existence of particular traditions within this large area. This information would help clarify how these items were circulating, and to explore the social, political and economic relations between different polities within the SCA. Owing to the plain and simple look of most of these precious metal objects, they are usually described as 'undecorated hammered sheets' or 'decorated by embossing', with no further details about their manufacture that would allow further comparison (e.g. Le Paige 1961; Money 1991; Téllez and Murphy 2007). So far, research has focused on specific finds that stand out (see examples above) (Boman 1908; Rolandi 1974; Ventura 1985; Rovira 1994; McEwan and Haeberli 2000; Angiorama 2004; González 2004a; Schlosser et al. 2009; Ventura and Scambato 2013 and others; Miguez 2014; Fernández 2016; Guerra et al. 2019) but the overall picture remains very partial and superficial.

A more comprehensive study of gold and silver is thus needed to understand the complexity and intricacies of this apparently 'simple' technology. Here, we make such an attempt, focusing on the assemblages recovered at a range of sites in San Pedro de Atacama ('SPA', see next section). With a collection spanning 142 objects, we applied a series of laboratory-based techniques complemented with careful observations of the artefacts to reconstruct their *chaînes opératoires* (Dobres 1999; Sillar and Tite 2000 and references within; Martinón-Torres 2002; Miller 2007) and to reveal their complex 'life histories' (Kopytoff 1986; Shanks 1998; Gosden and Marshall 1999; Gosselain 2000).

We consider the elemental composition, manufacturing techniques and designs, as well as the material changes undergone during the life of the objects, observed as wear-marks, repairs or modifications. Registering and interpreting these traits can offer important information about the use, re-use and meaning of these objects in a specific society (Kopytoff 1986; Joyce and Gillespie 2015; Sáenz Samper and Martinón-Torres 2017). The analytical methods employed include portable x-ray fluorescence, scanning electron microscopy coupled with energy dispersive X-ray spectroscopy, and proton-induced X-ray emission to determine chemical composition (Guerra and Calligaro 2004; Schlosser et al. 2009, 2012; Scott 2012; Martinón-Torres and Uribe Villegas 2015; Garrido and Li 2017; Guerra et al. 2019; Legarra Herrero and Martinón-Torres 2021; Plaza and Martinón-Torres 2021 and references within). Optical microscopy and macroscopic observations with a digital microscope were used to determine manufacturing techniques (Maryon 1971; Untracht 1975; Lechtman 1981; McCreight 1991; Carcedo 1998; Armbruster 2000, 2013; Armbruster et al. 2004; Carcedo et al. 2004; Perea 2010; Leusch et al. 2015). Considering the objects in their contexts, we reveal interesting situations where long and complex artefact life histories link two or more individuals.

Our results relate the SPA assemblage to Tiwanaku, NWA and local technology, broadening the interpretations regarding the meaning and cultural affiliations of these items. We propose that the funerary ritual at SPA would be a key factor in the development of local goldwork, as a series of artefacts appear to have been made or reshaped right before burial. Furthermore, a detailed examination of the composition and manufacturing techniques allows us to discuss the skill of the artisans and, even, to tentatively identify the work of single individuals or groups of craftspeople. Altogether, our research demonstrates that even seemingly small and unimpressive artefacts can be fruitfully interrogated from archaeological perspectives, with integrative approaches that go beyond overly generalising perspectives on gold as an exotic status marker.

## San Pedro De Atacama during the Middle Period

The oasis of SPA is located in the Circumpuna[3] de Atacama (hereafter the Circumpuna) at 2500 m above sea level ('masl') in the eastern limit of the Atacama Desert, northern

[3] The subarea of the Circumpuna de Atacama corresponds to the meridional section of the south-central Andes. This area comprises the Bolivian southern Altiplano (or Lípez), the Argentinean *puna* and northern Chile. It includes the Uyuni Salt Flat in the north (Bolivia) and the Arizaro Salt Flat (Argentina) in the south; the Pacific coast in the west; and the fertile valleys and ravines of NWA in the east (Martínez 1998).

Chile. The San Pedro Culture was a sedentary society, based on a village lifestyle (Muñoz 1989; Llagostera 2004). The settlement pattern has been characterised as consisting of nearly 14 distinct sectors, which are interpreted as being occupied by extended kinship units or *ayllus*[4] (Fig. 1). These *ayllus* shared political, economic and ideological aspects, maintaining, however, some individual particularities (Stovel 2002; Llagostera 2004; Salazar et al. 2014). The San Pedrinos[5] were agriculturalists, gatherers, llama herders, miners, traders and caravaners (Dillehay and Núñez 1988). Local artisans produced characteristic pottery, textiles, basketry, wooden, lapidary and copper-based artefacts (Núñez 1991; Agüero 2003; Stovel 2005; Carrión 2014, 2015; Salazar et al. 2014; Castro et al. 2016; Cifuentes et al. 2018; Horta et al. 2019).

During the MP (AD 400–1000), Tiwanaku influence is noticeable in SPA, coinciding with a period when SPA reaches its maximum demographic growth, development and expansion in terms of traffic and mobility networks. A major change in this period is an increase in the number of finished objects, raw materials and people from the central Altiplano and other areas of the Circumpuna, (Llagostera 1995; Lechtman et al. 2010; Nielsen 2013; Knudson and Torres-Rouff 2014; Echenique et al. 2021). The interactions with NWA, the Pacific coast and southern Altiplano show continuity from the Late Formative Period (400 BC–AD 400), whereas the interaction with the central Altiplano and east valleys of Cochabamba flourishes, especially during AD 700–1000 (Coyo Phase) when most Tiwanaku objects arrived in SPA (Llagostera 2006a; Castro et al. 2016).

Gold and silver objects stand out particularly for their relatively high concentration at this single locality. To date, 335 gold and silver offerings in SPA have been reported, associated with 68 burials in 16 cemeteries of the locality. Of these 335 items, 200 were recovered (the rest disintegrated during excavations given the poor post-depositional conditions, especially as regards the silver objects[6]). The objects are mainly small plain pendants, headbands, bracelets and pectorals, as well as rings, headdresses, beads, bells and ritual goblets, found in seven cemeteries: Casa Parroquial, Coyo-3, Larache, Quitor-1, Quitor-5, Solcor-3, Sequitor Alambrado (Fig. 1). As gold does not naturally occur in SPA (the nearest gold and silver sources are 100 and 80 km away, respectively), the raw materials and finished items have been considered non-local products (Boric et al. 1990; Ulriksen 1990; Zappettini et al. 2001).

It is noteworthy that these finds—gold in particular—are known to be exclusive to the MP; i.e. they are almost absent in periods before AD 400,[7] and after AD 1000, their consumption decreases until it almost disappears. The relatively large number of individuals bearing gold and silver objects in the cemeteries in SPA is very different from contemporary contexts in other areas of the SCA, where noble metals are much scarcer. Nevertheless, this makes SPA the perfect scenario to explore the development and characteristics of this technology at a local and regional level.

## The relationship between San Pedro De Atacama and Tiwanaku

The situation during the MP shows a dynamic and complex social context in SPA, with high levels of interaction with foreign polities, which was not exempt from tension and conflicts, as shown by evidence of violence (Torres-Rouff 2011; Uribe et al. 2016). In this scenario, social differences and local leaders emerged, primarily seen in the quality and uneven distribution of non-local items, snuff-taking implements and leadership emblems such as axes and maces (Llagostera 2004, 2006a; Cifuentes 2020; Llagostera and Costa-Junqueira 2020). In particular, Salazar et al. (2014) propose that the influence of Tiwanaku was crucial in promoting the local elites, who were explicitly demonstrating their affiliation to Tiwanaku polity through the use of metals (see also Tamblay 2004).

The relationship between SPA and Tiwanaku has been extensively discussed (see Llagostera 2006a; Salazar et al. 2014; and references within). Based on the presence of gold artefacts, pottery, snuff-taking trays and textiles with Tiwanaku iconography, some archaeologists have proposed that changes seen in SPA during the MP were caused by direct contact between the Tiwanaku State and the San Pedro culture, including people from Lake Titicaca setting up colonies in SPA (Thomas et al. 1985; Benavente et al. 1986; Barón 2004; Tamblay 2004). Today, the accepted theory is that the relationship with Tiwanaku was indirect; i.e. rather than colonies or administrators coming from Tiwanaku, SPA remained independent and autonomous, and contact was articulated by the dynamic trade routes mediated by communities from the southern Altiplano or other Tiwanaku centres, such as Cochabamba (Berenguer et al. 1980; Dillehay and Núñez 1988; Uribe and Agüero 2001; Llagostera 2004, 2006a; Núñez 2006; Salazar et al. 2014; Torres-Rouff et al.

[4] The *ayllu* is the basic level of social structure in the Andes. It refers to a group composed of kin, being descendants of a real or mythical common ancestor. They are grouped at different levels, from micro-*ayllus* (extended family) to macro-*ayllus* (ethic group). Each level has its own leaders and organisation (Janusek 1999; Nielsen 2006).

[5] We will use 'San Pedrinos' to refer to the ancient inhabitants of the oasis and salt flat of Atacama.

[6] Silver objects at SPA are probably under-represented due to corrosion. Some excavation records report these objects, but most of them did not survive the digging process.

[7] Except for a few unusual examples from the Formative Period, such as the gold artefacts from the site of Tulán (Núñez et al. 2017).

2015; Castro et al. 2016; Llagostera and Costa-Junqueira 2020 and more).

Nevertheless, Salazar et al. (2014) argue that the influence of Tiwanaku polity cannot be underestimated—first, because it is during its period of influence that SPA flourished, and secondly, as the metals buried with the local elites are mostly arriving from the central Altiplano. Elemental and lead isotope analyses of nearly 50 copper-based artefacts have identified in 45% of them a ternary alloy copper-arsenic-nickel characteristic of Tiwanaku, whereas a 30% was tin-bronze, either from Tiwanaku or NWA (Lechtman 1991b, 1996, 1998; Lechtman and Macfarlane 2005, 2006; Maldonado et al. 2010, 2013; Salazar et al. 2014; Macfarlane and Lechtman 2016); only 25% was made of unalloyed copper, representing local production (Cifuentes et al. 2018).

Therefore, about 75% of copper-based items used by high-ranked individuals are non-local, potentially from the central Altiplano. The same is assumed for gold and silver items, which are thought to be imported from Tiwanaku (Salazar et al. 2014). However, we agree with Stovel who warns that relating noble metals to Tiwanaku is premature, especially considering that (i) some items are stylistically different from their Tiwanaku counterparts and (ii) noble metals were also produced in other areas of the Circumpuna, such as NWA and the southern Altiplano, which have maintained long-lasting relationships with SPA (Stovel 2001; Torres-Rouff et al. 2015; Cifuentes et al. 2018). Consequently, in this paper, we aim to reconstruct as far as possible their production technology and consumption patterns, in order to explore the characteristics of this technology in SPA and the SCA, and to clarify the connections between SPA, Tiwanaku and other polities of the region.

## Materials and methods

We analysed 142 gold and silver finished objects (~2.5 kg) deposited in the Museo Arqueológico R.P. Gustavo Le Paige, recovered in Casa Parroquial, Coyo-3, Larache, Quitor-1, Quitor-5, Solcor-3, Sequitor Alambrado cemeteries. Most of the gold and silver objects are small and thin sheets that were hammered, cut and perforated to produce two- and three-dimensional objects. These items range between 1 and 51 cm height, 1 and 19 cm width, 12 µm and 5 mm thickness and 0.1 and 283 g. Broadly, they can be classified into two categories: ornaments and ritual objects. The ornaments include attachments, pendants, headbands, headdresses, bracelets, beads, rings and bands. The ritual objects include parts of inhalation tubes, bells, *keros*, portrait vessels, a miniature jug and an axe (Figs. 2 and 3).

Bulk chemical analyses of major elements in the 142 artefacts were undertaken in situ using Olympus Innov-X Delta Premium portable X-ray fluorescence spectrometers (pXRF), equipped with a Si drift detector (SDD) and a typical resolution of 143–157 eV FWHM for X-rays of 5.9 keV (on a steel standard). Readings were taken using the 'Alloy Plus' method with a single beam mode (Beam1), set up at a live-time of 20 s at 40 kV with a 2 mil Al filter in the X-ray path.[8] Quantification is based on a fundamental parameters algorithm, supplemented by in-house empirical standardisation. All the readings were obtained on unprepared surfaces and each sample was analysed three times; values given are an average of the three readings, in percentage by weight. Although the manufacturer and set-up are the same, two different instruments were used in this research (pXRF-2015 and pXRF-2016, after the year of analysis). Precision, accuracy and comparability within and between instruments were monitored using a series of certified reference materials. Results show a very good degree of correspondence between both instruments, allowing us to pool both datasets together (full details in Plaza and Martinón-Torres 2021).

To identify minor and trace elements, 38 samples were analysed at the AGLAE in Paris under the direction of Benoît Mille, using particle-induced X-ray emission (PIXE). The set-up used a 3 MeV external proton beam of 30–50 µm in diameter, 3–6 nA current and four Peltier-cooled SDD detectors. The surface patinas were mechanically cleaned and analysed using beam scanning areas of 500 × 500 µm. Data normalisation from different detectors was carried out using silver composition, with the programme GUPIX combined with the homemade software TRAUPIXE.

Forty samples were mounted as polished metallographic sections and analysed using a Hitachi s-3400 N scanning electron microscope with an Oxford Instruments energy dispersive microscopy (SEM–EDS) at the UCL Institute of Archaeology. The instrument was operated at 20 kV with counting times of 100 s, a working distance of 10 mm and a processing time of 5. To check precision, reproducibility and compatibility of the compositional data amongst instruments, three gold (MAC1–3, Micro-Analysis Consultants Ltd) and two silver (AGA1–2, MBH Analytical LTD)-certified reference materials were used. Finally, 133 objects were studied under the naked eye and using a digital microscope (Dino-lite Edge), to register manufacturing traits and traces of use and repair.

## Results

### Chemical composition

In order to understand gold technology, it is essential to consider the compositional data of the objects in a

[8] Elements sought: Ti, V, Ce, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ir, Ta, W, Os, As, Pt, Au, Hg, Pb, Bi, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Sb.


136
137
138
139
140
141
5cm
1cm
56
57
a.58 (n=3)
b.59 (n=7)
c.145 (n=3)
d.61 (n=2)
e.63 (n=3)
66
1cm
144
71
88
113/114
f.103 (n=3)
117
129
1cm
1cm
27
35
53
128
84
86
52
1cm
5cm
92
5cm
125
87
5cm
131
1cm
126
5cm
5cm
54
10cm
5cm
g.133(n=2)-135

◂**Fig. 2** Examples of 'finely made' gold and silver objects from San Pedro de Atacama. The numbers are the short forms of the 'popm' laboratory codes (standing for 'Proyecto Oro Periodo Medio'). Objects with more than one specimen: (**a**) popm58, 115–116; (**b**) popm59–60, 98–102; (**c**) popm145–147; (**d**) popm61–62; (**e**) popm63–65; (**f**) popm103–105; (**g**) popm133, 19 (photographs MT Plaza)

comprehensive and dialogical manner, always in direct relation to the metallogenic and geochemical characterisation of the geological sources and their relationship with the working techniques used.

The bulk chemical composition of 145 samples (from 142 objects, as some are made from separate parts) shows a widely scattered distribution where gold and silver concentrations vary widely (Fig. 4, Online Resource 2). Silver contents range between 3.3 and 73.1 wt%, whereas copper concentrations are between below detection limits and 6.2 wt%, except for four objects containing high copper percentages at 11.9–48.7 wt%. The composition of the 13 silver objects should be considered with caution, though, as all objects presented a thick corrosion layer. In this case, pXRF results reveal 100 wt%Ag but SEM–EDS analysis on cross-sections of samples popm42 and popm44 detected 0.5 wt%Cu and 1.5 wt%Cu, respectively.

We use the Ag-in-Au ratio or Ag/(Ag + Au)wt% as an exploratory tool to search for modes that might denote individual gold sources or possible alloying practices. This ratio has been used in archaeometallurgical studies to estimate the hypothetical amount of silver naturally present in the gold before it was alloyed, based on the fact that unalloyed gold has negligible amounts of copper (< 1 wt%) and assuming that all the silver in the gold was present as a natural impurity (Guerra and Calligaro 2004; Martinón-Torres et al. 2007, 2012; Hough et al. 2009; Uribe Villegas and Martinón-Torres 2012). The present case is different, however, in that copper values in SPA are typically very low anyway, and as the presence of pure silver objects suggests that this metal could have been available for artificial alloys with copper. In our case, this ratio facilitates comparisons between compositions. The Ag-in-Au ratio shows a scattered distribution where most values fall in the 25–30 wt% range ($n = 25$), followed by 10–15 wt% ($n = 22$) and 35–40 wt%Ag ($n = 20$) (Fig. 5a). Between 40 and 75 wt% silver, the frequency of objects decreases, appearing in two to eight artefacts. Overall, 58 wt% of the assemblage contains Ag-in-Au levels up to 30 wt%.

