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Abandoning arsenic? - Technological and cultural changes in the Mantaro Valley, Perú

ANIKO BEZUR
DEPARTMENT OF MATERIALS, SCIENCE AND ENGINEERING
UNIVERSITY OF ARIZONA

BRUCE OWEN
SONOMA STATE UNIVERSITY

Abstract: The copper artifacts excavated by the Upper Mantaro Archaeological Research Project (UMARP) demonstrate that arsenical copper was steadily replaced by tin bronze after the Inca invasion of the Mantaro Valley. This paper discusses some of the technological issues involved in the switch from one alloy to the other and explores possible social and political forces behind the change.

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Resumen: Los artefactos de cobre excavados por el Proyecto Arqueológico del Alto Alto de Mantaro (UMARP) en el Perú muestran que el bronce arsenical fue uniformemente reemplazado por bronce estañífero luego de la invasión inca del valle del Mantaro. Los objetos del primer período estudia-do (1000 a 1350 d.C.) son esencialmente de cobre. En el segundo período (1350 a 1450 d.C.) se observa el uso de arsénico, aunque en porcentajes menores de los esperados para modificar las propiedades del metal. Tras la conquista inca (1450 a 1533 d.C.) persiste el uso de cobre pero aparecen piezas que contienen estaño en porcentajes que modifican sus características (agujas más delgadas y largas, bordes más cortantes, *tupus* brillantes, piezas mejor fundidas) sin que sea notoria su utilización como bienes de prestigio.

The Upper Mantaro Valley lies in the central highlands of Perú. Researchers of the Upper Mantaro Archaeological Research Project (UMARP) surveyed sites at altitudes ranging from 3100 meters on the valley bottom to 3900 meters on rolling uplands. The research was designed to evaluate theories regarding social, political, and economic

changes experienced by Late Intermediate Period Xauxa chiefdoms upon their incorporation into the Inca state around AD 1450, and the strategies of the Inca state to integrate the Xauxa chiefdoms into its expanding imperial system. To achieve these goals, UMARP collected statistically comparable quantitative data from "commoner" and "elite" households of the Inca and the immediately pre-Inca periods. Elite and commoner contexts were established by architectural criteria and subsequently confirmed in almost every case by differential distributions of many categories of goods. These included decorated and imported ceramics, preferred diets indicated by animal bone, shell artifacts and artifacts made of copper, silver, and lead (Costin and Earle 1989; D'Altroy 1992; D'Altroy and Earle 1985; Owen 1986). UMARP defined two pre-Inca periods: Wanka I (AD 1000-1350) and Wanka II (AD 1350-1450). The period of Inca rule was designated as Wanka III (AD 1450-1533) and Wanka IV refers to the beginning of the colonial occupation. In Wanka I, small agricultural and pastoral settlements were dispersed from valley bottoms to higher elevation hilltops. During Wanka II, settlements tended to be larger, and located on higher, more defensible hilltops. Many sites were fortified, corroborating early historical accounts of widespread conflict during this period. The Inca conquered and pacified the region in Wanka III, resettling much of the population to smaller, valley bottom communities more suited to intensive maize production and imperial control (Costin and Earle 1989; D'Altroy 1992; Earle 1987; Earle et al. 1980).

Owen has compared the distribution of metal goods before and after the Inca conquest in contexts established as elite and commoner. He found that before the Inca conquest metal goods were present predominantly in elite contexts and were relatively rare. After the Inca conquest, the overall amount of metal goods in circulation increased and differences between their distribution in elite and commoner contexts decreased. Similar patterns were observed for shell and ceramic objects, suggesting that incorporation into the Inca state was accompanied by a democratization of access to a variety of valued status goods. The presence of few Inca-style cast tin bronze objects in elite contexts after the Inca conquest may indicate that the Xauxa elite now needed new kinds of metal objects to serve as material symbols of status or power. Since access to Inca-style cast objects was probably through state channels, the Xauxa elite were probably becoming more dependent upon the Inca for legitimation of their status. At the same time, objects with traced or graved decoration began to appear in elite households, with designs in a new, local style. Since Xauxa elite may have been able to control the production of these locally-made objects, they may reflect an effort by the elite to develop their own metal symbols of status, access to which would have been independent of the Inca state (D'Altroy 1992; Owen 1986).

