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Depletion gilding, innovation and life-histories: the changing colours of Nahuange metalwork

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*The technique of depletion gilding is well evidenced in pre-Columbian Andean gold work. Artefacts from the Nahuange period in Colombia (*c*. AD 100–1000) were subject to metallographic, chemical and microscopic analyses to provide regional comparative data on metalworking traditions. Results suggest that depletion gilding may have been an accidental discovery and, contrary to widespread assumptions, not always a desirable feature. This research illustrates how technological innovation may not always be immediately adopted, and considers how the life-history of gold artefacts may affect their appearance and microstructure. It also offers directions for future studies of depletion gilding elsewhere.*

Keywords: South America, Colombia, pre-Columbian, archaeometallurgy, depletion gilding, gold, life-histories

Introduction

Pre-Columbian goldsmiths of South America are renowned for having developed, among many other technical feats, a range of gilding techniques that rendered their objects golden, even if the quantity of gold in the bulk metal was relatively low. A variety of gilding methods are known that are predominant in different regions, depending on individual goldsmithing traditions. Gilding techniques can be broadly categorised into those that functioned by adding a gold layer on top of a different metal substrate (with subvariants, such as fusion, leaf-gilding or electrochemical plating), and those that involved removing copper (and, sometimes, silver) from the surface of a gold-copper-silver alloy (named ‘tumbaga’), leaving it more gold-rich and hence more golden in colour than the substrate (e.g. Scott 1983; Lechtman 1988; La Niece & Meeks 2000). The latter repertoire of techniques is broadly known as ‘depletion gilding’, and it was favoured in large regions of the Andes, including parts of present-day Colombia. Heather Lechtman’s pioneering research helped in understanding the technical sophistication of depletion gilding techniques; she also proposed interpretive models to explain this particular cultural choice (Lechtman 1973, 1977, 1984, 1988).

Essentially, depletion gilding is achieved by exposing a gold-copper-silver alloy to an oxidising environment, which leads to the formation of copper oxide scales on the surface. During removal of these oxides by burnishing or pickling with plant acids, copper is progressively removed from the surface of the alloy, and silver and gold replace it. By repeating the process several times, metalsmiths achieved remarkably golden (and gold-rich) surfaces, even if the bulk alloy was relatively gold-poor. The thickness of the golden layer could be as thin as 10µm or less, but it was sufficient to alter the appearance of the objects radically. As Lechtman posited, this process probably responded less to a concern with saving metals or reducing their melting temperatures, as to a cultural norm dictating that the golden ‘essence’ of the metal must be exhibited on the objects’ surfaces. Thus, depletion gilding became a key element of the Andean ‘technical style’ that straddles material and symbolic considerations, and it has continued to be recognised as such (e.g. González 2004).

While overarching models are useful to drive the discipline, higher-resolution regional studies often reveal idiosyncratic practices that do not fit easily into those paradigms. Here, we present the first analytical characterisation of Nahuange gold work from Colombia—a metallurgical tradition that developed in the northern Sierra Nevada de Santa Marta, based on copper-rich tumbaga alloys. Of particular significance is the discovery that goldsmiths often obtained depleted-gilded surfaces unintentionally, but these surfaces were painstakingly polished off to remove the golden layer and reveal the pinkish hue of the bulk alloy. Similar features were also found on some objects that had been gilded deliberately. The singularity of this tradition has implications for our understanding of the discovery of depletion gilding as a technique, the role of social agents in the acceptance or rejection of technological innovations, the complex life-histories of metal objects, the concept of value, and the diachronic development of Colombian gold-working traditions.

Background to Nahuange metalwork

The Sierra Nevada de Santa Marta is a pyramid-shaped mountain range close to the Caribbean coast of Colombia. It is over 5700m in height, with steep slopes that descend directly to alluvial plains to the west, the sea to the north, and with a range of arid plains and river valleys to the east and south. The mountain range therefore encompasses a wide range of climates and ecological niches in a relatively small area. Although it is a very prominent element of the landscape, it was not an impassable barrier, and allowed the movement of people and ideas (Figure 1).