The abundance of objects at 30 wt%Ag-in-Au or less is significant in this region, as this range is consistent with the silver content naturally present in gold deposits (Petersen 1970; Hérail et al. 1990, 1999; Fornari and Hérail 1993; Alarcón and Fornari 1994; Ramos and Fornari 1994; Palacios et al. 2001). Chemical analysis of native gold from primary and secondary deposits from the central and south-central Andes shows different silver levels, though these are consistently below 30 wt%Ag (Fig.5a). For instance, very pure gold up to 5–7 wt%Ag is found in south Peru (Sandia and Carabaya region), in Bolivia (south Lípez, the Eastern Cordillera and Yani region) and in Jujuy, Argentina (Mina Eureka, Colquimayo). Meanwhile, silver contents up to 10–15 wt% are registered in San Pedro de Cachiyuyo (northern Chile), Vilander (south Bolivia), Sandia and Vetasmayo (south Peru), Ancash and Pallasca (north Peru) and Rinconada (northwest Argentina). Finally, high silver levels are registered in Cerro Casale (northern Chile) with up to 21 wt%Ag; in the alluvial deposits of the Tumbes River (border between Peru and Ecuador) with 26 wt%Ag; and in La Joya district (Bolivia) with 30 wt%Ag (Petersen 1970; Hérail et al. 1990, 1999; Fornari and Hérail 1993; Alarcón and Fornari 1994; Ramos and Fornari 1994; Palacios et al. 2001; Angiorama 2004). Unfortunately, the few gold deposits near SPA have not been chemically characterised yet (see map in Online Resource 3).

Conversely, copper contents are very low (Fig. 5b). Thirty-six per cent of the sample contains up to 1 wt%Cu, which is consistent with the natural copper levels expected in alluvial gold (Townley et al. 2003; Guerra and Calligaro 2004; Guerra and Rehren 2009; Hough et al. 2009; Schlosser et al. 2009; Spiridonov and Yanakieva 2009). However, the highest frequency is between 1.0 and 1.5 wt% copper content and 87% of the assemblage contains up to 3.0 wt%Cu. Values between 3.0 and 6.5 wt%Cu represent 10% of the assemblage, while four objects stand out in their high copper contents: 11.9 wt%, 28.7 wt%, 38.7 wt% and 48.7 wt%.

Chemical analysis of samples from gold deposits in the central and south-central Andes usually show trace copper levels, i.e. < 0.1 wt% (Alarcón and Fornari 1994; Ramos and Fornari 1994). Higher copper contents up to 0.7 wt%Cu are reported in primary deposits from northern Chile (San Pedro de Cachiyuyo and Cerro Casale) and placer deposits in Zaruma, in the boundary between Peru and Ecuador (Petersen 1970; Hérail et al. 1990; Palacios et al. 2001). The placers in the Pallasca and Ninamahua region, north coast of Peru, contain copper levels up to 6–8 wt%—a very unusual composition (Petersen 1970). Comparatively, copper levels in native silver can range from trace levels up to 0.08 wt%, 3 wt%, 18 wt% and even 20 wt%Cu, whereas in silver minerals, copper can range from 0 to 45 wt%Cu (Schlosser et al. 2009; Murillo-Barroso 2013).

In the 38 samples analysed by PIXE, we detected nine elements at trace levels (< 0.1 wt%): Fe, Zn, Ti, Ni, Ga, Pb, Hg, Mn and W. Most of the samples share similar elements, mainly Zn, Fe and Ti. Overall, no evident groups are found by trace elements but some patterns helped in the identification of specific batches, supporting the information obtained by the pXRF and SEM–EDS (see full results in Online Resource 4).

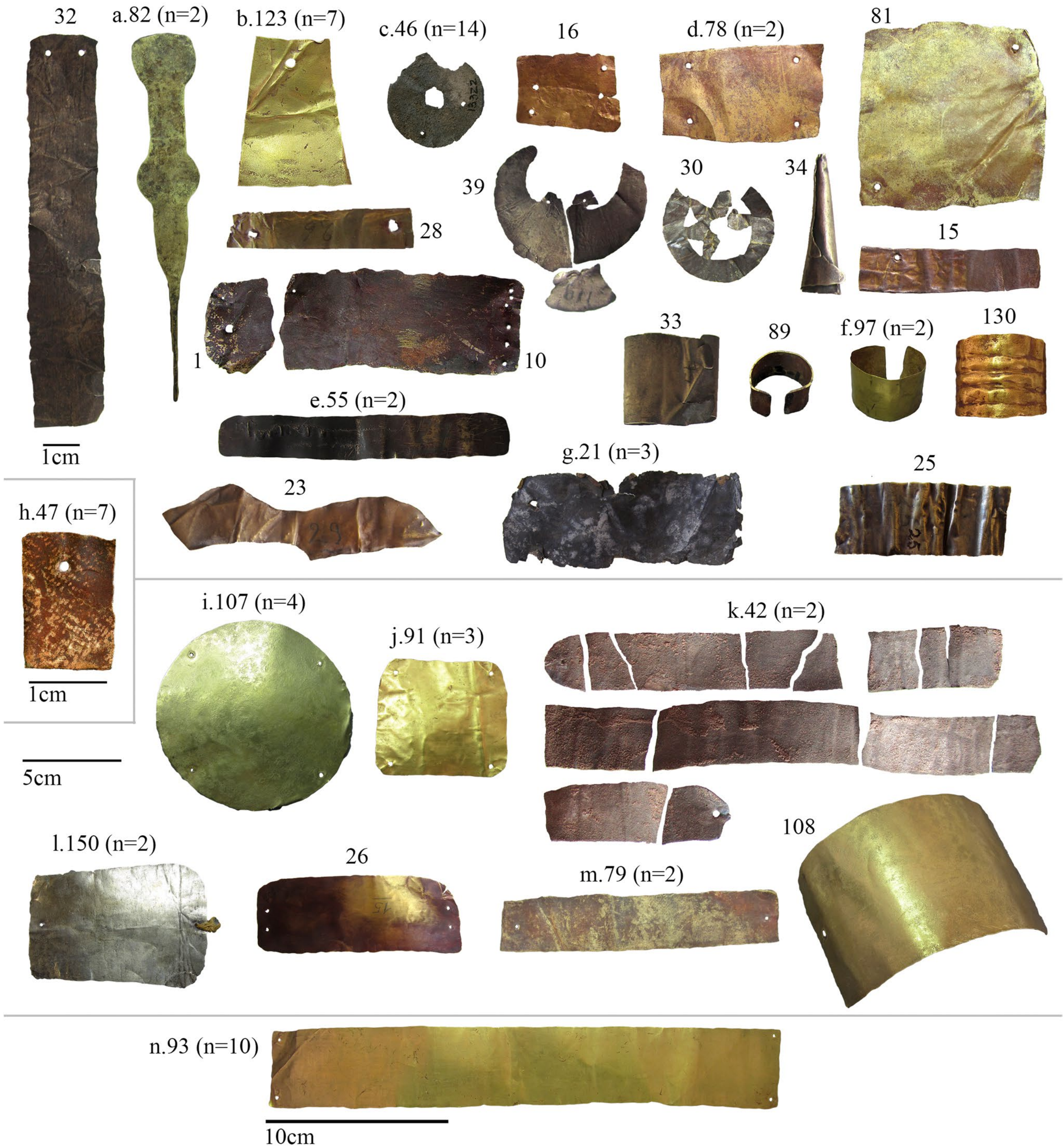


**Fig. 3** Examples of 'coarsely made' gold and silver objects from San Pedro de Atacama. These objects show manufacturing techniques and modifications that are more expedient or denote lower skill investment, compared to 'finely made' artefacts. The numbers are the short form of the 'popm' laboratory codes. Objects with more than one similar specimen: (**a**) popm82–83; (**b**) popm36, 119–124; (**c**) popm46, 143_1–7; (**d**) popm77–78; (**e**) popm24, 55; (**f**) popm96–97; (**g**) popm21–22, 29; (**h**) popm47, 50–51, 73–76; (**i**) popm90, 107, 118, 127; (**j**) popm91, 106, 109; (**k**) popm42–43; (**l**) popm150–151; (**m**) popm79–80; (**n**) popm17–18, 93–95, 110–112, 132, 142 (photographs MT Plaza)

The SEM–EDS examination of 40 samples as cross-sections identified minute inclusions embedded into the metallic matrix. Micro-inclusions are indicators of the type of gold used and the alloy practices employed, complementing the elemental information. For instance, the presence of platinum group elements ('PGE': Ru, Rh, Pd, Os, Ir and Pt)

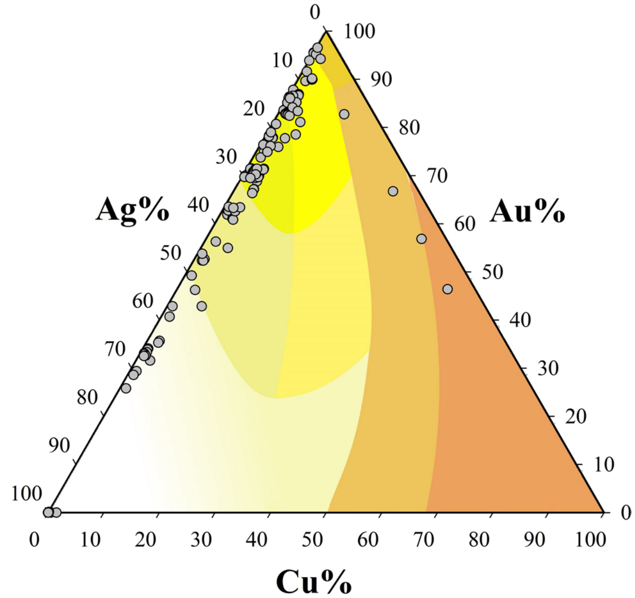


**Fig. 4** Gold-silver-copper ternary diagram (using SigmaPlot 12.0) presenting the chemical compostion of 142 metallic objects from SPA, by pXRF (except two samples obtained by SEM–EDS). Three artefacts are composed of two parts that were analysed independently, so the total samples plotted in the graph are 145 points, which are an average of three readings per sample. Results are normalised to 100 wt%

or tin as cassiterite are a strong indication of the use of alluvial gold (Meeks and Tite 1980; Guerra et al. 1999; Guerra and Calligaro 2004; Dussubieux and van Zelst 2004; Guerra and Rehren 2009; Hauptmann and Klein 2009; Standish et al. 2013). Other micro-inclusions found in alluvial gold are quartz or iron-bearing minerals. These are remnants of the original primary deposits in which gold is usually associated with quartz, limonite, hematite and pyrite as host minerals, which can be trapped in the gold grains (Tylecote 1970; Boric et al. 1990; Hauptmann et al. 1995; Chapman et al. 2002, 2006, 2011; Walshe and Cleverley 2009; Spiridonov and Yanakieva 2009). Except for PGE, these inclusions are not present in gold objects as metallic phases but as minerals; therefore, they would be predominantly lost during the melting of the gold as slag. Consequently, their presence would also suggest that gold in these objects was not completely melted and that the objects were probably shaped from alluvial grains applying cycles of cold-work and annealing. This is particularly possible when gold nuggets are relatively large and were directly worked, as it was observed by Garcilaso de la Vega in 1560 (1609, bk. 8) and Paloma Carcedo in ethnographic groups of the north coast of Peru (1998; see also Martinón-Torres et al. 2012).

Overall, no PGE or cassiterite inclusions were detected in the assemblage. However, in eight samples (20%), iron-rich and quartz inclusions up to ~9 µm in size were found (popm3, 8–9, 17, 22–23, 26, 36; Fig. 6a–b). These inclusions are probably tiny fragments of quartz and iron minerals trapped in the metal, suggesting objects that were hammered and annealed directly from gold grains. Eleven samples (28%) contain copper oxides inclusions, present as three different structures: elongated inclusions (as remnants of dendrites; Fig. 6c), rounded globules distributed across the core and globules aligned near the surface (popm1, 5–6, 13–14, 21, 27, 30, 33, 38–39). All of them are probably produced by the absorption of oxygen during melting; however, the latter may also result from embedding oxygen during annealing and hammering (Scott 1991, 2002). Finally, 12 samples (30%) contain minute inclusions (< 10 µm) of round and ellipsoid shape, composed of a mix of different elements such as Ni, Zn, Sn, Pb, Bi, As and Hg, in addition to Au, Ag, Cu and Fe (popm10, 12, 18–19, 24–25, 28, 32, 34–35, 37, 40; Fig. 6d). Elevated levels of oxygen up to 31 wt% suggest that these 'complex' inclusions are oxides. Possibly, these inclusions are impurities from the original ores, potentially from any of three major metals that were reduced during smelting or melting and incorporated into the alloy (Guerra and Rehren 2009; Hauptmann and Klein 2009); alternatively, they may have been acquired as contamination during the melting process (Rademakers and Rehren 2016). Interestingly, most samples with these kinds of impurities have silver levels over 30 wt%; only four cases are below 30 wt% (between ~12 and 29 wt%Ag), suggesting an association between high-silver levels and the presence of impurities.

#### Raw materials used in SPA assemblage

The compositional evidence suggests that the gold used in SPA comes from a variety of deposits, probably from different areas. Based on silver contents, we identify the use of unalloyed gold, artificial gold-silver alloys and silver. The different copper contents may reflect different situations, still supporting the view that the assemblage is composed of varied sources of gold.

Comparing the silver-in-gold contents in SPA assemblage and the gold deposits from the area, the distribution seen in the archaeological assemblage (Fig. 5a) might represent the use of varied unalloyed gold deposits, predominantly gold with medium-silver content (~10–15 wt%Ag) and high-silver content (~20–30 wt%Ag). The use of metallic silver is demonstrated by the objects around 100 wt%Ag. For samples above 30 wt%Ag, they may represent artificial alloys, where metallic silver was added or mixed with native gold, as is proposed for other objects of the SCA of similar compositions (Root 1949; Lechtman 1978; Rovira 1994; Angiorama 2004; Schlosser et al. 2009). Mechanically and physically speaking, a gold alloy up to 50–60 wt%Ag retains the malleability and ductility of gold, but it changes

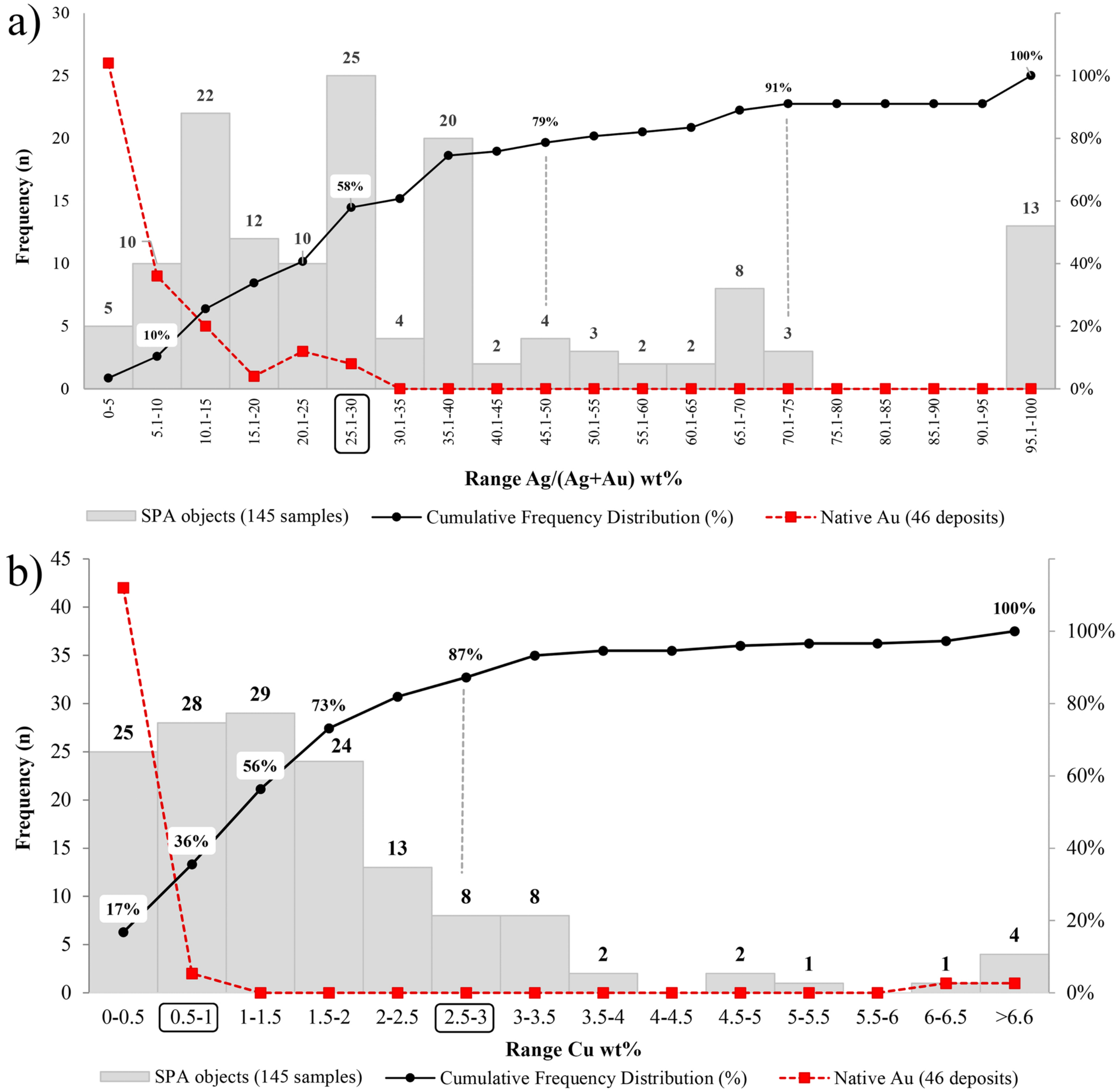


**Fig. 5** Frequency distribution histogram of (**a**) Au-in-Au or Ag/(Ag + Au) wt% ratio and (**b**) Cu wt% values in 145 samples of SPA. A cumulative frequency distribution line was plotted on top (black solid line), summing up the percentage of SPA samples at each compositional range. The number of native gold deposits with different Ag and Cu values is given for comparison (red dotted line). The ranges discussed in the text are highlighted in black boxes

its colour, microstructure, hardness, work-hardening (during deformation) and melting point (Hough et al. 2009). Actually, many of these properties were recognised by ancient metallurgists (Gordus and Shimada 1995).