Owen drew his conclusions primarily on the basis of visual characteristics and distributional information, although he did have access to some compositional information. To find further support for his hypotheses and

to be able assess technological changes between pre-Inca and Inca contexts a technical study of the copper objects is being carried out. A preliminary study of the composition and structure of the copper and copper alloy objects excavated by the UMARP was conducted at the Museum Services laboratory of the Getty Conservation Institute, Los Angeles, in 1995-96. The objects were examined by x-ray fluorescence spectroscopy (XRF) to establish whether they contained arsenic, tin, lead, iron, silver or any other metal in addition to copper.[1] The analyses did not require the sampling of objects and were therefore carried out on all objects. Objects designated as fragments or lugs were sampled for inductively coupled plasma - optical emission spectroscopy (ICP-OES).[2] This destructive analytical technique yielded weight percent elemental compositions which were normalized to 100% to allow comparison between objects. The trends observed in the data acquired by the two methods are identical and are outlined in this paper. Issues regarding compositional changes in copper and bronze objects.

Heather Lechtman has studied the connection between the expansion of the Inca empire and the availability and use of tin in places far removed from potential tin sources in northern Bolivia (1975; 1980; 1984). In order to evaluate this "tin bronze horizon" it is necessary to be able to compare objects that are from securely assigned pre-Inca and Inca contexts from the same region. UMARP offers just this, as research design from the very beginning emphasized the clear separation of pre-Inca and Inca contexts as well as the collection of statistically comparable data from each type of

1 XRF was carried out at at the Getty Conservation Institute with a Kevex 0750A Spectrometer in air using a barium-strontium secondary target at an accelerating voltage of 50 kV, 3.3 mA, and acquisition times of 240s.

2 ICP-OES was carried out at the Technical University of Budapest with the help of Dr. László Bezúr. Clean metal samples were removed from objects either by using a drill or a fine-toothed jeweler's saw. 15-30 mg of the sample was measured into a polyethylene tube (12 ml). To this 1 ml of nitric acid (70 % by weight, Merck Selectipur) was added and then 1 ml of tartaric acid solution (10 % by weight, Reanal analytical grade). Dissolution of the sample was aided by heating at 70 °C for 30 minutes in a block heater. Then the solutions were allowed to cool to room temperature and diluted to a total mass of around 10 g. The final volume of the solutions was calculated from the mass and the specific gravity of the solution. The instrument used was a Labtest Plasmalab ICP Spectrometer with a 40 channel vacuum polychromator. Calibration was done using matrix matched multielement standard solutions and reference materials were used to test the method described above. The samples were introduced by a Gilson Minipuls pump and were nebulized by a GMK V-nebulizer. The following parameters were used:

Plasma (Ar-Ar):	27.12 Mhz
Power:	1.3 kW
Outer argon flow rate:	11 l/min
Intermediate argon flow rate:	1.2 l/min
Inner argon flow rate:	0.8 l/min
Observation height:	13 mm
Sample flow rate:	3 ml/min
Integration time:	5 s

context. Furthermore, excavations concentrated on representative domestic sites as opposed to unique, special-purpose administrative or religious site. Very few collections satisfy these prerequisites for research on technological change; in fact the UMARP collection may be unique in this respect. This collection allows us to address four questions:

1. Was tin bronze really absent before the Inca conquest?
2. How prevalent was the new tin bronze technology after the Inca conquest?
3. How was tin incorporated to produce bronze?
4. What were some technical and ideological reasons for the adoption of tin bronzes?