<FIGURE 1, 13.5cm>

Archaeologically, the region is best known for the Tairona culture, which has been documented through excavations at famous sites, such as Ciudad Perdida and Pueblito. Tairona material culture is most conspicuously evidenced by thousands of gold-alloy artefacts preserved at the Museo del Oro in Bogotá. Research has begun, however, to reveal an earlier phase at several Tairona sites, with different habitation structures and characteristic material culture. This phase, broadly dated to *c.* AD 100–1000, is known as the Early or Nahuange Period—named after the bay where J. Alden Mason excavated a large tomb in 1922 (Mason 1931, 1936, 1939; Bischof 1969; Bray 2003). Further research is necessary to characterise the societies of the Nahuange Period and their socio-cultural development. The scarce Nahuange archaeological evidence indicates that villages appear to be spread primarily towards the Caribbean coast, associated with bays or valleys. Recent archaeological investigations have, however, revealed that Nahuange villages were also scattered up in the hills. Nahuange pottery has, for example, been found in the lower strata of Tairona terrace foundations at Pueblito and Ciudad Perdida (Giraldo 2010). Nahuange subsistence activities included agriculture and fishing. The complexity of the pottery, lapidary work and gold work suggests the existence of craft specialists. Little is known concerning the political or religious structure of Nahuange communities, although the rich tomb of Nahuange perhaps suggests some social inequality (Bray 2003; Langebaek 2005). It has been suggested that social and political change occurring around the tenth century AD led to the demographic growth and increasing political centralisation that seem characteristic of the Tairona (Oyuela-Caycedo 1987; Langebaek 2005; Giraldo 2010).

Nahuange material culture is only beginning to be understood. Studies so far have revealed cultural influences from several regions that were developed idiosyncratically. The morphology and iconography of Nahuange pottery share traits with ceramics recovered from the valleys of the Ranchería River in the Guajira, the Magdalena River and the Caribbean

Plains (Falchetti 1987; Langebaek 1987; Oyuela-Caycedo 1987; Bray 1990, 2003). Winged plaques and female figurines carved in green stones may be local manifestations of motifs that are widely documented in Venezuela, Aruba, the Sierra Nevada del Cocuy, the Caribbean Plains of Colombia, the Caribbean and the Isthmus (Plazas 2007).

Defining Nahuange gold work is one aim of an ongoing project led by Juanita Sáenz-Samper (2015). A major challenge is the scarcity of well-documented archaeological contexts for many of these artefacts. Furthermore, the morphological traits shared by Nahuange and Tairona metal artefacts, which are indicative of cultural continuities, can sometimes complicate the phasing of such artefacts. It is becoming possible, however, to characterise some specific traits of the Nahuange tradition by referring to metal objects that can be dated by association to dateable material culture, or whose charcoal-rich cores can be dated directly by radiocarbon (as was the case of one tumbaga figurine recovered at the eponymous tomb of Nahuange, dated to AD 427–536 – OxA 1577 at 95.4%; date modelled in OxCal 4.1, using IntCal13 calibration curve; Bronk Ramsey 2009; Reimer *et al*. 2013) (Falchetti 1987; Bray 2003; Sáenz-Samper 2015). In general, while ceramics are indicative of connections with the east, the typology and iconography of gold work compare strongly with artefacts from cultures of the interior, particularly the Early Quimbaya and Early Zenú of the middle Cauca Valley and the Caribbean Plains (Falchetti 1993).