Therefore, based on the silver content, we propose that 58% of the SPA assemblage was potentially made of unalloyed gold from more than one gold deposit, 33% of the objects were made of gold-silver artificial alloys where silver was added, and 9% were made of silver. Still, peaks at ~ 15 wt%Ag and ~ 25–30 wt%Ag in SPA objects may represent the use of a few specific deposits, unstudied deposits or even exhausted ones. Considering that artificial gold-silver alloys are identified (see below), we cannot rule out the possibility that silver levels between ~ 15 wt%Ag and 20–30 wt% may be artificial as well, resulting from adding silver to low-silver gold. Another process that may

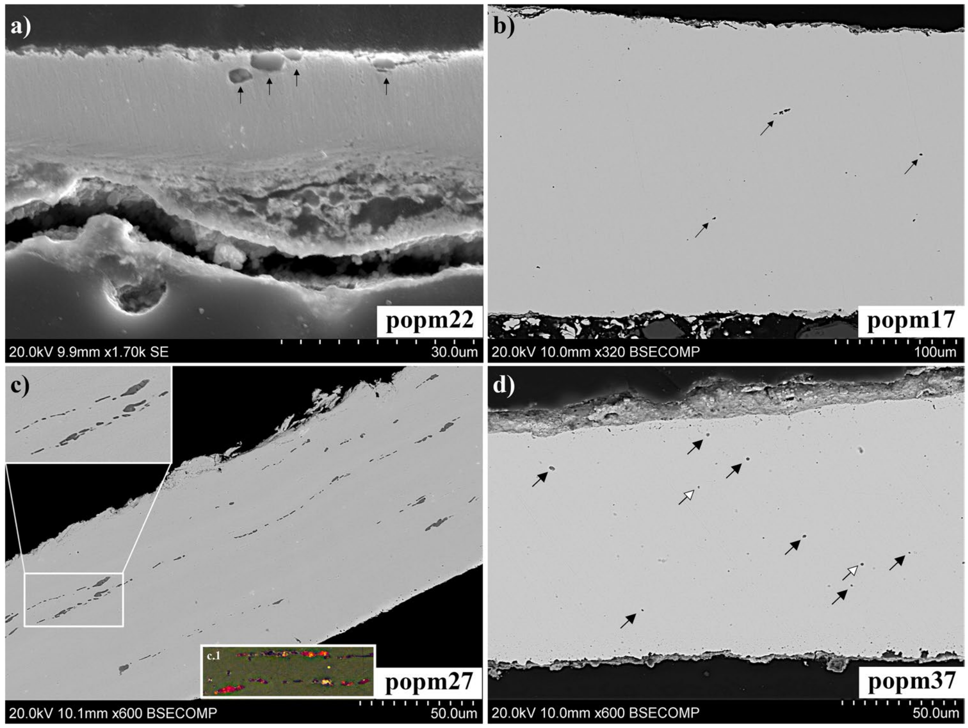


**Fig. 6** Secondary and back-scattered electron images by SEM–EDS showing (**a**) quartz inclusions (SiO2), (**b**) Fe-rich inclusions, (**c**) Cu-oxides dendritic structures and detail under OM (c.1), (**d**) a mix of Cu-rich (black arrows) and complex inclusions (white arrows) within the metallic matrix (images MT Plaza)

alter the silver content in the objects, compared to native gold, is the mixing of gold from different deposits, e.g. mixing gold with ~ 5 wt% and 20–30 wt%Ag. All of these options are possible, but difficult to identify conclusively.

Besides the absence of gold sources with silver levels over 30 wt%, the presence of copper-rich and complex micro-inclusions would support the idea that silver levels over 30 wt% would result from the mixing of gold and silver. Interestingly, when the occurrence of these micro-inclusions within the gold matrix was plotted against silver levels (Fig. 7a), most of the samples with copper-rich and complex inclusions fall in ranges over 30 wt%Ag ($n = 13$), whereas a smaller group was under 30 wt%Ag ($n = 7$). Samples with quartz and iron-rich inclusions only, on the other hand, appear in objects under 30 wt%Ag.

It is plausible, therefore, that the presence of complex and copper inclusions, understood as impurities, were introduced when silver was added, either as natural impurities of silver or artificial contamination from the alloying process. The possibilities are diverse. Impurities may derive from recycling silver-copper objects (Patterson 1971; Rehren et al. 1996); from re-melting silver artefacts with vestiges of intergranular corrosion, increasing Zn, Fe and Ca levels (Patterson 1971, p. 306); from using native silver sources, which can present impurities such as Pb, Cu, Bi and Ni (Patterson 1971; Pernicka 1987; Tylecote 1987; Zappettini et al. 2001; Meyers 2003; Murillo-Barroso et al. 2014); or from adding smelted silver acquired by cupellation (Meyers 2003; Rehren 2011; Murillo-Barroso 2013). Other contamination sources may be the use of dirty crucibles or other tools. Evidence of the reuse of crucibles with gold traces is registered in NWA (González 1997, 2003, 2004a, b), while tin bronze objects with minor amounts of Ag, Pb, Fe, Zn and Ni are reported specifically in Jujuy (Angiorama 2001). In those cases, traces of such bronzes could contribute as impurities. In Jujuy, a prill found in Los Amarillos contained copper as a major element with minor amounts of Au and Ag and traces of Zn and Al (Angiorama 2001).

Regarding the copper content, there is a group of objects that contain under 30 wt% silver, and copper between trace levels and 0.8 wt%. These values correspond to gold reported in different areas of the SCA and probably represent natural sources of unalloyed gold, with varied silver and copper levels. Objects under 30 wt%Ag with copper levels 1–5 wt% may also reflect natural compositions, bearing in mind that some gold deposits may contain up to 2 wt%Cu (Ogden 2000) or 6–8 wt%Cu, as in the case of the placer deposits from the north coast of Peru (Petersen 1970; *cnf.* Guerra et al. 2019). However, these relatively 'high' levels of copper above 1% may have been artificially, but unintentionally, added by one or more of the following options (Fig. 7b):

(i) Copper was introduced with silver if goldsmiths mixed gold with copper-silver alloys. In this case, we would expect that objects with high-silver content would also have high-copper levels; however, this is not the case for all artefacts. Most artificial gold-silver alloys (> 30 wt%Ag) have around 1 wt%Cu,

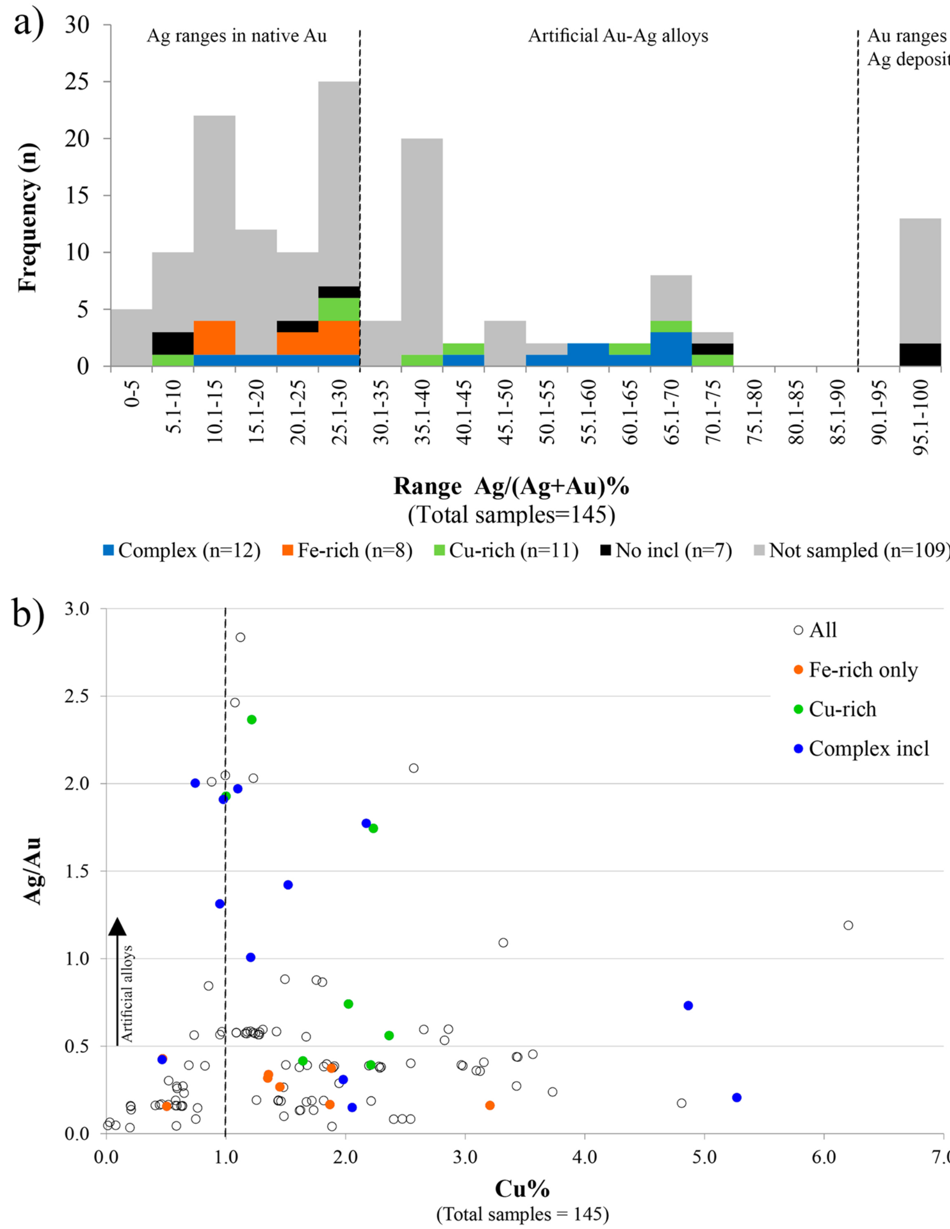


**Fig. 7** **a** Frequency distribution histogram of Ag/(Ag + Au)wt% values showing the presence of inclusions in SPA samples. **b** Scatter plot comparing Cu wt% against Ag/Au ratio, in colour samples with inclusions within the metallic core. Ratio 0.5 represent silver levels over 30 wt%Ag, interpreted as artificial alloys

and a few have over 3 wt%Cu. The two silver objects observed under the SEM–EDS contained 0.5 wt%Cu and 1.5 wt%Cu, still very low copper content but that would dilute in gold with copper levels near 1 wt% or increase copper levels in golds between 0–0.3 wt%Cu.

(ii) The use of gold deposits with naturally high copper levels, such as those reported on the north coast of Peru (Petersen 1970). This option must remain open until the chemical composition of more gold deposits from the region and around SPA are generated. The presence of Fe-rich inclusions in some of these objects—proposed as potential evidence of unalloyed gold—may support this idea, at least for some of the items (Fig. 7b, orange dots).

(iii) Copper was acquired as contamination during melting by reusing dirty crucibles, recycling previously alloyed metal or copper minerals introduced during the collection of gold.

Potential contamination sources would be the reuse of dirty crucibles or the recycling of objects. As previously mentioned, there is evidence of reused crucibles with gold traces in NWA; still, future experiments would be useful to clarify the relative amount of copper introduced during such process. Alternatively, it has been shown that both alluvial and mined gold can be enriched with copper during collection, elevating copper levels up to 5–8 wt%Cu in finished objects (Chapman et al. 2006; Guerra and Rehren

2009, p. 156; Hauptmann and Klein 2009, p. 79). In this sense, it should be noted that gold deposits associated with copper minerals are common in the western slopes of the Andes (Boric et al. 1990; Zappettini et al. 2001; see Online Resource 5).

Four objects show copper levels over 10 wt% that are clearly artificial, producing a gold-copper-silver alloy named *tumbaga*[9]: 11.9 wt%Cu (popm129), 28.7 wt%Cu (popm131), 38.7 wt%Cu (popm52) and 48.7 wt%Cu (popm27). Such high levels indicate the use of a technology of high-temperature alloying technology where copper was intentionally added (Martinón-Torres and Uribe Villegas 2015; Uribe Villegas and Martinón-Torres 2012). Supporting this, the trace elements detected in sample popm27 showed a specific combination of Ni and elevated levels of Zn, Ga and Pb not found in other objects, and probably related to the added copper. Given the rarity of these alloys within SPA, the addition of copper may represent an exogenous technology. The scarcity of items with high copper levels would support the proposition that the small copper amounts detected in the rest of the assemblage were unintentional; i.e. if metallurgists were deliberately adding copper, then one would expect to find more copper-rich alloys.

In general, the variety of silver and copper levels indicates that no particular preference in terms of alloys is observed in SPA, pointing to a random and probably opportunistic supply of metal. This is consistent with the fact that there are no known gold or silver deposits in the immediate vicinity of SPA (Online Resource 3), so gold and silver had to be introduced by exchange, either as metallic gold or as finished objects. However, the low copper levels would suggest that artisans are not producing or preferring alloys with high copper content (e.g. *tumbaga*), even if copper was available and used in SPA and the SCA (Cifuentes et al. 2018). Contents up to 5 wt%Cu (96% of SPA assemblage) in gold alloys will not affect the colour[10] or melting temperatures (Schlosser et al. 2009, p. 416); thus, the production of low-Cu alloys may respond to aesthetic preferences (e.g. preferring golden/yellow colours), or may relate to the specific meanings of the metals. Another option is due to technical constraints: considering that most objects are made of sheets, the addition of copper will produce a harder metal that would be more difficult to hammer, and would probably need different skills and manufacturing techniques (McDonald and Sistare 1978; Corti 1999; Lechtman 2014). In any case, the compositional evidence reinforces the proposition that copper alloys and noble metals probably formed part of two different spheres, technologically and (perhaps) symbolically.

## Manufacturing techniques

In total, 133 objects were studied under naked eye and using a digital microscope to establish the techniques used to produce them. All working marks were registered and classified. The manufacturing sequence of gold and silver sheet objects was divided into three main stages: formation, decoration and final treatment (Maryon 1971; Carcedo 1998; Armbruster 2000, 2013). For each stage, we identify specific techniques involving tools and actions that leave characteristic marks on the objects' surface and internal microstructure. Table 1 summarises the techniques identified in SPA; full results are given in Online Resource 6.

Overall, the objects were forged to shape; i.e. the solid metal was plastically deformed by hammering and annealing to produce plain sheets and wires that were used to create two- and three-dimensional items (Untracht 1975; Lechtman 1981; Armbruster 2013), except for a single gold axe that given its volume was most likely made by casting (analysed by Salazar et al. 2011). Themanufacturing techniques identified in SPA are forging (54%), cutting (65%), perforating (68%) and raising[11] (21%). A few objects were folded (2%), wrapped (2%) or made by wires (2%). Joining techniques[12] were identified in three objects only (2%), as well as the

[9] The term *tumbaga* is understood in this paper as a ternary alloy made of Au–Ag-Cu.