Arsenic and tin alloys of copper before the Inca conquest

Objects from Wanka I (AD 1000-1350) contain little or trace arsenic, and undetectable or trace amounts of the other possible alloying element, tin. The objects may be regarded as having been made of copper with trace contaminants (Pb, Fe, S, As, Ag). None of the objects found in Wanka II (AD 1350-1450), the immediately pre-Inca period, contained more than a trace amount of tin. On the other hand, the average arsenic content of the objects is 1.5 weight percent. About half of the objects contain less than 1.5 weight percent arsenic (see Figure 1). According to Budd and Ottaway (Budd 1990; Budd and Ottaway 1989), below this concentration the presence of arsenic does not appear to improve the work hardenability of copper. Northover (1989) puts the mark slightly higher, at 2 weight percent arsenic. The objects analyzed were predominantly needles or fragments of needles. It is equally likely for a needle to have more or less than 1.5 weight percent arsenic. The question is whether the Xauxa understood and exploited arsenical copper for its hardness. The evidence at this point is equivocal. They might have been ignorant of the advantages of arsenical copper, or they might have recognized them, but been unable to control the arsenic content. The situation is further complicated if one allows for the possible reuse and recycling of metals, since each melting operation could cause any initial arsenic content to decrease, regardless of the intentional nature of its incorporation in the first place.

Another reason for the deliberate use of copper-arsenic alloys may have been to take advantage of the formation of a silvery surface due to macrosegregation. Budd and Ottaway (1989) have observed change in the color of chill cast ingots with 4 weight percent or more arsenic. Currently there is no information on whether observable macrosegregation will take place in cast objects with less than 4 weight percent arsenic and a much smaller volume-to-surface area ratio than the ingots used in prior experiments.

It is clear that tin bronzes were not present in contexts preceding the Inca occupation of the Mantaro valley. Instead, copper based artifacts were made

