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ORIGINAL PAPER

# A handheld XRF study of Late Horizon metal artifacts: implications for technological choices and political intervention in Copiapó, northern Chile

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**Abstract** A sample of 403 Late Horizon (~1400–1530 AD) metal artifacts from Copiapó in the Atacama Desert of northern Chile, consisting of at least 14 artifactual categories, were examined by a Niton pXRF analyzer for compositional information. The results revealed patterned use of different alloys in the Copiapó region, including a very strong, region-wide reliance on bronze alloys, with tin being a primary or secondary alloying element. The wide use of a non-local metal (tin) in the Copiapó region is interpreted as the result of the Inca Empire's political control over indigenous economic productive activities, despite the long distance to the empire's core area. However, arsenical bronzes featured local artifact typologies in a relatively large quantity during the same period, suggesting that the Incas' preference for bronzes alloyed with tin should have influenced but not fully changed the indigenous metallurgic traditions. This shows that the Inca state had powerful but not absolute control over metal resources in the Atacama Desert.

**Keywords** Inca empire · pXRF · Metal artifacts · Bronze · Atacama desert

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## Introduction

### Shift of metallurgical traditions in the Inca Andes: from arsenical to tin bronzes

For Incas, metals were one of the most important prestige objects distributed across the Inca Empire. Metals were firmly rooted in the Inca's religion and became an important medium to spread the imperial ideology (Lechtman 1985; Morris 1995; D'Altroy 2015). In the Andes, arsenical bronze was the first copper alloy to have been produced and used. With the rise of the Inca Empire around 1400 AD, tin bronzes were "suddenly" ubiquitous while arsenical bronzes seemed to be abandoned (or at least, greatly diminished their importance). Compared to arsenic that is very common in the Andean rocks and minerals, tin was a rare metal and probably can be obtained within only a few regions throughout the Andes, which allowed the Incas to establish and consolidate a greater political and economic power through their control over the production and use of tin-containing alloys. This phenomenon has been interpreted as "a political act" designed to control the artisanship and to consolidate Inca's ownership over the more important tin sources (Lechtman 1996:478). The shift from arsenical to tin bronzes is believed to have occurred at every level of the Inca administrative hierarchy in the Andes (Owen 2001; D'Altroy 2002, 2015; Lechtman 2007) and was closely related to a developing political economy based on a system of wealth finance, embodied by the production of portable prestige goods (c.f. D'Altroy and Earle 1985). Examples of Inca's ability to execute such control in metal production can be noticed everywhere across the Empire, in places as far as Mantaro Valley in Peru (Owen 2001), Calchaquí Valley in Argentina (Earle 1994), and Tarapacá Viejo in northern Chile (Zori et al. 2013).

The Incas did not invent tin bronze themselves. They probably learned to produce it by borrowing technological traditions that had been well established in the pre-Inca times in southern Bolivia and northwestern Argentina (Lechtman 1996; Lechtman and MacFarlane 2006). In pre-Inca Argentina, tin ores were easily obtainable, and tin bronze production was carried out in commoner domestic contexts, with no attached artisans or elite involvement during most of their cultural sequence (Gonzalez 2004; Angiorama 2005). In this region, evidence of elite control over metal production did not emerge until 1200 AD (for example, workshops discovered in Rincon Chico and associated to ritual platforms in Catamarca). In contrast, in the western side of the Andes (such as the Atacama region in northern Chile, the geographic focus of the present study), tin ores were very rare, and tin bronzes could only be made using tin from elsewhere or be obtained as final products via long-distance exchange (Lechtman and MacFarlane 2006; Salazar et al. 2011). In short, the Incas developed a much stronger interest in tin bronze mainly for its merits in shaping and maintaining a wealth-financed political economy. The Atacama Desert offers an opportunity to investigate the nature of Inca Empire's intervention into local craft production in the western side of Andes, especially when one considers the many collections of metal artifacts and the abundant evidence for mining and metallurgic production during the Late Horizon.