[10] Adding copper to a gold-silver alloy will change the colour to red or orange shades. However, according to Scholsser et al. (2009), at up to 5%Cu a gold-silver alloy will not modify the original golden/yellow colour.

[11] Raising is a specific technique used to produce hollow objects from flat sheets—such as bowls, cups and beakers—by compressing the metal using hammers and stakes (Carcedo et al. 2004). It is a complex and slow technique that includes several steps, such as numerous cycles of hammering using different hammers and stake shapes. The main indication of the use of this technique is the absence of joint lines—either horizontally or vertically—in the body of the thin-walled 3D artefact. Twenty-eight artefacts from SPA (21%) fit with the use of this technique: 21 small bells, six goblets and one miniature jug. During the revision of these objects, there was no indication of joint lines (inside or outside), the bases were flat and even, and there were no metal layers overlapping on the body. In the case of the bells, the interiors were neither hammered nor polished, ruling out the possibility that joint marks on the inside were erased.

[12] Unions between parts—either metallic or non-metallic—are virtually absent in SPA, with the exception of three rings: popm89, popm113/114 and popm117 (Figs. 2–3). The aim in these cases was to decorate the ring fixing a metallic adornment on a band. Apparently, for the rings popm113/114 and popm89, the adhesive used was not metallic. A brittle and dark-grey substance was observed. Compared to the composition of the ring, the pXRF analysis on these dark-grey areas yielded slightly higher silver content in popm89 (32.6 wt%Ag (substance) and 28 wt%Ag (ring)), whereas in popm113/114 the dark-grey substance appeared slightly higher in copper (6.7%Cu (substance) and 2.9 wt%Cu (ring)). However, the pXRF values are exploratory and cannot be taken as conclusive indications of soldering: as the appearance of the substance was not metallic, light elements or indeed organic compounds potentially used as glues would not have been recorded. Further analyses are required in these cases to identify the exact joining technique used.

**Table 1** Summary of the manufacturing techniques identified in the SPA assemblage

| Manufacturing techniques ($n=133$) | | | N° of objects[1] | % | Total % |
|---|---|---|---|---|---|
| **A- Forming techniques** | | | | | |
| 1- | Forging | Sheets | 69 | 52 | 54 |
| | | Wires | 3 | 2 | |
| | | Hollow vessels: raising | 28 | 21 | 21 |
| 2- | Cutting | Perpendicular cutting | 9 | 7 | 65 |
| | | Slide cutting | 65 | 49 | |
| | | Indirect cutting evidence (straight and even edges) | 12 | 9 | |
| | | Uncertain cutting technique | 24 | 18 | 18 |
| 3- | Perforating | Punching | 62 | 47 | 68 |
| | | Cutting | 26 | 20 | |
| | | Rotation | 3 | 2 | |
| 4- | Use of guide marks | | 27 | 20 | 20 |
| 5- | Use of templates | | 4 | 3 | 3 |
| 6- | Joining | Metallurgical joining[2] | 1 | 1 | 2 |
| | | Use of a non-metallic adhesive | 2 | 2 | |
| 7- | Folding | | 2 | 2 | 2 |
| 8- | Wrapping | | 2 | 2 | 2 |
| **B- Decoration techniques (present in 36 objects only (27%))** | | | | | |
| 9- | Chasing | | 18 | 14 | 14 |
| 10- | Engraving | | 11 | 8 | 8 |
| 11- | Embossing | | 7 | 5 | 5 |
| 12- | Openwork | | 3 | 2 | 2 |
| 13- | Appliqué | | 3 | 2 | 2 |
| **C- Finishing techniques** | | | | | |
| 14- | Polishing surfaces | Using abrasive materials | 38 | 29 | 48 |
| | | Rubbed with a hard smooth tool (fine-grained stone) | 3 | 2 | |
| | | Compressed surface with a hard material | 23 | 17 | |
| | | Smooth worn-out surfaces | 55 | 41 | 41 |
| 15- | Polishing edges | Using abrasive materials | 9 | 7 | 38 |
| | | Compressed edges | 13 | 10 | |
| | | Folded edges | 7 | 5 | |
| | | Hammered and bent edges | 22 | 17 | |
| | | Smooth worn-out edges | 32 | 24 | 24 |

Note that an object may include more than one technique. 1: In some cases, more than one type of technique was found in a single object. 2: The object was not available for further analyses. Therefore, we were not able to identify the type of metallurgical joining technique used (e.g. soldering, welding or others)

use of guide marks (20%) and possible templates (3%). Forty-eight percent of the objects present polished surfaces and 38% polished edges as finishing treatments. Only 27% of the assemblage is decorated, mainly by chasing (14%), engraving (8%) and embossing (5%). We identified 11 motifs (Online Resource 7), where the most common decoration is composed of geometric shapes, found in 24 objects (18%): lines, circles, crosses and S volutes. These are followed by zoomorphic motifs ($n=5$, 4%) such as felines, birds and camelids; and anthropomorphic shapes, like human faces ($n=4$, 3%). Possible phytomorphic shapes (flowers?) are seen in two cases (2%) and unrecognisable designs are found in two objects (2%).

A first salient point from the technological analysis is that, even within what looks like a very basic technical repertoire, it is possible to identify large variability in terms of specific ways of shaping, cutting, perforating and finishing treatments, showing different qualities based on relative skill levels, standardisation and labour investment (Costin and Hagstrum 1995; Kuijpers 2018a). Skill is understood here as the 'ability to recognise and respond to the qualities of the material' (Kuijpers 2017, p. 5); it refers to the level of proficiency, knowledge, talent and effort displayed by an artisan, which can change over time (Kuijpers 2015, 2018a; Martinón-Torres and Uribe Villegas 2015). Standardisation is the 'relative amount of uniformity in materials, dimensions, forms or decoration' in a given assemblage (Costin 2005, p. 1064). Beyond the broad level of similarities in artefact form, technical standardisation can result from routinised and frequent practice, as well as the use of a particular technological sequence, and may therefore be indicative of a more skilled specialist; less standardised items may indicate multiple non-specialist producers and correlate with lower skill or specialisation.[13] Labour investment refers to the length of the *chaîne opératoire* and the effort required to make the object. In this particular case, we consider the application or not of decoration, finishing treatments (e.g. polishing the edges or surfaces), treatment of the perforations, etc.

Second, the combination of manufacturing marks with different wear degrees has allowed us to explore in more detail the life history of certain items, recognising ornaments that were likely modified and repaired during their biographies (Sáenz Samper and Martinón-Torres 2017; Legarra Herrero and Martinón-Torres 2021). Third, the combination of specific technological attributes, chemical composition and contextual data suggests that certain groups of items may be tentatively assigned to individual artisans, while others likely derive from several craftspeople working together (Martinón-Torres and Uribe Villegas 2015).

#### Variability, quality and skill

From a macro-perspective, all gold and silver objects found in SPA appear as part of a broad technological tradition, using plastic shaping techniques to produce thin and small to medium objects weighing a few grams, which were cut and perforated (the total assemblage weighs 832 g, excluding the goblets). The exceptions are the six goblets, which are large and heavy (1412 g in total), but still raised from a single sheet; and the cast gold axe from Casa Parroquial that was not available for this work (Salazar et al. 2014, Fig. 6:5). This technological tradition using 'cold' mechanical techniques to produce and decorate gold objects is also described for the goldwork in NWA (González 2003, 2004a; Tarragó et al. 2010). In both areas, this tradition coexisted and contrasted with a 'hot' copper-based metallurgy mainly producing cast and solid objects, including melting and mixing (González 2004b; Salazar et al. 2011, 2014; Cifuentes et al. 2018).

However, this description is too general and conceals a heterogeneous assemblage, composed of multiple micro-styles represented by different forms, quality, gestures, tools and technical options taken along the *chaîne opératoire* (Wallaert 2012). Examples of this variability are displayed in Fig. 8, which shows, amongst other things, the different ways of forging, cutting and perforating detected. Overall, some technological features are more common, such as cutting by sliding a blade,[14] perforating by punching and cutting, untreated or flattened burrs, and both polished and unpolished surfaces. Other techniques are relatively rare and unique within the assemblage such as forging wires, perpendicular cuts, perforations by rotation, wrapping sheets on wood or copper supports, joining two parts, raising large goblets and decorating using pointillism (Table 1).

Within this variety, we observed a difference in the quality and complexity of the work, suggesting the work of artisans with different skills in execution. For instance, there are artefacts made by long technological sequences and employing complex techniques, with special attention to finishing treatments (Fig. 2). They include the 28 hollow objects made by raising, which require great expertise and skill in their manufacture, as well as specific equipment (Untracht 1975; Armbruster 2000; Carcedo et al. 2004; and others); 15 ornaments with smooth surfaces and straight edges that were carefully finished by grinding and polishing, standing out from the general assemblage; and nine artefacts made by uncommon techniques, such as the wire rings, the axe and tube wrapped in gold and the rings with attachments. We propose that these 52 items (39%) relatively finely made reflect the work of experienced and skilled artisans, who paid special attention to finishing techniques to produce well-defined and shiny artefacts. If attributes such as labour investment and skill are considered as proposed by Kuijpers (2017, 2018a), Costin and Hagstrum (Costin 1991; Costin and Hagstrum 1995), these objects stand out in (i) the use of complex crafting techniques such as raising (especially the goblets and the bells); (ii) their even and well-defined shapes; (iii) the careful and thorough treatment of edges, surfaces and perforations; and (iv) their decorations. These features would represent first the employment of additional steps in the *chaîne opératoire* and, therefore, more energy to produce them, compared to undecorated and unpolished items; and second, a qualitative difference in more care, control and technique mastery in terms of skill, showing high proficiency and dexterity. A prime example of this is the conic-bells, which have standardised dimensions,

[13] Although, as noted by Costin (2005), a frequent practice can improve skill and lead to more standardisation, Kuijpers (2017) recognises the existence of specialist 'virtuosos' who can master a specific material (such as gold) such that they are able to create original and unique artefacts. We recognise, therefore, that a highly skilled artisan could potentially make standardised objects, as well as unique items—but either way, these should be distinguishable in the more skilled application of techniques. A key issue here is to distinguish formal standardisation (in the overall appearance of the finished artefacts) from technical standardisation (in the manufacturing sequence).

[14] We are not sure about the tool used for this type of cut. Some possibilities are a burin-like stone tool or a type of chisel. Further experiments would help to clarify this issue.

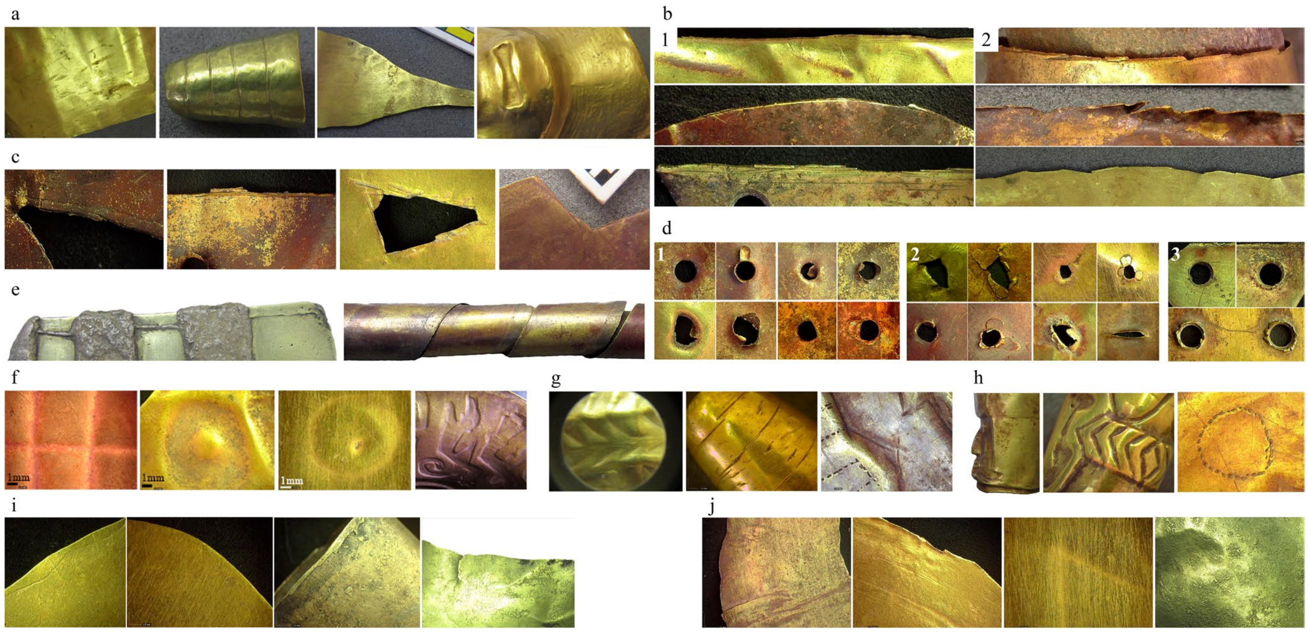


**Fig. 8** Examples of the variety of techniques and tools used to (**a**) forge, (**b**) cut, (**c**) use guide marks, (**d**) perforate, (**e**) wrap, (**f**) emboss, (**g**) engrave, (**h**) chase, (**i**) treat edges and (**j**) treat surfaces (photographs MT Plaza)

design and manufacture techniques within each set, suggesting the work of relatively high-skilled artisans able to reproduce identical small objects. We propose that these objects were probably made by master crafters or very skilled common craftspeople, as defined by Kuijpers (2017).

On the other hand, a second group comprising the remaining 79 objects of the assemblage (59%) were made by shorter technological sequences, and applying coarser techniques with no emphasis on finishing treatments (Fig. 3). They are flat ornaments with unpolished or coarsely polished surfaces. The edges of these objects show unpolished and uneven cuts, and shapes are slightly irregular. Most perforations are rough with untreated burrs; however, in some artefacts, burrs were flattened. Only a few of these are decorated. Moreover, when sets of similar objects are identified, e.g. pendants 47, 50–51, 73–76 or popm119–124, they are not as standardised in shape as the bells in the finely made group. Overall, in the coarsely made group, both the labour investment and skill of the artisans' work appear to be less than in the finely made group, showing no special concern with obtaining even and polished borders or burnished surfaces (Costin and Hagstrum 1995). Given the quality of these items, they were probably produced by non-specialists, creating good-enough ornaments; or even amateurs, in cases that stand out in their lack of care or crude manufacture (Kuijpers 2017). We acknowledge, however, that these objects might also reflect cursory production by skilled artisans, with no time to enhance details on surfaces, borders or perforations (Wendrich 2012a).

In both, finely and coarsely made groups, a range of different forms and manufacturing techniques are identified, which together with the relative different skill, labour investment and standardisation levels suggest that several producers were involved in the manufacture of this assemblage, probably including non-specialists and metalworkers with different degree of specialisation (Costin 1991, 2005; Costin and Hagstrum 1995; Armbruster et al. 2004; Leusch et al. 2014, 2015; Kuijpers 2017, 2018a). This technological diversity is identified in the goldwork at every cemetery from SPA included in this research, and it agrees with the chemical data that pointed to varied gold sources. This formal and technological variability probably reflects a mix of items essentially acquired by trade or exchange from different sources. A similar model has been proposed for the inhalation of wooden tablets and tubes, which also show heterogeneous styles, technology and raw materials in SPA (Llagostera et al. 1988; Llagostera 2006b; Horta 2012; Niemeyer et al. 2013; Salazar et al. 2014). Furthermore, given the technological and compositional heterogeneity and variability of the grave goods from SPA, there is every reason to propose that these objects are primarily entering SPA as finished objects, instead of as metal stock to be shaped locally. Yet, there is evidence to propose that certain items were locally made and modified, as discussed in the following sections.

### Modification, reuse and repairs

Within the assemblage, 36 objects (27%) show evidence of more than one technique for cutting and/or punching, combining polished or worn edges with fresh cuts, are incomplete or have interrupted shapes. As this variability is hard to explain by technical constraints of the manufacture, we propose that these objects were modified or repaired at some point in their life histories. Moreover, given the modifications on these ornaments, it is very likely that they 'changed hands' more than once during their lives.

Twenty-seven objects (20%) show different cuts and perforations, five cases (4%) present only additional cuts, three (2%) only additional perforations, and one item (1%) presented a later chasing work. In general, the modifications tend to be of lower quality and rough, compared to the original work, which makes them more recognisable. In this classification, however, it is highly likely that we missed objects that were completely modified or were heavily used, erasing all evidence of previous work.