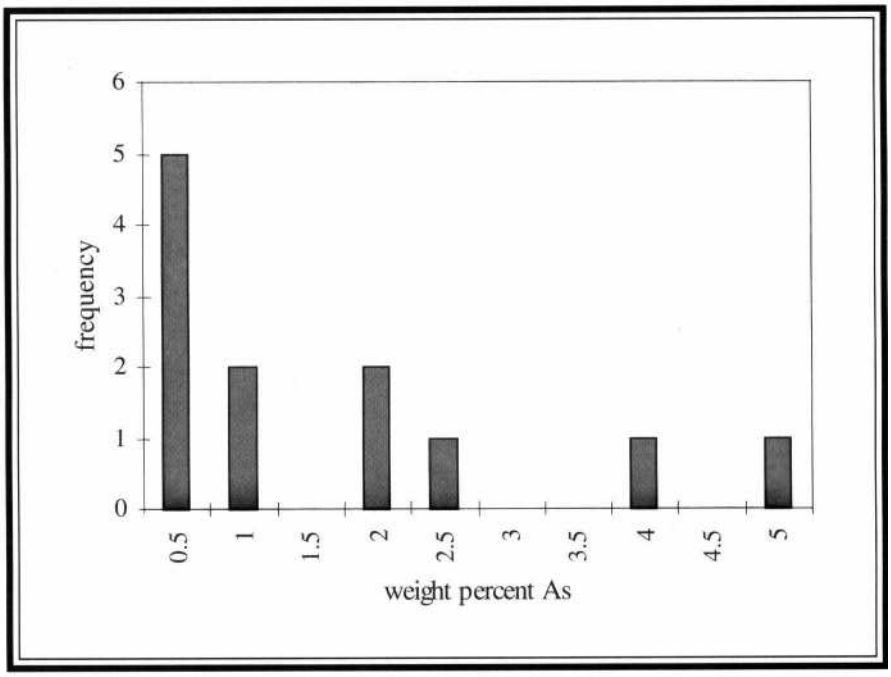


Figure 1: Arsenic content of Wanka II objects analysed by ICP-ES

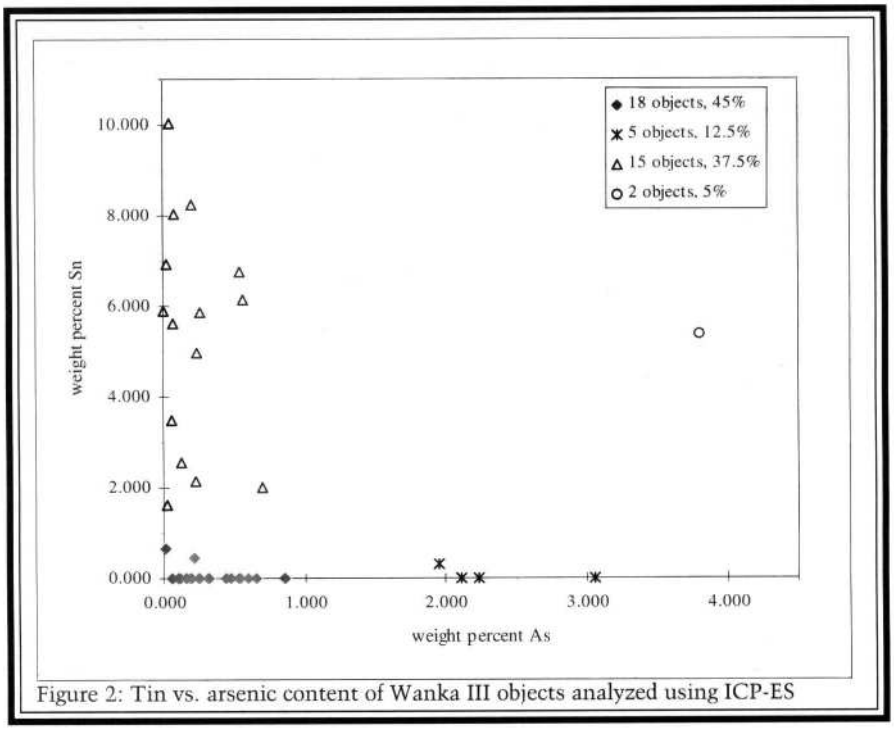


Figure 2: Tin vs. arsenic content of Wanka III objects analyzed using ICP-ES

of relatively pure copper or arsenic containing copper. At this point the evidence for the intentional incorporation of arsenic into copper is scant and it is likely that the presence of arsenic was due to its inclusion in or with the ores and fluxes used in smelting.

Tin bronze technology in Inca contexts

The average arsenic content of all objects from the Inca period (Wanka III), including both arsenical coppers and tin bronzes is 1 weight percent, compared to the 1.5 weight percent of pre-Inca objects. On the other hand, the average tin content of all Inca period objects is 3 weight percent. Almost half of the objects contain less than 1.5 weight percent arsenic and less than 1 weight percent tin (see Figure 2).

A further 12.5 percent of the objects contain less than 1 percent tin but more than 1.5 percent arsenic. All but one object in this group is an ingot, and may or may not have been the product of intentional alloying. Either way, a significant 57.5 percent of objects contain virtually no tin and represent the persistence of the products of local or regional pre-Inca technology. There are several possible explanations for this persistence of tinless copper. One possibility is that pre-Inca metal smelting technologies continued to be used after the Inca conquest of the region. Another is that objects manufactured prior to the Inca conquest continued to be used, and were eventually deposited in Wanka III contexts together with later, tin-containing artifacts made under the Inca.

Under 40 percent of Wanka III copper objects analyzed contained enough tin to perceptibly alter their properties. In the subsequent Spanish colonial Wanka IV period, however, over 80 percent of the analyzed objects contained enough tin to affect their properties. Thus the period of Inca occupation appears to be one of technological transition. The nature of transition is hard to determine because one cannot necessarily consider that all objects found in a certain context were manufactured in the period of deposition. One of the following three scenarios may characterize the technological transition:

1.The transition was a gradual matter of changing preferences, taking place as the Inca established systems of distribution capable of providing tin from distant sources, and as local metalworkers independently adopted new and additional procedures.

2.The transition was relatively fast, perhaps due to clear advantages attributed to tin alloys, but the curation and/or recycling of earlier objects obscures the rapid adoption of the new technology.