### Understanding alloy elements and alloy types from compositional analysis of Late Horizon metals: new data from northern Chile

Mining as a productive activity was greatly pursued by the Incas during their expansion into the Atacama Desert, Copiapó region, northern Chile, during the Late Horizon (~1400–1530 AD). It is believed that the Incas' strong interest in important mineral resources led them to their imperial expansion to the south. Hundreds of exploited mining sites were left along such a southward expansion (Raffino 1982). In El Abra, a copper mine close to the Loa river, technical studies on lithic hammers have suggested a certain level of specialization in mining during the Late Horizon (Salazar and Salinas 2008; Salinas et al. 2010), and central places for temporary storage and distribution of lapidary and metallurgical objects have been found at Catarpe, near the San Pedro de Atacama (Lynch and Núñez 1994; Núñez 2006). Moreover, numerous centralized Inca mining camps yielded evidence of regular state-sponsored feasting and rituals, which served as part of state reciprocity or "commensal politics" to ideologically involve local population in corvée labor for mining work (Salazar 2008; Salazar et al. 2013a, 2013b). Examples of Inca centralized mining/metallurgic sites in northern Chile include Infieles mining complex (Cantarutti 2013), Inkawasi-Abra (Salazar 2008; Salazar et al. 2013a, 2013b), Cerro Verde (Adán 1999; Castro et al. 2004, Varela 1999; Salazar et al. 2013b), Tarapacá Viejo (Zori et al. 2013), and Viña del Cerro (Niemeyer 1993; Castillo 1998). As Berthelot (1986) once stated in his ethnohistoric model, the Incas seemed to maintain a direct control over mining, which led to an impressive spatial concentration of large-scale mining activities. The well-preserved foundry at Viña del Cerro in Copiapó Valley, a copper smelting complex representing a typical Inca specialized production center and consisting of a plaza, a ceremonial platform (or *ushnu)*, and 26 smelters, is the best example of centralized, large-scale Inca controlled metal production in the Atacama region (Niemeyer 1986; Niemeyer 1993; Castillo 1998).

It has been clear that different mining activities were conducted quite intensively in the Atacama region to exploit ores for metallurgy and production of other important goods (such as lapidary and pigments). Metallurgical-related activities left rich material evidence including hundreds of Inca metal artifacts housed in regional museums. However, several issues still remain unclear as to the nature of interactions between the Inca Empire and the Atacama region, such as "did the Incas exercise their "selective intervention in artisanry" (D'Altroy 2002:303) in the Atacama region, as they did in other regions of the Andes? How was such intervention reflected in the production of metal artifacts? Were there alloy types that seemed to be compositionally standardized for specific artifact categories? How did metal artifacts (utilitarian or prestige) that were stylistically and functionally recognizable as "local" compare to those unique to the Inca Empire in their chemical compositions?" A compositional study of a large sample of metal artifacts of different forms and functions would help to find answers to these questions.

## Materials and methods

### Late Horizon artifacts from the Copiapó region, northern Chile

All the metal artifacts investigated in the present work came from the Copiapó Valley in northern Chile (Fig. 1). According to their shape, size, and (possible) function, these artifacts can be divided into at least 14 categories, including bracelets, tumis, axes, brass knuckles, earrings, chisels, circular plates, tweezers, rectangular plates, fishhooks, small bells, bars, needles, tupus, and rattles (Gutierrez 2012). Tumi knives, tupus, and bracelets are the most diagnostic Inca style metal artifacts. Other categories such as fishhooks, chisels, earrings, and bars are metal objects that were produced and used in both pre-Inca and Inca times in the Copiapó region. All metal artifacts to be investigated in the present work were chosen from the Museo Regional de Atacama, Museo Nacional de Historia