In 18 cases (14%), the modification involved dividing larger sheets to increase the number of similar-looking ornaments, creating sets that were buried together. Examples of this practice are provided by six trapezoid pendants (popm119–124) found in Larache burial 358 (Fig. 9a). These pendants show cracked and worn external edges that contrast with the fresh and sharp cuts used to divide them. Guide marks were drawn before the cut, some of them in incorrect places. Interestingly, all pendants fit together except the last one, suggesting that a seventh pendant is missing, whereas burial 1714 has an identical pendant (popm36)—same shape, perforation techniques, dimensions and composition—that fits perfectly in the gap. The only difference is its condition: popm36 is heavily worn, deleting the cutting marks. The similarities indicate that these pendants were

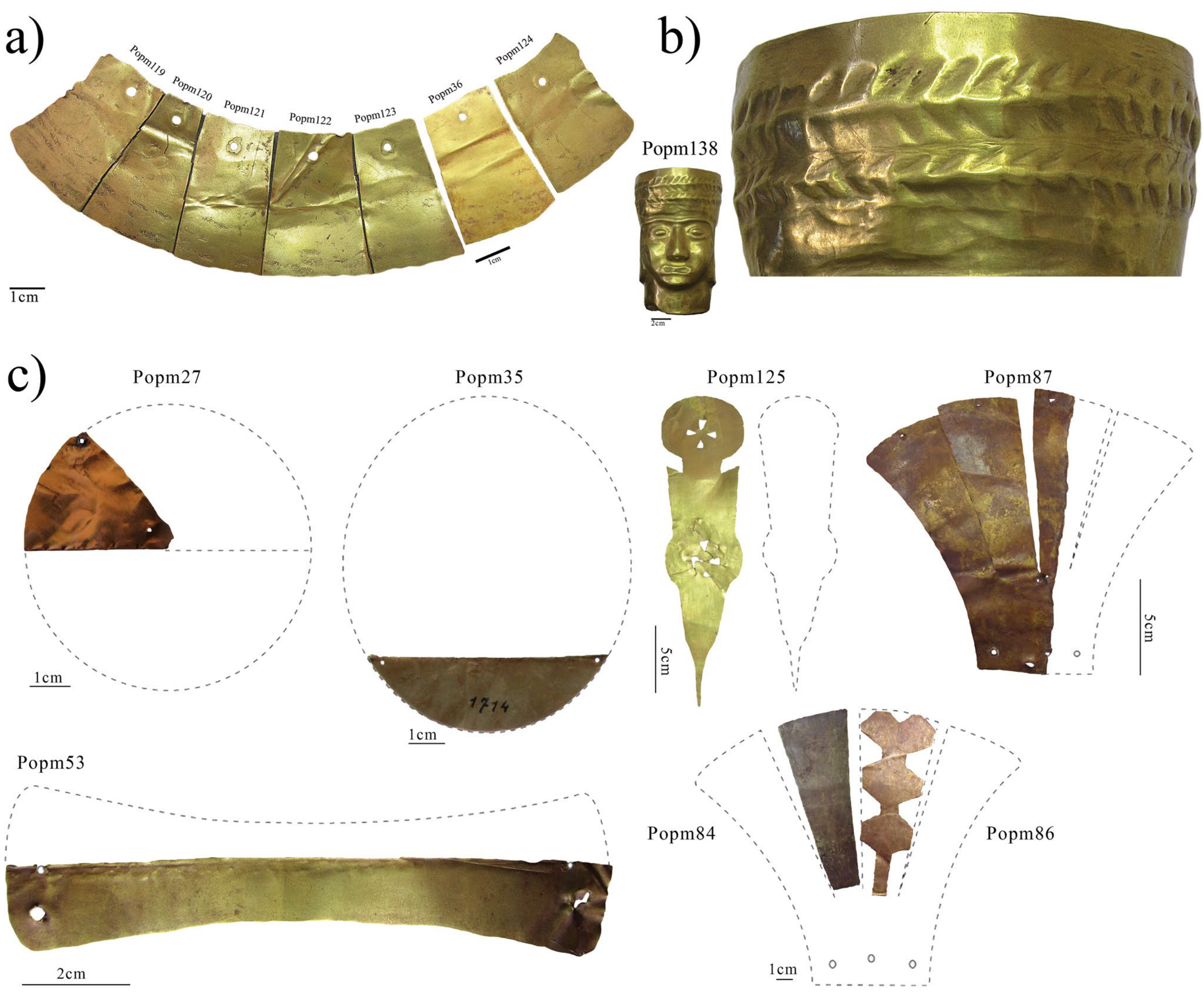


**Fig. 9** **a** Examples of fresh cuts and divided items. Popm119–124 (B.358) and popm36 (B.1714) from Larache, **b** Detail of the hat in popm138. The technique used is very different in tools and quality from the rest of the goblet; it also represents a SPA headdress-style. **c** Examples of incomplete pendants, original shapes are projected with dotted lines (photographs MT Plaza)

all modified together, but popm36 followed a different trajectory: it was separated from the lot, used afterwards and deposited independently. Similarly, worn and matching fresh slide cuts, as well as guide marks, appear in seven 12 pendants from Casa Parroquial in burial 16 and 18 (popm47, 50–51, 73–81), forming rectangular pendants of different sizes (Plaza and Martinón-Torres 2021). Perforations are identical within the objects from Larache (cut perforations with flattened burrs) and Casa Parroquial (punched perforations with a conical-pointy tool, burrs not treated), suggesting that in both groups of pendants, the perforations were made after the cuts, as part of the modification.

In 10 items (8%), modifications were made in single objects, oriented to change their shape or design. In these cases, only one or two sides of the item were modified (with visible fresh cuts) and perforations were added, such as the attachments popm16, popm28, popm53, popm27 and popm35 (Fig. 9c).

Based on the sheet popm84 which is similar and of identical composition, it is proposed that the headdress popm86 was completely reshaped, from a trapezoidal sheet into a complex shape based on three lobules (Fig. 9c). In fact, it is possible that popm84 and popm86 were part of a single headdress, similar to popm87 that was broken up, given the rough marks at their bottom. In popm125, the modifications changed the original shape creating a neck and adding openwork decoration at the centre. Some unfollowed guide marks (mistakes?) are still visible on the surface (Fig. 9c). The hat of portrait vessel popm138 was also modified. A pair of braids was added by scratching and engraving using a sharp pointy tool (Fig. 9b). The motif is sunken in several parts, suggesting that too much pressure was applied from the exterior, while the inner support was not enough. The technique and quality of the braid work differ from the techniques used to chase the face. Remarkably, the braided hat is characteristic of SPA, pointing to a modification that adapted the vessel to a local headdress-style. Interestingly, popm125, popm138 and pendants popm119–124, all of them modified, were found in Larache, burial 358.

Presenting both fresh and worn edges, in five cases (4%), the objects were deliberately fragmented, simply cutting into one or two ends (popm9, 11, 15, 87, 150). No clear intention to create a new shape or divide a larger piece was identified in these cases. In four objects, additional perforations were added to repair (e.g. popm1, 10, 87) or for attaching the sheet to a support (e.g. popm142).

Longer life histories are seen in popm27 and popm87, with the presence of more than one modification technique, suggesting several interventions (Fig. 9c). In popm27, two additional ways of cutting and perforating are present, whereas in popm87, different techniques were used to cut the edge and perforate the ends of the appendices (perpendicular cuts with a blade), and to repair the thin appendix (punched and round).

Overall, modifications—including deliberate fragmentation and repairs—are rough and unpolished, obtained by cutting and perforating, i.e. by 'cold' mechanical techniques. The use of guide marks to outline the new designs suggests some planning. Considering that all modifications look fresh or unused, and many were grouped within the same burials (23 artefacts in 4 burials), there is every reason to propose that these modifications were locally made, shortly before the objects were deposited. To understand these cases, the time factor is key; i.e. the modifications identified here would have occurred sometime after the objects were made, at different moments of their life histories. Modifications then would represent later interventions, either to change their original shapes or to divide or repair them. The adaptation of the portrait vessel popm138 to an indigenous headdress-style would support the idea that these items were adapted to local tastes. Moreover, these modifications are not particular to a specific cemetery; they appear in at least five of seven cemeteries: Larache, Quitor-1, Quitor-5, Sequitor Alambrado and Casa Parroquial.

Finally, three objects have modifications that are different compared to the rest, indicative of relatively long and intricate life histories, suggesting that not all objects followed the same trajectories. For instance, the cuts in popm87 are the crudest and roughest of the assemblage, and the cutting technique used (perpendicular cuts) is not common in SPA. Conversely, the modifications in popm35 and popm27 are very neat and the rotary technique used to perforate them is rare (see the "Discussion" section, Fig. 15). It is possible then that these three artefacts were modified before they arrived at SPA, where popm87 and popm27 were subsequently repaired and re-cut for a second time.

### Individual artisans and groups of craftspeople

In SPA, there are, at least, nine subgroups of objects sharing chemical and technological traits, supporting the hypothesis that each represents the work of a single artisan (Table 2: sets 1–9). These cases include batches of 2–7 objects made of the same metal (Fig. 10), using the same manufacturing sequence and techniques, as shown in Fig. 11a. These cases would represent specific 'production events', defined as objects made at the same time, from a single batch of metal (Blackman et al. 1993; Freestone et al. 2009; Uribe Villegas and Martinón-Torres 2012; Legarra Herrero and Martinón-Torres 2021). They include seven ornaments in B.889 and two bands of unknown burial in Quitor-1, five sets of bells in B.Body1, B.Body2, B.1714, B.356 and B.359 from Larache; and a pair of pendants in B.8 and headbands in B.18 from Casa Parroquial. The consistency seen in the metal used, the way of shaping, cutting, perforating and decorating, together with the design of the objects, would represent the work of individuals with idiosyncratic techniques and skills

**Table 2** Sets identified in SPA based on the correspondence of chemical composition and manufacture traits. *CP*, Casa Parroquial. See Figs. 2 and 3. 'Identical' composition refers to sets of results that are identical within the instrumental error

| Sets | Objects | Chemical composition | Manufacture traits | Cemetery | Burial | Id, popm_ |
|---|---|---|---|---|---|---|
| **1** | 2 headbands | Identical | Same style | CP | 18 | 17–18 |
| **2** | 2 pendants | Identical | Same style | CP | 8 | 1, 10 |
| **3** | 3 bells | Identical | Same style | Larache | Body1 | 145–147 |
| **4** | 2 bells | Identical | Same style | Larache | 359 | 61–62 |
| **5** | 2 bells | Identical | Same style | Larache | 1714 | 64–65 |
| **6** | 3 bells | Identical | Same style | Larache | 356 | 58, 115–116 |
| **7** | 7 bells | Identical | Same style | Larache | Body2 | 59–60, 98–102 |
| **8** | 7 ornaments | Identical | Same style | Quitor-1 | 889 | 32–34, 37, 150–152 |
| **9** | 2 attachments | Identical | Same style | Quitor-1 | No burial | 5, 48 |
| **10** | 3 goblets | Two chemical groups | Two or three styles | Larache | 358 | 136–138 |
| **11** | 3 wire rings | Identical | Two styles | Larache | 356, 359 | 103–105 |
| **12** | 3 headdresses | Two chemical groups | Same style | CP | 13, 22 | 84, 86, 87 |
| **13** | 24 ornaments | Three chemical groups | Three styles | Larache | 359, 356, 358, 1714 | 36, 90–91, 93–97, 106–112, 119–124, 132, 142 |
| **14** | 15 ornaments | Identical | Same style | CP | 11, 16, 18 | 47, 50–51, 73–85 |

(Martinón-Torres and Uribe Villegas 2015), producing sets of objects that were acquired and deposited together in the same burial. Between the groups, conical bells reveal the highest proficiency level, specifically seen in their small size and great standardisation within each set, suggesting the presence of artisans with high levels of experience and skill (Fig. 12a), compared to the headbands or pendants from Quitor-1 or Casa Parroquial which are much coarser and irregular in their make (Kuijpers 2015, 2018b).

In four sets, the combination of techniques would suggest the participation of more than one person in their making (Table 2: 10–13). They would represent 'production groups' defined as objects that were made together by producers sharing a technology (Costin 1991, p. 33). These objects usually combine specific manufacturing techniques and typology (Costin 1991; Costin and Hagstrum 1995; Armbruster et al. 2003; Leusch et al. 2015); and may include artefacts made in single or multiple metal batches, but sharing particular technological attributes. In these cases, objects were made either by using the metal of one, two or three metal batches (Fig. 10), but following the same technological sequence. In these examples though, manufacturing traits show subtle differences that would represent different 'attributes of execution' or unconscious motor habits as defined by Whittaker (1987), which would indicate the work of different 'hands' or people (Costin and Hagstrum 1995;

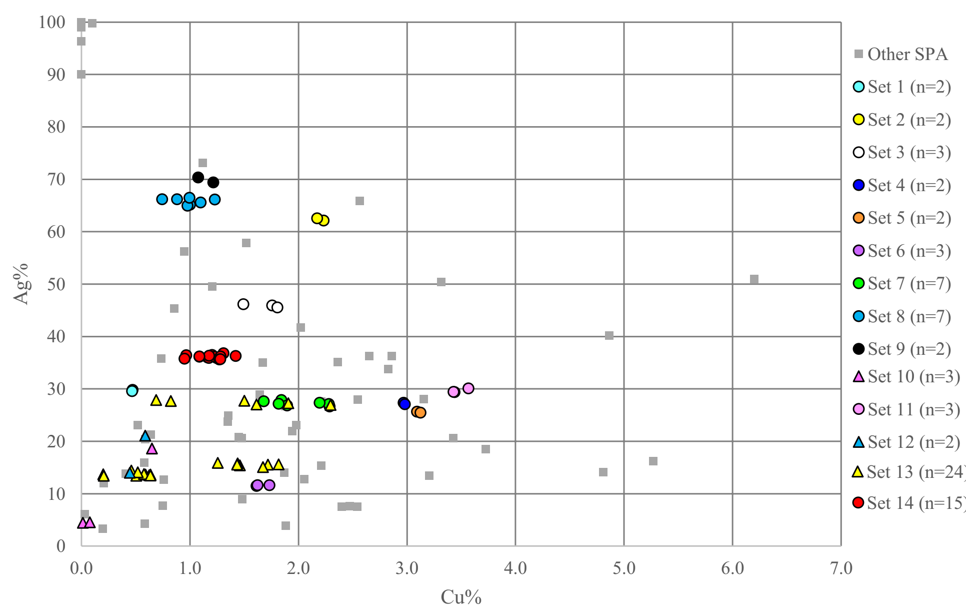


**Fig. 10** Scatterplot of the copper and silver values for artefacts at SPA, highlighting the compositions of the sets discussed in this paper

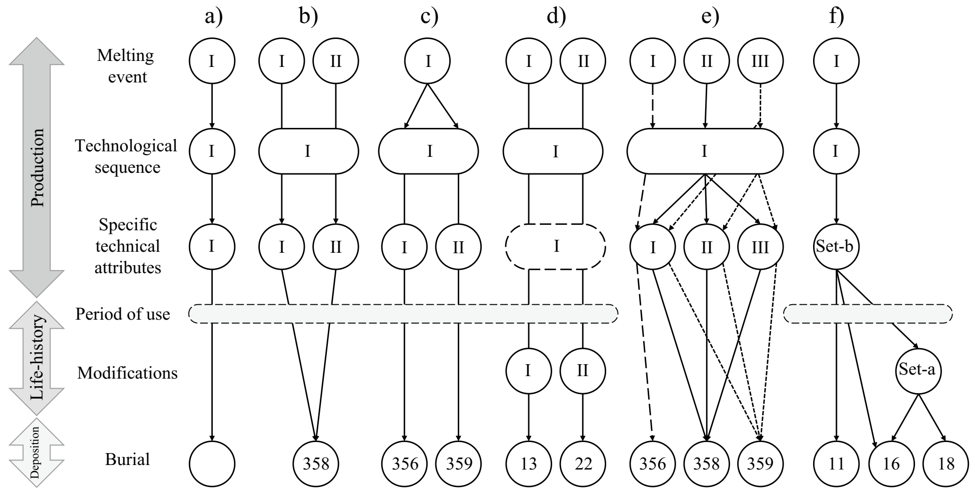


**Fig. 11** Diagram of the *chaînes opératoires* showing the production, life history (consumption) and deposition of different sets of objects from SPA. It identifies the work of individual artisans (**a**, **f**) and groups of craftsmen (**b**–**e**). Dotted ellipse in d indicates that specific technological attributes are unclear. In e, objects do not show evidence of use. Roman numbers indicate the different alternatives in each stage


**Fig. 12** **a** Seven identical bells from Larache, burial Body2 (set 7; originally there were nine bells). Note the high standardisation degree in their manufacture, compositions are identical (2%Cu, 27.3%Ag, 70.7%Au). **b** Detail of the portrait vessels from Larache, burial 358. Popm137 showed better skill and finishing treatments than popm138 but the technical sequence is identical in both. **c** Wire rings from Larache, B.356 and B.359. Note the similarities, but also small differences such as the level of polishing and the shaft crossed on top (photographs MT Plaza)

Martinón-Torres and Uribe Villegas 2015). In three cases, the resulting sets were deposited in more than one burial, but within the same cemetery (Fig. 11b–e).