3.The transition was essentially instantaneous, as might be expected if the Inca state imposed technological norms or took

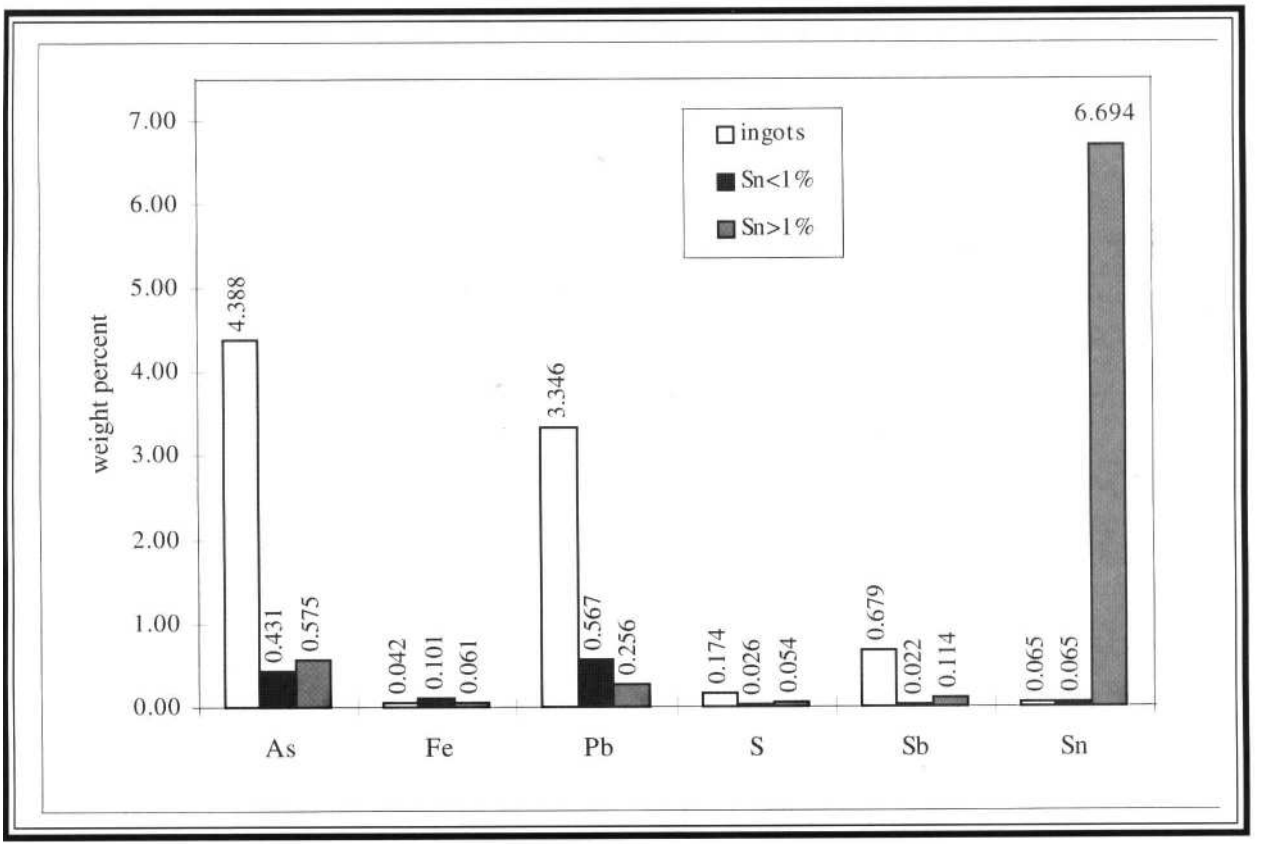
control of some or all metal production, but once again, the change is disguised in the archaeological record by curation and/or recycling.

Although the nature of the transition at this point is still uncertain, it has been demonstrated that in the Mantaro, the adoption of copper-tin alloys clearly began during the Inca occupation. Nevertheless, a sizable proportion of copper based objects without tin were also in use under the Inca, even if they were not necessarily all made during this time.