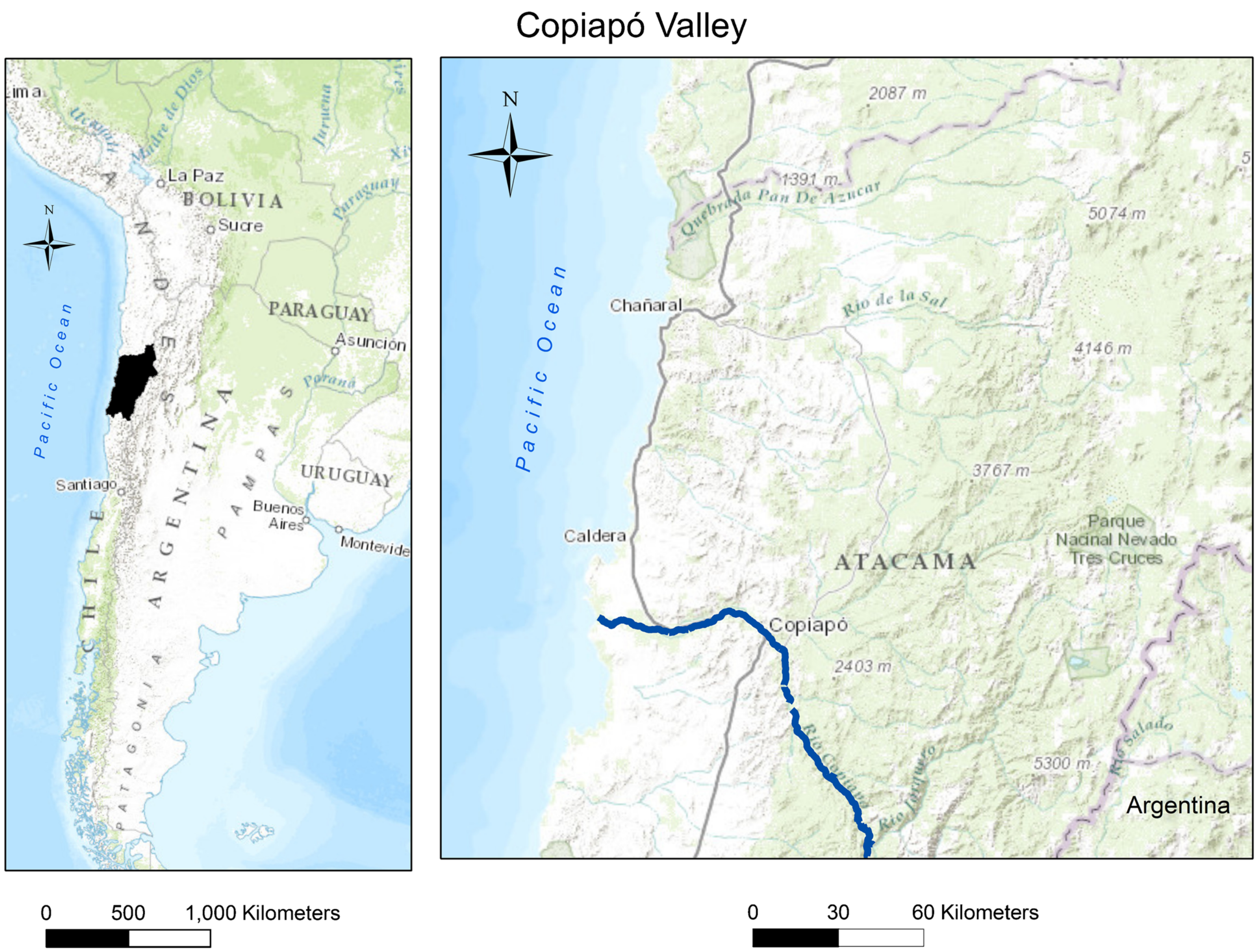



**Fig. 1** Locations of the Copiapó Valley in the Atacama Desert, Chile

Natural, and Museo de Historia Natural de Valparaiso (Fig. 2), and the sample size is 403 objects.

Most of the metal artifacts to be investigated (381 out of 403) were unearthed from cemeteries and graves from Caldera, a coast town in northern Chile, while the other 22 were excavated from other sites located in the middle and upper segments of Copiapó Valley. The metals were dated to the Late Horizon by diagnostic pottery and other burial offerings associated with them. The (detailed) archaeological context of these metals, however, was either undocumented or unavailable. For many of them, it remains unknown as to which burial they were unearthed from, whether they were associated with other artifacts (or not), and how many burials these metals represented. It is possible that some metal artifacts, although excavated from the Late Horizon cemeteries, were really produced in pre-Inca times and survived as "heirloom" pieces. However, the presence of a few metal artifacts that might pre-date the Inca times should not be a problem for this study, since our purpose is to understand the long-term and region-wide cultural and technological traditions and the changes introduced by the Incas. The 403 metal artifacts represent the largest collection of Late Horizon artifacts ever to be analytically investigated in northern Chile. Moreover, they represent an almost complete list of forms and functions of metal artifacts recognized for the Copiapó region.