The first two examples are set 10 with three goblets in B.358 (Fig. 11b) and set 11 with three wire rings in B.356 and B.359 (Fig. 11c), all from Larache. The set of goblets comprises two portrait vessels and a *kero* found in the same burial, all made by raising (Untracht 1975; Bray 1978; Carcedo et al. 2004; Hill and Putland 2014). The portrait vessels are very similar in their dimensions (base/rim/height) 69/142/92 mm in popm137 and 66/145/90 mm in popm138, although chemical compositions are different (Fig. 10). They have similar eyes, mouths, noses and ears, in both cases obtained by chasing using a wooden mould from the inside (see Carcedo et al. 2004). Some hammering marks such as those seen below the rim and neck are the same as well, suggesting the use of similar tools. Interestingly, both share a very specific detail: a slight inclination of 101° of the body, which is not easy to note but allows one to look straight at the face when the goblet is on a surface (Fig. 12b). A subtle difference, however, is the quality of the work. The details in popm137 are better achieved than in popm138. The ears for instance are clearly defined in the former, whereas in the latter, they are blurry and misaligned. In popm137, the chasing work used to define the face includes the use of blunt and pointy punches, leaving fine lines and different hammer marks that were not applied in popm138. The bases are also different; in popm138, the base is flat, whereas in popm137, the centre is sunken. The same sunken base is seen in the *kero* popm136, which was made of the same metal as popm137 (4.5 wt%Ag and > 0.1 wt%Cu; Online Resource 2). The case of the three wire rings is similar. The three wire rings were hammered and bent following the same sequence, and they are almost identical in design and dimensions, but popm103 shows less care in the finishing treatments than popm104–105, which are impeccable. Moreover, the way in which the shanks were crossed to form the loop is the opposite, which appears as an unconscious gesture suggesting the work of different 'hands' (Fig. 12c).

Based on the manufacture and techniques used, it is possible to recognise enough similarities but also quality and skill differences to propose that the goblets and wire rings were made by more than one person, but following an identical technological sequence. Namely, one artisan would have made goblet popm138, and another would have made popm136 and popm137, each artisan working with their own metal stock. Similarly, wire rings popm104–105 were made by the same craftsperson and popm103 by another, all of them using the same metal stock in this case. These examples include artefacts that show different quality in the details but are remarkably similar in their shape and forming technology. Given the similarity of the objects, it is clear that specific details were passed, shared and presumably learned between artisans (e.g. the inclination of the goblets). This would suggest the work of groups of specialists or workshops, where people are actively sharing techniques or are subjected to formal or more controlled training—e.g. a master-apprentice relationship—, explaining the consistency and subtle variations at the same time (Costin 1991; Costin and Hagstrum 1995; Creese 2012; Wallaert 2012; Wendrich 2012a, b).

Similarly, but less certain, is set 12, which is composed of headdresses popm84/86 and popm87 in B.13 and B.22 from Casa Parroquial (Fig. 11d). These items are the two headdresses with appendices, which were cut and modified. The original ornaments would have been carefully forged, cut and ground, producing even and straight edges that were meticulously polished, together with both surfaces, showing high-quality work. The thorough finishing treatment deleted all manufacturing traits, making it impossible to identify particular 'hands', but they do share a general work style. When compared with a similar headdress found in the NWA (see the "Discussion" section, Fig. 15a), especially popm87, they share several technological details, such as the location and technique used for the perforations, as well as the shape, the surface treatment and the treatment of the cuts (ground and polished). The similitude of all these ornaments and the proficiency of their making may suggest the existence of a specialised artisan or workshop producing complex and high-quality gold items but using different types of gold. Their good quality, however, did not prevent their modification and reuse in SPA.

The fourth example includes set 13 of 24 coarse-made ornaments distributed in B.356, B.358 and B.359 from Larache (Table 2: 13). This is a production group composed of three batches (Fig. 10). Each batch has its particular composition, but they follow the same technological sequence to make very similar ornaments (mainly discs and headbands; Fig. 11e). Although the hammering marks are the same in the three sets, they combine three different ways to perforate and cut the edges, showing different qualities and skill levels (Fig. 13a). This would suggest that a group of possibly three artisans were part of the same 'community of practice', i.e. a group of craftspeople sharing their knowledge and practising together (Wenger 2010; Wendrich 2012a), possibly as an independent workshop (Costin and Hagstrum 1995). Still, not necessarily under a formal training scheme, as proposed for the goblets or wire rings, given the lack of standardisation between the shapes, cutting and perforation marks. The quality of the work would indicate less proficiency, compared to the finely made objects described before. In terms of raw material, they have access to more than one type of gold, which was used in discrete melting events for each set. The batches may represent independent commissions produced at different times; or production by units, making

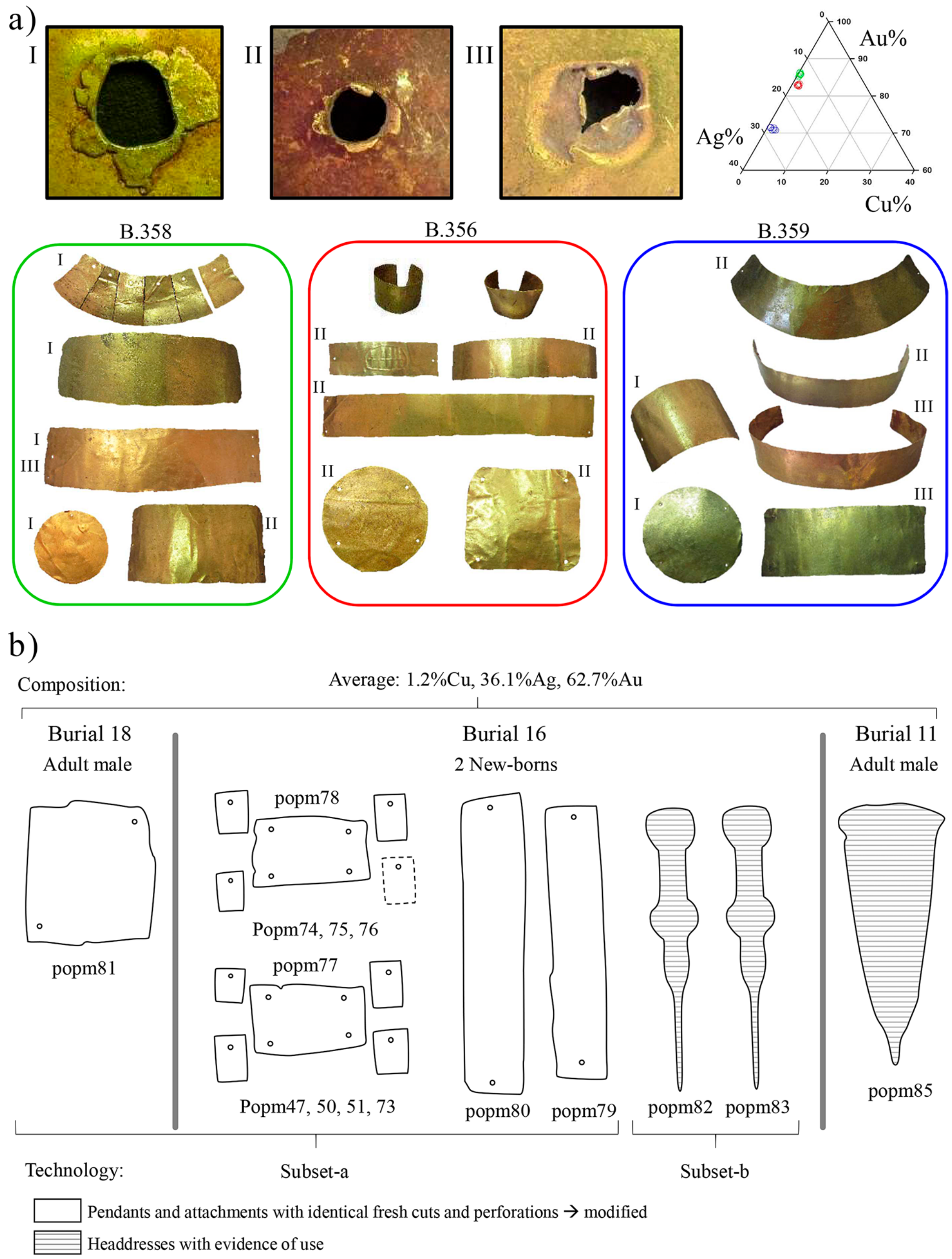


**Fig. 13** **a** Example of the combination of three different perforation styles and qualities **(I–III)** and chemical composition in set 13 of 24 coarse-made ornaments distributed in B.356, B.358 and B.359 from Larache. Similar combinations occur for cutting techniques but all items share the same hammering and surface treatment. **b** Set 14 from Casa Parroquial, burial 11, 16 and 18 (photographs and drawings by MT Plaza)

a complete set for each casting event (for a sophisticated example from China see Martinón-Torres et al. 2011, 2014). It is noteworthy that the chemical and technical connections between these three burials, in the case of set 13, as well as the wire rings. These technological connections certainly reveal a close relationship between the individuals from Larache, a male (B.358) and two females (B.356, B.359) that only DNA analysis would help to clarify.

The last case includes 15 objects from Casa Parroquial deposited in three different burials: B.11, B.16 and B.18 (Table 2:14) (Plaza and Martinón-Torres 2021). This is an interesting case where we identified a later modification, and the association between objects is inferred from their identical composition and specific manufacturing traits, present in more than one burial (Fig. 11f). This group is composed of two subsets. The main difference between both is that subset-a has fresh cut and perforation marks, whereas headdresses in subset-b are used and worn (Fig. 13b). These two subsets share an identical composition, which is also identical to a third headdress popm85. Popm85 shares the hammer marks and surface treatment of subset-a, but it has clear evidence of use (worn edges and surface) as objects in subset-b. In terms of distribution, 11 of 12 ornaments from subset-a and both headdresses from subset-b are found in B.16, deposited with two newborns. These objects form two identical bundles composed of a headdress, a long band, a rectangular attachment and four small pendants. Popm81, also from subset-a, is a square attachment deposited in B.18, of a male adult; and popm85 is a headdress found in B.11, also a male adult.

Considering that (i) subset-a shares identical and fresh manufacture marks—except for a few worn borders, and both subset-b and popm85 have evidence of wear; (ii) the forging technique used on subset-a is similar to popm85; (iii) the combination of both working styles in burial 16; and (iv) the shared elemental composition of all items; we propose that these 15 items do not represent a typical production group, understood as a group of objects made together by a particular group of craftspeople sharing a tradition (Costin 1991). Instead, we interpret them as a batch of objects that were modified in divergent ways at some point in its life. In other words, they are a set of objects, made together from a single metal stock and subsequently used as ornaments, but, at some point in the objects' life histories, part of the batch was modified to create new ornaments. Based on this, it is proposed that the original group comprised at least four items, including subset-b and popm85, where a fourth item (e.g. a sheet forged as popm85) was modified and cut into 12 smaller pieces (subset-a) to create specific grave goods for the new-borns. Subset-a, in this case, would be the product of a single artisan given the identical techniques used in their modification; and based on the fresh manufacturing marks, the work was probably completed just before the ornaments were deposited as funerary offerings.

## Discussion

### Circulation: imported gold and silver objects

We proposed above that most objects in SPA presumably arrived as finished objects, being produced elsewhere. The reasons to support this claim are, first, the variability of designs, manufacturing techniques, work quality, chemical compositions and types of artefacts seen in the seven cemeteries considered here, which strongly suggest that these objects were made by multiple producers (including individual artisans and groups of craftspeople), with their own techniques and gold sources, and different skill and specialisation levels. Such characteristics are in stark contrast with those identified in local crafts such as pottery (Tarragó 1976, 1989; Stovel 2002, 2005, 2013), basketry (Núñez 1991), snuff-taking wooden trays (Horta 2014), copper beads (Horta and Faundes 2018), textiles and headdresses (Oakland 1992, 1994) which are very standardised and homogenous in their designs and technological style (Salazar et al. 2014).

Secondly, to date, there is no direct evidence of silver or goldwork production in SPA that would support the practice of those many artisans; i.e. no technical ceramics, native gold, silver minerals or any production debris related to noble metals have been identified in SPA so far (Salazar et al. 2014; Cifuentes et al. 2018). The lack of production evidence may be affected by a recovery issue, as goldwork usually leaves scarce production evidence and tools used that can easily go unrecognised (Armbruster et al. 2004; Perea 2010). Nevertheless, the presence of copper prills, slags, small copper ingots and technical ceramics recovered in Solor-3, Solcor-3, Sequitor Alambrado, Coyo and Beter has revealed local small-scale copper production in SPA, indicating that the knowledge and means to work metals were available at SPA (Salazar et al. 2011, 2014; Maldonado et al. 2013; Cifuentes 2014; Cifuentes et al. 2018).

The question, therefore, is from where these objects are circulating. To answer this, we compared the SPA assemblage, chemically and technologically, to 109 gold objects from Chile ($n = 36$), Bolivia ($n = 14$) and Argentina ($n = 59$). This information was complemented with published material and artefacts from the museums' online catalogues to identify specific features when the images were good enough. We also included 30 items from SPA that were not physically available for our analysis, making a total of 173 SPA objects. Table 3 summarises the main technological traits identified in different regions of the SCA. As mentioned, all gold and silver objects from the SCA belong to the same 'sheet technology', being made by plastically deformed sheets. Casting is rare, being identified in five objects only. However, we recognise specific features that allow us to point towards the possible origin of some of the SPA objects.

Based on chemical composition, manufacture traits and designs, we argue that nearly 22% of the objects from SPA were probably produced and imported from Tiwanaku, including the Titicaca Basin and Cochabamba Valley, whereas ~ 22% was probably imported from NWA. These objects appear to be scattered throughout the period, without showing a specific chronological trend. Such finds have a major effect on the interpretation of gold users in SPA, as they suggest that the use of noble metals not only relates users to the Tiwanaku polity or the Altiplano (Salazar et al. 2014) but also to neighbouring areas, especially the Jujuy and Humahuaca areas. Moreover, they provide a starting point to recognise different technological traditions within the SCA, inviting future research to confirm, complete and correct them.