The production of tin bronze

The comparison of the compositions of ingots with objects that have less than and more than 1 weight percent tin gives us some clues as to the manufacture of tin bronzes (see Figure 3). The arsenic, lead, and antimony content of ingots is significantly greater than that of worked pieces and

Figure 3: Comparison of average composition for Wanka III ingots and worked objects



fragments whether or not they contain tin. If we assume that the ingots examined represented an early stage in the manufacture of the objects, then the decrease in the concentration of arsenic, lead, and antimony may suggest a manufacturing step wherein the ingots were melted in an oxidizing atmosphere and cast into rough blanks with were then further worked and annealed. McKerrell and Tylecote (1972) have documented the loss of arsenic under such conditions. Lead and antimony would also easily become oxidized and removed from the molten copper by forming a slag with the crucible material (Craddock 1995, 202-203). The fact that none of the ingots contain tin suggests that tin bronze did not circulate as a raw material. One possibility is that tin metal or ore was exchanged, and tin bronze objects were prepared locally by procuring tin and adding it to molten ingots of copper or arsenic containing copper. Another possibility is that tin bronze objects were not made locally at all, and arrived in the region as finished artifacts.

Technical and ideological reasons for the adoption of tin bronzes

Why were tin bronzes so thoroughly adopted in the Mantaro? One possibility is that tin bronzes were noticeably better than tinless alloys in some way. As discussed earlier, less than 1.5 weight percent arsenic in copper does not appear to offer advantages over the use of pure copper. If alloying with arsenic was in fact practiced in the Mantaro valley, then the process was not consistent. In contrast, the addition of tin to molten copper would afford metalworkers greater control over the alloying process. This argument that using tin bronze afforded metalworkers more consistent alloy composition and hence was preferred by the metal producers makes sense only if metalworkers actually took advantage of the properties of tin bronzes. The specific uses of tin bronzes does seem to suggest that metalworkers exploited the advantages of the new material. Needles that contain tin are generally longer or thinner with a sharper point than unalloyed needles. The tin content would have facilitated the fabrication of sharper points that dulled less than their copper counterparts. Furthermore, the tin content would have made long needles less likely to deform under stress. The exploitation of the superior hardness of tin bronzes is perhaps best demonstrated by edge tools. Only three such objects have been found in Inca contexts: two chisels and an ax. They all contain tin and their edges are work hardened. The ability of tin bronzes to take on and retain a reflective surface appears to have been used in the manufacture of tupu pins worn by women. The addition of tin lowers the melting point of copper and improves its casting behavior. Since the only cast objects were found in Inca contexts, and they all contain tin, it is likely that the above properties of tin bronzes were indeed exploited in the making of cast objects. In summary, it is very likely that the properties afforded by tin bronzes were recognized and exploited for both worked and cast objects. We are unsure

whether the toxicity of arsenic was a factor in abandoning the manufacture of arsenical copper pieces.

The use of tin bronzes for prestige purposes presupposes knowledge of, exploitation of, and preference for its mechanical properties or the formal characteristics that those properties make possible. Some of our material evidence supports the existence of this knowledge and these preferences. For a given type of artifact to function as a prestige good, access to that type of artifact must also be at least somewhat restricted. Owen found precisely this sort of preferential elite access to silver objects, and to a lesser extent to copper-based objects in general (1986). The question now is whether there is a similar pattern of preferential elite access to objects that contain tin, as compared to copper-based objects that do not. Fortunately, the UMARP data set allows us to evaluate this. In Wanka III contexts 33 percent of commoner objects as opposed to 50 percent of elite objects contains more than 1 weight percent tin. However, with our small sample sizes, the difference between 33 and 50 percent is not statistically significant. These data indicate that the elite may have had somewhat more access to tin bronzes, but the degree of preferential access to tin bronzes enjoyed by the elite, if it existed at all, was minimal in comparison to their greater access to silver and to copper objects in general. This suggests that tin bronze, as a material in contrast to other copper alloys, was not particularly preferred for purposes of prestige or status legitimation.

Tin bronze technology was clearly introduced into the Mantaro valley by the Inca. Either it was adopted gradually, coexisting with copper and arsenical copper production for a transition period, or a large number of old, pre-Inca and pre-tin objects continued in circulation. In either case, the copper based objects of all types in use under the Inca included both tin bronzes and copper materials without tin, diluting any practical effect of the technological change. It appears that the properties of the new tin bronze materials were known and exploited. However, the lack of distributional differences so far indicate that as a prestige good, tin bronze was not valued significantly more highly than copper or arsenical copper.

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