## Compositional analysis by a Niton handheld XRF analyzer

The invention of handheld XRF (hhXRF) devices was an important step toward non-destructive compositional analysis of archaeological materials. Successful case studies worldwide have witnessed the effectiveness, reliability, and consistency that handheld pXRF analyzers can achieve in extracting compositional data out of archaeological ceramics, metals, glass objects, paintings, and so forth (Charalambous et al. 2014; Craig et al. 2007; Frankel and Webb 2012; Liritzis and Zacharias 2011; Martinón-Torres et al. 2014; Shackley 2010). There are still complaints about low accuracy and low precision by hhXRF analyzers (Orfanou and Rehren 2015). However, for certain research purposes (qualitative analysis in particular, for example: the patterned distribution


**Fig. 2** Fourteen categories that characterized the 403 investigated metal artifacts

of different identifiable compositional groups, the patterned use of different alloys, etc.), the compositional data generated by handheld XRF devices can be as meaningful and useful as those obtained by analytical approaches such as inductively coupled plasma atomic emission spectrometry and neutron activation analysis. The nearly non-destructive feature and low cost are two other characteristics that have made hhXRF popular in compositional studies, especially those that need to be done on site or in situ.

In this study, we used a handheld Thermo Scientific Niton XL3t 900s GOLDD++ XRF analyzer. The hhXRF analyzer is equipped with a 50-kV X-ray tube (tube specs: 50 kV, 100 μA, 2 W maximum), an Ag anode target excitation source, and a silicon drift detector (SDD) with active area of 5 mm$^2$ fitted with a polymer window (MOXTEK AP 3.3 film) which ensures superior X-ray transmission in the low-energy range down to Be Ka. The X-ray beam focal spot size is about 3 mm in diameter; that is, for each individual reading generated by this particular hhXRF analyzer, it provides compositional information across an area of about 7 mm$^2$ on the samples' surfaces. All spectra were acquired using a regular standard metal mode and with a 60-second total analysis time (Liu et al. 2012). The calibration of the instrument was done by the fundamental parameters (FP) method designed by the manufacturer (Niton).

While the hhXRF investigation was carrying out, some metal artifacts were noticed with signs of corrosion and patination. No tested metals were cut or sampled to avoid causing damage. Usually two or three readings were collected on different parts (cross-section and/or surfaces) of each analyzed sample that showed signs of corrosion and/or uneven surfaces. The chemical compositions obtained by collecting multiples readings on each sample do vary; however, the relative abundance or proportion of the few major detected elements (for instance, Cu, Sn, Pb, As, and Zn) remained quite similar. As our primary focus was to identify as accurately as possible the types of alloys that characterized the investigated metal objects and the patterned distribution of these alloys, such variability in compositional data is considered acceptable as long as the relative abundance of different detected major elements remains stable. In this regard, the detectable major and minor alloy elements (with concentrations of 0.01–100 % in weight percentage) should be good to reveal the alloy types and possible percentages of metal artifacts made from each identified alloy type. The identification of different alloy types was done by setting up some "threshold" values, a common practice in compositional analysis of ancient metals, for concentrations of elements that were considered as possible alloying elements. For example, arsenic (As), zinc (Zn), or lead (Pb) would not be considered as an alloying element (intentionally added alloy) if they were less than 1 % in metal artifacts; rather, there would a greater chance that they were introduced by arsenic-, zinc-, or lead-bearing ores coexisting with copper ores. On the other hand, they would be accepted as "alloying elements" if they were 1 % and higher. It has been suggested that copper alloys with 0.5 % or higher tin (Sn) should produce a significant improvement in mechanical property of final alloys (Lechtman 1996), indicating that even 0.5 % tin could refer to intentional addition behaviors. Therefore, we considered tin as an alloying element when its concentration is 0.5 % or higher in the tested metal artifacts.