#### Northwest Argentinean technology in SPA

Overall, and looking at the evidence gathered from NWA, including the Puna, Humahuaca Ravine and the Yungas, the objects that most resemble the SPA assemblage are those from Humahuaca Ravine. They share shapes, types, manufacturing techniques and composition. In particular,

**Table 3** Summary of the main technological features documented in different areas of the SCA

| | Bolivia | | Argentina | | | Northern Chile |
|---|---|---|---|---|---|---|
| | Central Altiplano, Tiwanaku; Cochabamba Valley | The southern Altiplano: Potosi, Lipez | Puna | Humahuaca Ravine | Yungas | |
| Raising | Common. Vessels and conic bells | Rare. 1 conic bell | Uncommon. 5 conic bells | Uncommon. 2 bells and 1 keros (maybe 4 keros more) | Uncommon. 5 conic bells | Rare. 1 conic bell |
| Casting | 3 items | N.D | 1 pectoral | N.D | N.D | N.D |
| Soldering | N.D | N.D | N.D | 1 ring | N.D | N.D |
| Wrapping with gold/silver sheets | N.D | N.D | N.D | 1 wooden tube | N.D | 1 wooden figure |
| Decoration techniques | Embossing, chasing, engraving, wiggle cut or pointillism, stone inlay, openwork | Embossing, chasing | Embossing, chasing, openwork | Embossing, chasing, bimetallic items | Embossing, chasing | Embossing, chasing, stone inlay, openwork |
| Designs | Plain pendants and complex items, lavishly decorated with intricate shapes, using openwork | Relatively simple pendants | Relatively simple pendants | Relatively simple pendants | Relatively simple pendants | Relatively simple pendants. Complex shapes |
| Quality of work | Different qualities, however most items are finely made | Finely made | Finely and coarsely made | Finely, coarsely and poorly made | Finely and coarsely made | Finely and coarsely made |
| Recurrent decoration motifs | Feline heads; schematic birds with open wings, anthropomorphic faces and the Tiwanaku deity | Anthropomorphic faces, geometric figures (circles, rectangles, triangles, lines), a bird. The bow-tie shape pendant appear to be more abundant in this area | Llama-shaped pendants, anthropomorphic and feline faces | Llama-shaped pendants; only one bird pendant, anthropomorphic masks | Llama-shaped pendants and Maltese cross | Dotted lines, the character with the radiate head (*'personaje de cabeza radiada'*) and a bird |
| Modifications, repairs | N.D. Possibly some new perforations in fragments recovered in Lake Titicaca | Possibly in 1 pendant. Two objects were repaired | N.D | Documented in 5 items. Repairs in 3 cases | N.D | Documented in 1 pendant |
| Observations | | | Rotation to perforate. It is an heterogenous assemblage | Use of anticlastic raise technique. Similar to many SPA materials | | Objects are not from the Middle Period |

*N.D.* not documented

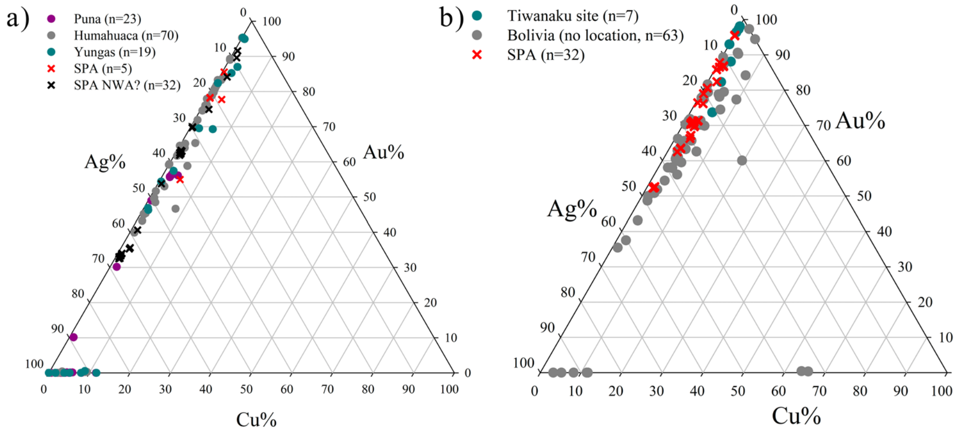


**Fig. 14** Gold-silver-copper ternary diagrams (SigmaPlot 12.0) comparing (**a**) NWA (Puna, Humahuaca and Yungas) compositions against five ornaments from SPA (red crosses; pendant 91.1.11 was not analysed) and other artefacts of NWA aspect (black crosses. Sources: Boman 1908; Rolandi 1974; Ventura 1985; Angiorama 2004; González 2004a; Ventura and Scambato 2013; Miguez 2014). **b** Compositions from Bolivia, Tiwanaku and SPA (Sources: Fernández 2016; Guerra et al. 2019)

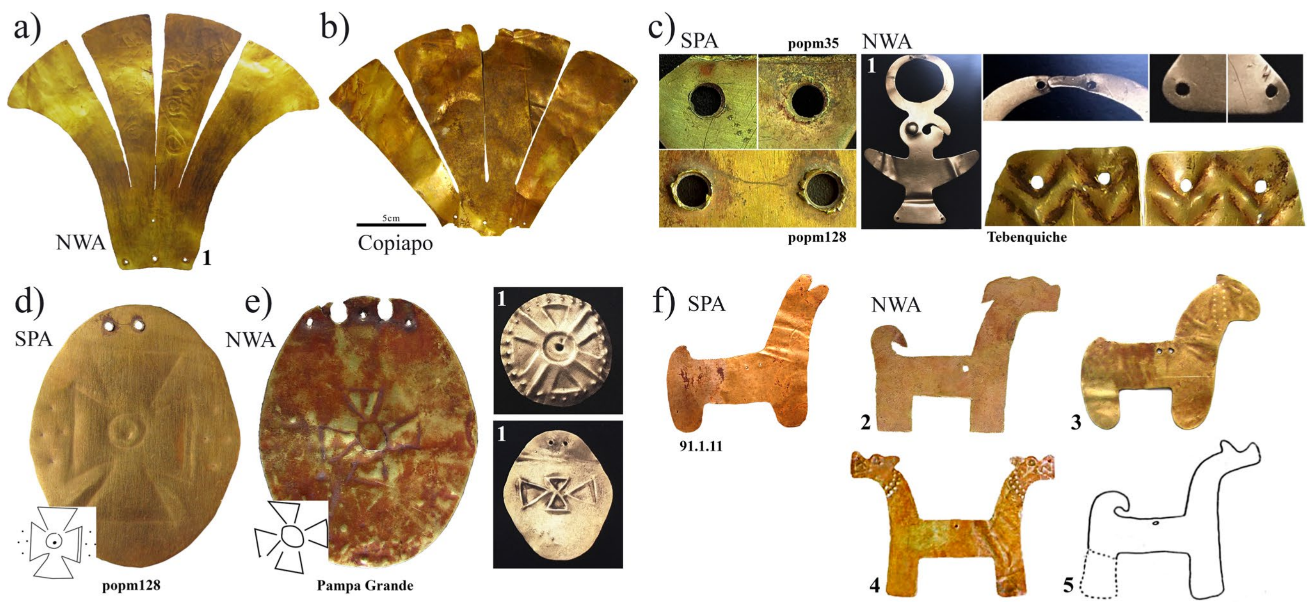


**Fig. 15** **a** Headdress from NWA, unknown location; **b** headdress from Copiapó (Chile), but thought to be made in NWA (nº 2731, Museo Chileno de Arte Precolombino). **c** Rotation technique in SPA and NWA artefacts from unknown site and Tebenquiche (nº-2277–(52–33), Museo Etnográfico 'Juan Bautista Ambrosetti' (FFyL, UBA)). **d** Pendant from SPA, **e** pendants from NWA with Maltese crosses, from Pampa Grande (nº50188, Archivo de la División Arqueología del Museo de La Plata, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata. 2017) and other unknown locations. **f** Llama pendants from SPA and NWA: 2–La Isla de Tilcara, 3– Manuel Elordi 1, 4– Colección Linares, 5– Tabladitas (sources: 1– Goretti 2012; 2,4– Tarragó et al. 2010; 3– image courtesy of Beatriz Ventura 2017; 5– Ventura 1985; the rest are photographs taken by MT Plaza)

the gold grave goods from Huacalera (Pelissero 2014), La Isla de Tilcara (Tarragó et al. 2010), Muyuna, San Jose and Los Amarillos (Angiorama 2004) are very similar to the pendants and attachments from Casa Parroquial, Quitor-1 and the coarsely made ornaments from Larache (set 13, Table 2). They are quadrangular attachments with perforations in four or two corners, small rectangular or trapezoidal pendants, bands used as bracelets and thin long headbands. All are plain and partially polished, and a few items show repairs and later modifications (Table 3). Compositions are also similar, primarily showing very low copper levels as seen in Fig. 14a. Some differences should be noted though. Band-rings, headdresses and conical bells are more frequent in SPA whereas, from NWA, gold-folded bells, camelid-shaped pendants and embossed masks are more common.

We estimate that 38 objects from SPA would come from NWA (22%). Unfortunately, in 32 of them, the evidence is inconclusive because of the simplicity of the items, even though their composition (Fig. 14a, black crosses), appearance and techniques are very similar. The 32 items include 19 from Casa Parroquial (popm1, 10, 17–18, 47, 50–51, 73–83, 85); seven from Quitor-1 (popm32–34, 37, 150–152); two from Sequitor Alambrado (popm15–16); one from Quitor-5 (popm26); and three from uncertain cemeteries (popm24, 28, 55). An exception is presented by six objects (4%) with particularly strong evidence to support that they were made in NWA: three from Casa Parroquial (popm84, 86, 87), two from Larache (popm35 and N°91.1.11) and one from an unknown site (popm128; Fig. 15). The composition of these SPA ornaments and NWA material is coherent, as seen in Fig. 14a (red crosses).

From Casa Parroquial, there are three reused ornaments that are proposed as parts of two headdresses, with four appendices: popm87, 84 and 86 (Fig. 9c). These finely made objects have straight and even edges that were ground and polished, as were their surfaces. Popm87 still preserves some of the original perforations, which were punched with a pointy tool, and the burrs were carefully flattened. The flattened burrs were certainly considered part of the decoration because they were left visible on the front side. An identical and complete headdress is reported in NWA (Goretti 2012, p. 169). It shares the same design and manufacturing techniques as popm87, including the perforation work (Fig. 15a). The only difference between the headdresses is the embossed decoration in the example from NWA. Considering the similitude between the ornaments from both areas, and the fact that headdresses in SPA often appear cut and modified, it is likely that these artefacts were imported from NWA and were modified, or repaired, in SPA. Another similar headdress, also ascribed to NWA, is reported in Copiapó (northern Chile); however, its shape is slightly different to popm87 and the headdress from NWA (Fig. 15b).

Likewise, pendants popm35 (Larache) and popm128 (site unknown) present technical and decorative traits that relate them to NWA. Technologically speaking, both pendants are finely made, being two of the finest items in SPA assemblage. Both pendants were carefully cut, ground and polished; polishing marks are very regular on both sides, producing a smooth and shiny surface. Most significant, however, are the perforations made by rotation, an infrequent technique observed heretofore only in two objects from NWA (from Tebenquiche and an unknown context, in Goretti 2012, Fig. 174). The two Argentinean examples using this technique were finely made too, employing great care, skill and dexterity, as were popm35 and 128 (Fig. 15c).

Popm35 is an undecorated part of a disc that was reused, and the perforations are part of the modification. Given the good quality of the modification, we proposed (see above) that popm35 arrived at SPA already modified. It is possible then that popm35 was made and modified in NWA. Regarding popm128's decoration, it has a Maltese cross-embossed in the centre and four dots on each side (Fig. 15d). This particular motif is identified in other pendants from NWA, such as the pendant from Pampa Grande, which is very similar to popm128 (Fig. 15e). As a motif, though, the Maltese cross is also recurrent in the iconography of Tiwanaku, being depicted in pottery, stone and metals from the period (Posnansky 1957, fig. LXXVAa; Young-Sánchez 2004, figs. 3.28, 6.36). Finally, the only llama-shaped pendant from SPA was found in Larache (Fig. 15f). Unfortunately, the pendant was not accessible for analysis but, from the available images, some technical traits are deduced, such as the fine surface and edge treatments. Considering that all similar llama-shaped pendants are in NWA (Ventura 1985; Tarragó et al. 2010), it is very likely that the pendant from Larache also came from NWA (Fig. 15f).

### Tiwanaku technology in SPA

To identify a potential Tiwanaku technology for gold and silver technology, we analysed seven objects from Tiwanaku and used published information of finds from the Lake Titicaca, the Island of the Sun and the Moon (Young-Sánchez 2004, Fig. 1.8; C. Delaere pers. comm. 2016), the San Sebastián treasure from Cochabamba (Money 1991), the offerings of the Pariti Island (Bennett 1936, figs. 30–31; Posnansky 1957) and the Kalasasaya grave goods (Money 1991; Korpisaari 2006, Fig. 5.29). Striking examples are also found in museums (Sagárnaga 1987; Korpisaari 2006; Guerra et al. 2019).

Overall, Tiwanaku objects are more sophisticated, complex and fine in their manufacture than objects from SPA or NWA. They used techniques rarely seen in other areas (Table 3), such as lavish decorations combining embossing, chasing, openwork and stone inlay (Money 1991; Korpisaari 2006); cutting complex shapes and intricate designs, the use of raising in at least 16 items (Bennett 1936; Money 1991; Fernández 2016; Guerra et al. 2019); and the wiggle cut and pointillism techniques to decorate (McCreight 1991, p. 22; Young-Sánchez 2004). Although some objects would be classified as coarsely made, the limitation with the Tiwanaku items is that most of them were looted and, usually, the most beautiful examples were kept in museums or private collections, producing an artificial bias by neglecting small, plain and ordinary gold objects.

Nevertheless, within SPA, an important group ($n = 38$, 22%) of gold ornaments made with Tiwanaku technology can be traced, tentatively, to the central Altiplano. They include three *keros* and three portrait vessels (popm136–141), six wire rings (popm103–105), two pendants (popm30, 67) and 24 conical bells (popm56–66, 98–102, 115–116, 145–147).

All these grave goods, except two, are from Larache; and their compositions are consistent with those of Bolivian and Tiwanaku objects (Fig. 14b).

There is a series of indications supporting an 'altiplanic' manufacture for the *keros* and portrait vessels. First, their style. The gold *keros* in SPA represent the classic Tiwanaku style with the hyperboloid form, flaring rims and *tori* as decoration. According to Janusek (2003, pp. 60–62), *keros*—commonly made in ceramic and wood, but also documented in metal and stone—are very standard in their design and dimensions, which are 16–20 cm in height and 12–18 cm in rim diameter. These are the same proportions seen in metallic *keros* from SPA (and from El Volcan, NWA, in Gatto 1946) being *ca*.17 cm in height and 15 cm in diameter. The style of the *tori* also replicates the forms seen in pottery: double, triple or two separated *tori*, such as those in popm136 and 140, or a single large, rounded torus such as popm139. Pottery *keros* were produced on a massive scale during the Tiwanaku IV and V periods (AD 500–800 and 800–1150, respectively) by highly trained specialists (Janusek 2003). Likewise, portrait vessels found in SPA are the metallic version of Tiwanaku portrait vessels made in pottery, wood and stone (Berenguer 2000, p. 91; Le Paige 1964, Fig. 127.2; Sagárnaga 2007, Fig. 1; see also vessel in Ethnologisches Museum, V.A.64570). Like the 'altiplanic' examples, portrait vessels in SPA include metallic and wooden items that are naturalistic representations of single individuals, portrayed with a characteristic circular hat. In SPA, in only one gold portrait vessel from Casa Parroquial, an individual was represented chewing coca—a feature common in pottery, stone or wooden vessels (Janusek 2003).

Secondly, the evidence of specialised production. (i) As previously proposed, at least two people were employing the same technological style in the shaping of the goblets from Larache. (ii) Raising is a complex and slow technique that needs specialised training, and a range of tools—such as hammers and stakes—of different shapes and dimensions, as well as moulds and other materials to decorate the vessels (Untracht 1975; Bray 1978; Carcedo et al. 2004; Hill and Putland 2014). (iii) Raising as a technique is common in the Titicaca basin, being represented by different vessels with varied shapes and sizes. (iv) *Keros* and portrait vessels, in particular, were highly valued ritual objects that followed relatively strict codes, reflected in standardised designs made by 'specialists intimately familiar with the hieratic iconography of Tiwanaku elites', as observed by Janusek (2003, pp. 60–61). Based on the above, it is reasonable to propose that *keros* and portrait vessels were made by a group of specialists or in workshops, where people are actively sharing techniques or are subjected to formal training, and where the 'correct way' of making a *kero* can be controlled and taught (Creese 2012; Wallaert 2012; Wendrich 2012b, a). Although no Tiwanaku metallurgical workshops have been found so far, this model agrees with evidence at the Tiwanaku urban centre—and other centres under Tiwanaku influence—where other craft specialists (e.g. potters, panpipes makers) were grouped in households and neighbourhoods (Janusek 1999). These conditions would promote communication and exchange of ideas, as would allow contact in practice, where different 'ways of doing' are learned and transferred (Wendrich 2012b, a). Furthermore, the composition of goblets popm136–137 made of pure gold, with silver under 10%, also supports an 'altiplanic' connection, given that gold of such purity is common in Tiwanaku objects, but heretofore rare in south Peru or NWA. The same workshop model would explain the manufacture of the wire rings from Larache. Identical wire rings, but made in bronze, have been excavated in Tiwanaku (Fig. 16a) and shaped with the same manufacture sequence observed in the wire rings of SPA (Lechtman 2003, Fig. 17.23–17.24; Lechtman and Macfarlane 2005). Interestingly, their making also identifies two individual artisans, both working within the same technological style.