## Results and discussion

The compositional analysis by handheld XRF analyzer revealed a great variability, in terms of both alloying elements and alloy types, in the 403 metal artifacts. Figure 3 shows the proportion of each identifiable alloy type in the total sample. Tin bronzes (including Cu-Sn bronzes and Cu-Sn-As bronzes) are very common, which account for 64 % of the total (403) analyzed metal artifacts. Arsenical (Cu-As) bronzes occur at the second highest frequency (20.8 %), followed by copper-silver alloys (9.2 %), and then by nearly pure copper (2.5 %). These proportions are by no means the most accurate estimates that can be generalized about Late Horizon metal artifacts in the Copiapó Valley; however, they do help us get some sense of technological choices and traditions that featured the Inca metallurgy in this region. For example, tin as an alloying element was more emphasized than arsenic in the Copiapó region despite being a foreign metal. Of the 403 metal artifacts, 262 had tin as a primary or secondary alloying element, in contrast to 88 which had arsenic as primary alloying element. The clear preference for tin suggests that the Incas' technological choice (for tin over arsenic) was indeed introduced into the Copiapó region (southern Andes) and strongly influenced local metallurgical activities. Furthermore, tin bronzes were not produced into certain types of metal artifacts to meet needs of some particular physical and mechanical properties, but into almost all types of metal artifacts. Lastly, from a material science perspective, while tin bronze and arsenic bronze overlap in most of their mechanical behavior, arsenic bronze is highly ductile even at extreme levels of deformation (Lechtman 1996). If the selection of alloys were purely based on mechanical properties, we would expect that artifacts such as tweezers were made more likely by arsenical bronze than by tin bronze. However, that was not the case in our sample, as we will present in the following discussion.

Some other interesting findings can be noticed in Fig. 4. For instance, nine out of 14 artifact categories represent the most abundant subsample with 13 to 85 artifacts being assigned for each category. Taking the 344 artifacts from these nine categories as a subset of data, we find out that the patterned use of different alloys in the production of metals remained the same. Additionally, the great variability of alloy types still persisted, and the high/low relations stayed quite steady among percentages of metal artifacts made from different alloys: (1) arsenical bronzes were noticed in all artifact categories but tumi knives; (2) categories such as fishhooks and plates showed a higher chemical variability but still relied heavily on tin bronzes; (3) 67.7 % of the 344 artifacts were made from tin bronzes while 21.5 % of them were made from arsenical bronzes. Copper-based silver alloys accounted for 5.2 % of the 344 analyzed artifacts, while those made from nearly pure copper represent only a 2.9 %; and (4) metals other than tin and arsenic, such as lead (Pb) and zinc (Zn), were also noticed in some artifacts. However, they should not be considered a common practice, because they were too low in frequency and concentration.

A more statistical approach to present (or test) the patterned use of different alloys for Late Horizon metal artifact (as described in Figs. 3 and 4) can be done by assigning a certain confidence level (a 95 % confidence level was chosen here) to percentages estimated for metal artifacts made from different alloys in each artifact category. The results are shown in Fig. 5, from which one can see clearly that, on average, more than 60 % of the tweezers, fishhooks, earrings, chisels, plates, and tumi knives were made from tin bronzes, while 25 % of them or less were made from arsenical bronze. We can be

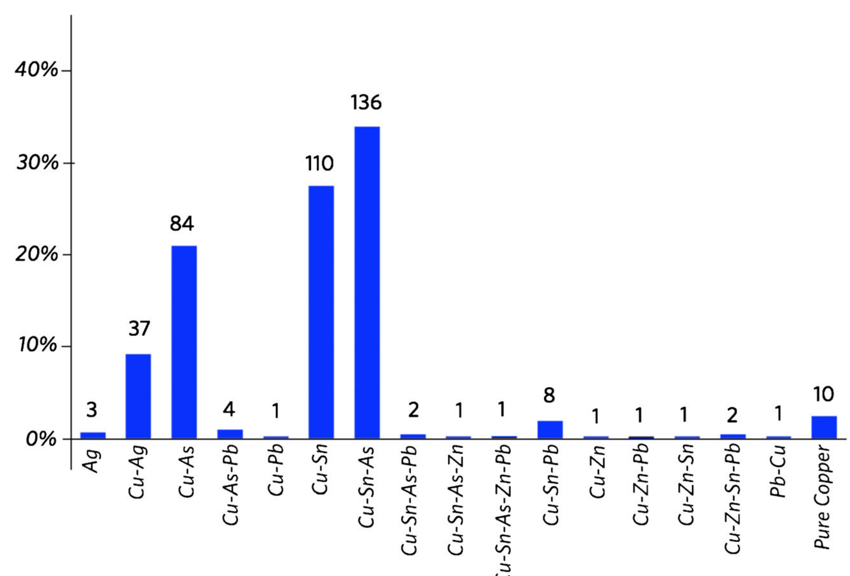
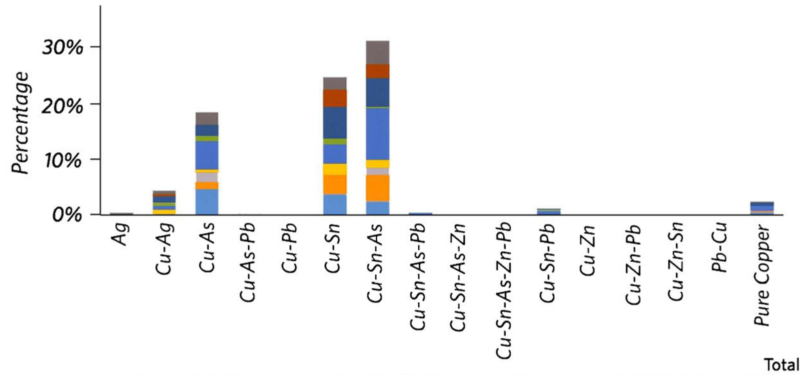



**Fig. 3** Counts and percentages of metal artifacts of different alloy types




| | Ag | Cu-Ag | Cu-As | Cu-As-Pb | Cu-Pb | Cu-Sn | Cu-Sn-As | Cu-Sn-As-Pb | Cu-Sn-As-Zn | Cu-Sn-As-Zn-Pb | Cu-Sn-Pb | Cu-Zn | Cu-Zn-Pb | Cu-Zn-Sn | Pb-Cu | Pure Copper | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tweezer | 2 | 3 | 9 | | | 9 | 17 | | | | | | 1 | | | 1 | 42 |
| Tumi knife | | 1 | | | | 12 | 10 | | | | | | | | | | 23 |
| Plate | | 5 | 8 | | | 23 | 20 | | 1 | 1 | 1 | | | | | 2 | 61 |
| Needle | | 2 | 4 | | 1 | 4 | 1 | | | | 1 | | | | | | 13 |
| Fishhook | | 3 | 20 | | | 14 | 37 | 2 | | | 2 | 1 | 1 | 1 | | 4 | 85 |
| Earring | | 3 | 2 | | | 8 | 6 | | | | | | | | | | 19 |
| Cone | | | 7 | 2 | | | 5 | | | | | | | | | | 14 |
| Chisel | | | 5 | | | 14 | 19 | | | | | | | | | 1 | 39 |
| Bar | | 1 | 19 | | | 15 | 10 | | | | 1 | | | | 1 | 2 | 49 |

**Fig. 4** Alloy percentages for the nine most abundant artifact categories

95 % confident that there was a strong preference to tin bronzes than to arsenical bronzes in producing/using metal artifacts of these five categories. Tumi knives, as a diagnostic artifact of the Inca Empire, were made nearly exclusively from tin bronzes, with only one exception (a copper-silver alloy). Such a strong preference to tin alloys can be seen as direct evidence for the Inca Empire's control and influence over metallurgical production and distribution of metal artifacts thousands of miles away. In the case of bracelets, four artifacts were also produced entirely from tin bronze. With regard to tupus, six of the eight analyzed specimens were alloyed with silver, one with tin, and yet another one with arsenic. Tupus are also a diagnostic item of the Inca expansion, and their preference for silver indicates their special status as prestige goods. The differences among percentages of cones and needles made from tin or arsenical bronzes were less clearly seen at a 95 % confidence level, possibly due to the smaller sample size (14 and 13 artifacts, respectively). As for bars, they were made from both tin and arsenical bronzes, without a clear, statistically significant preference for either of them.