The final connection with Tiwanaku is given by the decoration techniques and motifs used in *kero* popm140 from

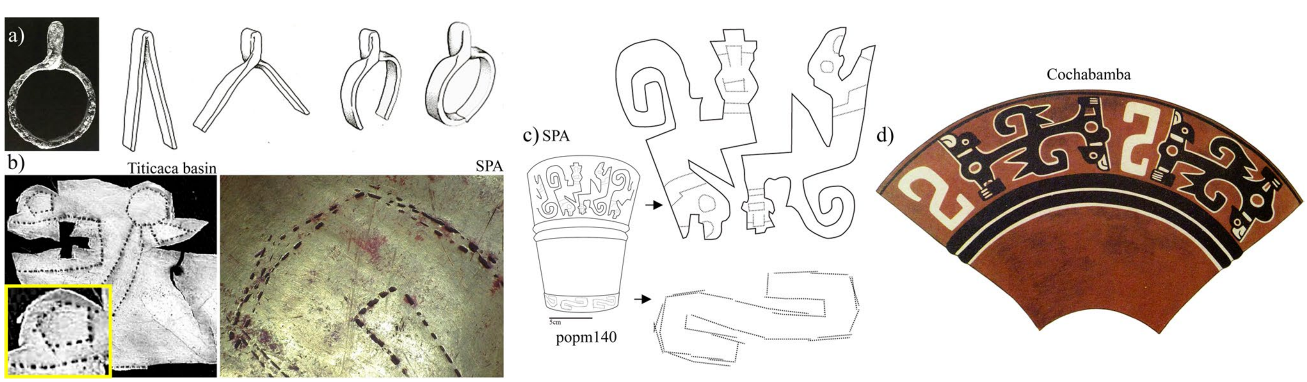


**Fig. 16** **a** Wire ring found in Tiwanaku and their forming sequence proposed by Lechtman (2003, Fig. 17.23–17.24). **b** Use of pointillism in a pendant from the Pariti Island (Titicaca basin; Korpisaari et al. 2012, Fig. 13) and *kero* popm140 (SPA). **c** Design in *kero* popm140 (SPA). **d** Design in a *kero* from Cochabamba (Posnansky 1957, fig. LI)

Casa Parroquial (Fig. 16c). First, the use of embossing and chasing to decorate the upper section of metallic *keros* is reported in a gold *kero* from Pariti Island (Bennett 1936, figs. 30–31), reflecting in both examples great expertise and skill. However, more relevant is the use of pointillism in popm140 (Fig. 16b), as this technique has been identified only in the central Altiplano and related to Tiwanaku objects (Korpisaari et al. 2012, p. 13). Second, the design represented in popm140 (the *condor*) is a recurrent Tiwanaku motif, usually seen in pottery and stonework. However, some particularities of the figure such as the curly tail, the spiky wing, the S volute at the bottom and the orientation of the figures alternating them up and down, are remarkably similar to a design reported by Posnansky in a *kero* from Cochabamba (Fig. 16d; from Posnansky 1957, fig. LIc). It is possible then that popm140 from Casa Parroquial was made with Tiwanaku techniques and style, but in Cochabamba, the same place where the San Sebastián Treasure was found.

Other objects that probably come from the Titicaca basin are the small raised conical bells; however, their assignation as Tiwanaku seems less consistent for the moment. As seen in the goblets, these bells were made by raising, a technology that was certainly employed and mastered in Tiwanaku. They are usually found in pairs or small groups, showing an internal consistency in their forming techniques and designs, suggesting that were made together by a single person. Still, designs vary amongst groups, indicating that several people were making bells (although the contemporaneity of the work is not clear at this point). Most of them are decorated with horizontal bands made by chasing or engraving. In SPA, there are two variants: a plain body ($n=1$) and a plain body with a neck ($n=5$). The variant with a neck is also found in San Jose, Humahuaca. These bells are relatively widespread across the SCA, but at a low frequency (one to four bells in seven sites: Caspana, Sud Lípez, Rinconada, Tabladitas, Cerro Morado, Huaira-Huasi, San Jose; Online Resource 8). The only exceptions are Larache in SPA with 21 bells (still, they may be 24 in total) and the Titicaca Basin with at least 40 bells (Fernández 2016; Guerra et al. 2019).

## Local metalwork

Within the 133 objects analysed, some stand out due to their fresh manufacturing marks (39%), suggesting that they were made shortly before their burial.[15] We argue here that these items are evidence of small-scale local metalwork. When compared, these artefacts can be grouped into two types of metalwork. The first group includes 28 (21%) imported objects that were intentionally modified, whereas the second group encompasses the 24 (18%) coarsely made ornaments from burials B.356, B.358 and B.359, whose production sequence and wear marks suggest that they were locally produced, i.e. shaped from an ingot and not modified.

### Local modifications

In the first case, modifications were made using basic mechanical techniques such as cutting and perforating. The presence of unusual and coarse technical solutions, such as folding and hammering in headbands popm17–18, would point to a preference for 'cold' or mechanical manufacturing techniques, as opposed to melting and casting to make new ornaments. For that task, basic knowledge of the mechanical properties of gold and how to operate chisels, burins and punches would be necessary.

Indications supporting the idea of the local origin of these modifications are: (i) the modification was applied to all types of objects, both finely and coarsely made, including objects from NWA and Tiwanaku, suggesting that local individuals modified whatever was arriving; (ii) the fact that most modified ornaments are deposited in groups showing identical modification marks. (iii) The ubiquity of these modified objects in most cemeteries included here (five out of seven) spanning the whole MP; and (iv) the local availability of the tools necessary to modify these artefacts such as chisels and burins (Cifuentes et al. 2018). In this case, perhaps, it was not essential to be a metalsmith to cut these items. Non-metallurgical specialists might have made this type of 'cut-and-punch' work—either people with basic crafting experience or artisans of other crafts, but with little or no experience in precious metals as material. Although these options are not mutually exclusive, we lean towards the second because, even if the techniques employed in those cases are described as 'coarse' compared to other gold objects, we would argue that the presence of guide marks, proportioned forms and some relatively complex designs (e.g. popm86, popm125) produced perfectly acceptable results, indicating planning, good aesthetic perception and experience in 'making things'.

As such, these modifications could represent evidence of the multi-crafting activities of SPA artisans, as proposed by DeMarrais for this type of cooperative and heterarchical societies (2013), where individuals engaged in a range of crafts, acquiring different and diverse skills. This means that craftspeople in SPA were able to work different materials and produce a range of different goods, similar to what is observed archaeologically in the Calchaquí Valley, Argentina (DeMarrais 2013) or in other living societies from North America (Spielmann 1998). In SPA, the presence of toolkits to produce different crafts (e.g. beads, weaving, woodwork, smelting) found in association with the same individuals in cemeteries such as Solcor, Coyo and Quitor would support

[15] Nonetheless, we cannot rule out the possibility that some items were made or modified elsewhere and kept with no use until their use as grave goods.

the idea of multi-crafting activities (Salazar et al. 2014; Horta and Faundes 2018). Especially in Quitor and Coyo, the considerable number of chisels, burins, punches, weaving kits, implements to make mineral beads, brushes and pigment cakes, amongst others, would point to Coyo's or Quitor's craftspeople as the probable candidates to modify imported gold and silver artefacts. It is noteworthy that local modifications of imported objects are also found in other supports. For instance, Horta (2012) argues that it was a common practice in SPA to modify wooden trays of Tiwanaku style by inlaying mineral beads in their borders. It would be interesting to look for more evidence of modifications in other materials and to explore whether the modifications were a cross-material tradition in SPA.

The possible reasons for these modifications will be discussed below; however, it is worth advancing here that, from an economic perspective the modification, reuse and cutting of finished objects may be connected to a shortage of raw material or finished objects (Gosselain 2000). At the same time, a local modification may give more value or resignify the meaning of these objects (Helms 1993; Spielmann 1998, 2002; Horta 2012), adapting them to local needs which, we claim, are closely related to the mortuary ritual.

### Local production

In the second group, the manufacturing features seen in the coarsely made artefacts of burials 356, 358 and 359 (Fig. 13a) would reflect the work of a small group of metalsmiths who produced three sets of ornaments. Given the specific compositions and the manufacturing features, the artisans would have been involved in different stages of production, from melting to finishing treatments, including forging and shaping, including as well as the modifications seen in objects from burial 358 (e.g. the portrait vessel's headdress). The similarity of ornaments between sets, the fresh manufacturing marks and the absence of traces of use, would point to a particular commission for the funerary ritual.

If this is the case, artisans would have required a specific place to work—such as a house or workshop—probably located in SPA. Their work, including melting and forging gold sheets, would denote a more complex skill-set, compared to the individuals modifying imported objects, which may reveal the existence of local metalwork specialists. Yet, the possibility that these items were acquired by trade, but used only and especially for the burial, cannot be ruled out conclusively.

Finding direct evidence in the form of tools or metallurgical remains with traces of gold production would be decisive in proving this point, but there is no evidence of this type in SPA heretofore. Still, in Coyo-3, there are two ceramics with compelling features (see Costa-Junqueira and Llagostera 1994, Fig. 6): small size, thick walls and closed shapes, very similar to crucibles used for melting in Europe, some of them interpreted as jeweller's implements given the small volume of metal produced (see examples in Tylecote 1982; Bayley and Rehren 2007; Eniosova and Rehren 2012). These ceramics have not been analysed yet; thus, future study should assess their use; for now, their involvement in gold or silver melting processes remains uncertain. Still, given the evidence for copper metallurgy in Coyo, Solor, Solcor and Sequitor, artisans from these *ayllus* would be potential candidates for this type of local work (Cifuentes 2014; Salazar et al. 2014; Cifuentes et al. 2018): craftspeople familiar with liquid metalwork, but not necessarily so with more delicate working and finishing techniques.

Lastly and regarding the gold used to locally make the ornaments from Larache, it is possible that the starting material consisted of some imported artefacts that were melted. A potential indication of this is given by the seven bells from B.Body2 (also from Larache) of Tiwanaku style, showing relatively high skill level and with evidence of use. On average, these bells have a composition of 2 wt%Cu and 27.3 wt%Ag, almost identical to the ornaments from B.359 with 1.8 wt%Cu and 27.4 wt%Ag (Online Resource 2). The elemental similitude between both bundles may be a coincidence, but it could also suggest that objects that arrived together were locally recycled or remelted, highlighting how the combination of chemical and technical analysis can reveal the complex biographies of these objects.

Building on the arguments above, we propose that most gold and silver objects were arriving at SPA as complete ornaments from different areas of the SCA, mainly the central Altiplano and NWA. However, often these were modified locally, probably by local artisans using mechanical or cold techniques, regardless of the artefacts' quality or origins. The coarsely made ornaments from burials 356, 358 and 359 would also suggest the existence of local, small-scale production, involving melting and hammering gold, which still would need further evidence to be confirmed.

### Local metalwork for the mortuary ritual

The local tradition identified above, recognisable by their fresh manufacturing marks, also indicates that part of the assemblage was created and modified specially for the burial. Objects acquired during the life of the individuals, used as ornaments on textiles or the body, as well as in drinking rituals or psychotropic consumption, are expected to present evidence of wear or usage marks such as damaged or torn perforations, repairs and worn edges and surfaces. Generally, a regular manipulation or use would delete and erode tool marks from the surface, as well as around the edges in an inconsistent manner (Perea and García-Vuelta 2012). Conversely, newly made objects with little or no use would present fresh and sharp features and manufacturing marks. It is assumed here that unused grave goods would have been made shortly before or especially for the burial (Perea et al. 2013, 2016; Martinón-Torres and Uribe Villegas 2015). Given the softness and malleability of gold, this seems a reasonable assumption. In SPA, a mix of used and newly made objects are present as grave goods. In particular, most of the assemblage (53%) shows wear or usage marks, indicating that they were used in life; while 39% are the locally modified and produced items described in the previous section, which were made specially as grave goods. The remaining 8% was unclassified.

It is possible then that the local goldwork was stimulated by the need of using these metals in the mortuary ritual. The relatively coarse quality of the local metalworkmay reflect the relatively low demand for these objects (used by a few individuals only), which would have employed the expertise of local artisans in particular situations or for specific commissions (who were not necessarily specialised metallurgists). Given that the raw material was limited, they would have utilised what was available, i.e. foreign finished ornaments. This model would be very similar to what Spielmann (1998, 2002) and DeMarrais (2013) define as 'ritual mode production', but on a very modest scale. These authors propose that in heterarchical societies, craft production can be developed to 'fulfil ritual obligations and create and sustain social relations' (Spielmann 2002, p. 197; see Legarra Herrero and Martinón-Torres 2021 for broadly similar phenomena in the Early Bronze Age goldwork in Crete). In those cases, particular artisans would create a moderate number of symbolic objects that would be used in ceremonies or as social markers.

Given the characteristics of SPA local goldwork, we interpret this precious metalwork as part of a ritual production. The ritual importance of gold and silver can be deduced from their active role in the mortuary ritual, both as objects present in the ritual, as well as objects especially made (or modified) for it. This symbolism could be rooted in their aesthetic qualities, chemical stability, their scarcity as raw material and their own histories, i.e. as objects that are moving from different areas (Lechtman 1993; Spielmann 2002; González 2004b; Nielsen 2007). Similarly, another local ritual production may be the production of wooden snuff-taking paraphernalia (Horta 2014), also considered highly symbolic (Llagostera et al. 1988; Torres 1998; Llagostera 2006b). Still, the presence of pendants modified in SPA with evidence of wear such as popm36 indicates that not all items were only used for the funerary ritual. Unfortunately, this type of object is difficult to identify and they can be easily missed out and, as such, they were probably more frequent than we estimated here.

## Conclusions

The comprehensive and scientific study of gold and silver offerings from SPA has provided useful insight into this understudied technology at a local and regional level. Overall, we have characterised one of the largest assemblages of gold (and silver) objects of the region, combining their elemental composition and manufacture technology, revealing the complex life histories of these offerings, which in many cases changed hands, shape and meaning through time.

At a local level, the variety of compositions, designs, types and qualities of the manufacturing traits indicate that most gold objects were imported to SPA as finished items. Nonetheless, our results point to a complicated and dynamic scenario for the MP: as expected, we were able to trace some objects to a Tiwanaku technology, indicating that part of the assemblage probably came from the central Altiplano or Titicaca Basin. However, we also identified a different tradition that suggests that part of the gold and silver objects would come from NWA, specifically connecting SPA with Humahuaca and Jujuy. Our results thus encourage further exploration of the connections with NWA, complementing previous analysis of copper objects, which identified a tin-bronze alloy that may come either from the Altiplano or NWA (Salazar et al. 2011, 2014; Cifuentes et al. 2018). Furthermore, our findings challenge previous interpretations that considered gold offerings in general as items used to demonstrate affiliation with Tiwanaku (Barón 2004; Tamblay 2004; Salazar et al. 2014). From now on, it will be necessary to analyse objects in more detail before assigning them Tiwanaku or another source.

We also recognised for the first time a local tradition that exploited the multi-crafting ability of SPA artisans. They modified some of the imported artefacts to fit local preference when needed, and possibly made some gold offerings in SPA. In both cases, we noted the fact that these modifications and new items were made especially for the burial, indicating that the mortuary ritual was a key factor to promote local goldwork not seen before or after the MP.

At a regional level, our study reveals that this 'sheet technology' is more complex than hitherto recognised, and its informative potential much greater. Combing thorough analyses of composition, manufacture, designs and use, it was possible to provide insight into particular technological traditions within the SCA. We proposed specific attributes for different areas that future research should complete and probably refine. Nevertheless, this research is the first step in considering gold and silver technology as a proxy to understand the circulation of materials and ideas within the region, but also how materiality and value were adjusted locally.

Furthermore, this research gives new information into the role and skill of pre-Hispanic gold workers. It was possible to propose that several craftspeople worked gold with different abilities and skill levels. The work of single individuals and groups of artisans was detected, giving the first insights into the organisation of goldwork production, at least in some of these areas. On the one hand, Tiwanaku style objects display traits that are consistent with the models of embedded or attached production identified in Tiwanaku urban centres (Costin 1991; Janusek 1999). On the other hand, the technological features of the items made in NWA and SPA are consistent with the work of independent non-specialists, working alone or in small groups at a household level, probably as part of a ritual mode of production.

Consistent with the data available, these proposals are a promising starting point to guide and encourage further research on the topic, ideally including mining and production sites, as well as experimental archaeology and consideration of other materials and crafts to obtain a holistic view of technology (e.g. Shimada and Craig 2013). As we have sought to demonstrate, using integrative approaches to interrogate a group of mainly modest artefacts can allow us to go beyond the overly generalising perspectives of gold as a status marker. Indeed, the gold from San Pedro denotes an affective dimension in the use of this metal through sharing by partition—a tradition that challenges received wisdom of gold as a commodity hoarded by just a few.

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**Availability of data and material** The archaeological collections from SPA can be accessed at the Museo R. P. Gustavo Le Paige s. j., San Pedro de Atacama. Sampling and analytical procedures, and data, are included in the paper and supplementary material. Upon request, M.T. Plaza is happy to provide further information.

## Declarations

**Ethics approval** Not applicable.

**Consent to participate** Not applicable.

**Consent for publication** The following institutions have authorised the publication of the photographs taken during her PhD by M.T. Plaza of the objects that belong to their collections: The Instituto de Investigaciones Arqueológicas y Museo R. P. Gustavo Le Paige s. j. (Fig. 2–3, 9–10, 12–13, 15); Archivo de la División Arqueología del Museo de La Plata, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, 2017 (object 50188 in Fig. 15e); Museo Etnográfico 'Juan B. Ambrosetti', Facultad de Filosofía y Letras, Universidad de Buenos Aires, Buenos Aires, Argentina (object 2277–(52–33) in Fig. 15c); Museo Chileno de Arte Precolombino (object 2731 in Fig. 15b). Figure 15f3 is courtesy of Beatriz Ventura 2020.

**Conflict of interest** The authors declare no competing interests.



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