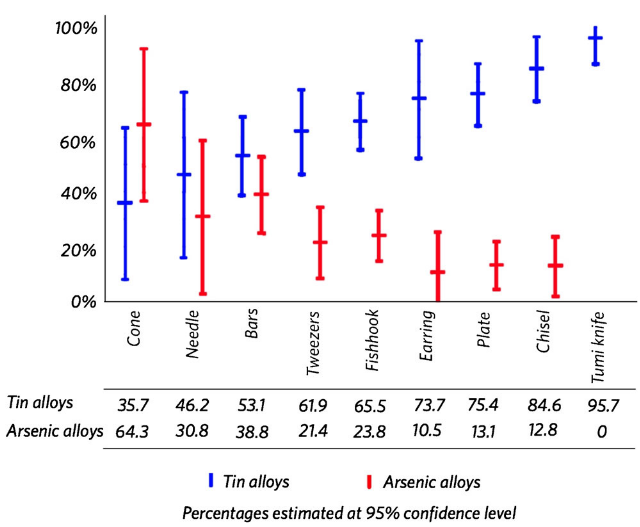



**Fig. 5** Percentages of metal artifacts made from tin or arsenic bronzes. (Estimated at 95 % confidence level, $p = 0.05$)

As for arsenical bronzes that were the second most common alloy, it remains uncertain whether they were produced by metalsmiths living in the Copiapó region or produced somewhere else. Besides the presence of the aforementioned but not well-studied Inca foundry of Viña del Cerro in the upper Copiapó Valley, archaeological discoveries of metallurgic workshops are missing in the region. However, artifacts such as brass knuckles, which were produced/used in the Copiapó region and northwest of Argentina but not yet reported for the Central Andes, suggests some local technological traditions at a smaller regional scale. To take this assumption one step further, we can argue that artifacts produced into a non-Inca style reflect a technological continuity by metalsmiths from smaller polities to serve their own needs.

It has been recognized that the Incas had developed a series of strategies to maintain their power of control over conquered territories, which included resettlement, kinship alliances, militarism, intervention in local economies, sponsored feastings, and re-creation of ritual spaces (e.g., Bauer 2004; Bauer and Covey 2002; Covey 2006; D'Altroy 2002; D'Altroy et al. 2007; Julien 2004, 2012; Morris 1995, 1998; Stanish 1997, 2007). Prestige goods (such as tin bronzes in the Copiapó region), then, could serve as a perfect medium to express political favors (D'Altroy and Earle 1985). Incas strongly depended on intermediate elites to manage conquered provinces (Elson and Covey 2006; Morris and Covey 2006), and they could have made use of their political advantages to acquire metals artifacts. To summarize, the coexistence of Inca Empire's technological choices (production of tin bronzes) and more local metallurgical traditions (production of arsenical bronzes) suggests a metallurgy system strongly influenced but not fully controlled by the Inca Empire in the Copiapó region, which leaves room for local alternatives for prestige and utilitarian goods.

## Conclusion

The pXRF analysis of 403 Late Horizon artifacts has clearly shown the diverse technological choices in producing/using metals in the Copiapó region, which highly focused on tin bronzes and less on arsenical bronzes and bronzes alloyed with other metals. Based on the compositional results, we argue that the Incas' preference to tin bronzes exerted a strong influence on metallurgical activities in the Copiapó Valley. However, such a preference did not lead to a complete abandonment of local metallurgical traditions. Tin bronze coexisted with arsenical bronze, but the former clearly acquired a dominating role in the production and use of metal artifacts in the region during the Late Horizon. For this particular reason, we strongly believe that the argument that arsenical bronzes were completely replaced by tin bronzes throughout the Andes (c.f. D'Altroy 2002, 2015; Lechtman 1996; Lechtman 2007; Gonzalez 2004; Earle 1994) does not fit the situation in the Copiapó region. Similar to what has been proposed for other provinces such as the Mantaro Valley (D'Altroy 2015), our findings suggest that it was more likely that the Incas intervened in local metallurgic artisanship by incorporating tin bronzes into local technological traditions, but they did not replace and control them completely. The existence of local metallurgical traditions and the manufacturing of arsenical bronzes possibly carried out beyond the Inca's control altogether argue for the partial retention of control over productive means by local artisans. The emphasis in utilitarian items (such as fishhooks), which were not rooted into the Inca political-ideological system, also supports such an observation (Latorre and López 2011, Salazar et al. 2010, Gutierrez 2012). To summarize, the Inca state had powerful control over metal resources, but their control was not absolute, especially as far from Cuzco as the Atacama Desert is.

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