Nahuange gold work was predominantly used for body adornment and display. Common typologies include pectorals (especially double-spiral, circular, triangular or ornitomorphic), pendants (mainly anthropomorphic, ornitomorphic, frog- and feline-shaped, or triangular), nose pendants (rhomboidal, elliptical, triangular or semilunar, among others), ear pendants, flat discs, belts/diadems and bracelets. Decorative motives include spirals, volutes, circles, dotted lines, and schematic representations of birds and other animals. Although relatively flat objects predominate, three-dimensional figurative pendants cast by the lost-wax technique are also common—especially in the form of birds, frogs and quadrupeds with a raised tail (Figure 2) (Sáenz-Samper 2015). A more detailed discussion of the problems and potentials of defining the Nahuange culture, its origins, broader connections and evolution will be addressed in later publications. We concentrate here on the technical analysis of artefacts that are probably attributable to the Nahuange period. The aim is to provide an initial approach to understanding the materials and technologies that characterise Nahuange metalwork, as a basis for future comparisons with the later Tairona and other traditions. Particular emphasis is placed on surface treatment techniques, as these are shown to be among the most idiosyncratic, and prompt further analytical consideration of archaeological gold work.

Analytical methods

All the artefacts studied belong to the public collections held at the Museo del Oro in Bogotá. Within a broader analysis of Nahuange and Tairona artefacts, 44 complete and fragmentary Nahuange objects were examined visually and under low-power digital microscopy to assess morphology and surface texture. Several analytical techniques were employed to characterise manufacturing traits of the objects. Optical, digital and scanning electron microscopy (SEM) of whole artefacts or fragments were used to identify traces of the tools and the techniques employed in surface polishing and decoration. Metallography, scanning electron microscopy-energy dispersive spectrometry (SEM-EDS) and wavelength dispersive electron microprobe (EPMA) analyses of polished cross-sections provided further information about the microstructure and hence the artefact-manufacturing sequence. Particular attention was paid to the possible existence of surface layers, and their microstructure and composition, in comparison to the main body of the objects. In addition to those samples analysed chemically by SEM-EDS and EPMA, non-invasive analyses of a number of objects were carried out by portable X-ray fluorescence spectrometry (pXRF). These results were combined with those of previous (unpublished) surface XRF analyses (both on surfaces and cross-sections) undertaken by the Departamento Técnico Industrial (DTI) of the Banco de la República de Colombia (Sáenz-Samper 2015). New invasive analyses were performed at the UCL Institute of Archaeology; surface analyses (low-power digital microscopy and chemical) were conducted both at UCL in London and at the Museo del Oro in Bogotá (see online Supplementary Material (OSM)). All compositional values reported here are in percentage by weight (%).

Results

Visual and microscopic examination

A large proportion of Nahuange metal artefacts are flat ornaments made on thin sheets (mean thickness 207µm, median 118µm, n = 5). Their slight curvature, together with the presence and arrangement of decoration, facilitates identification of their fronts and backs. Most objects show a very shiny, highly polished, pinkish front surface, which contrasts with a matt, scaly, yellower back surface (Figures 2 & 3). Microscopic examination helps visualise the extremely fine polishing marks on the pink surfaces. In some cases, the high density, straightness and parallel arrangement of these polishing marks suggest the use of a rotary polishing device—an issue requiring further investigation, especially considering the lack of rotary kinetic energy use in pottery making and transport in this region (Sáenz-Samper 2015). High magnification surface imaging also allows inferences concerning the techniques and tools employed for decoration. Here, chiselled, chased and punched forms predominate, as occasionally evidenced by the ragged profile of the chiselled lines and the metal displacement caused by punching and embossing (Figure 4). Microscopic examination also shows remnants of a more yellow surface layer on the pink surfaces. These are typically confined to corners and crevices that would have been harder to polish, or to the inside part of the narrower chiselled decoration lines (Figures 4 & 5). These features indicate that during their manufacture or later life-history (and following decoration), some of these objects were fully covered by a golden layer, and that this was later removed from their fronts by polishing.

<FIGURE 2, 13.5cm colour>

<FIGURE 3, 13.5cm colour>

<FIGURE 4, 13.5cm colour>

<FIGURE 5, 13.5cm colour>

Three-dimensional cast artefacts are generally pink or orange all over, and exhibit different degrees of polishing (Figure 2). They are often cast using a variant of the lost-wax technique that involved the use of thick cores made of a fine, charcoal-rich material, inside the wax model. After casting, this core remains exposed through openings on the back or bottom of the metal artefacts. These objects also include occasional pseudofiligree spirals or other details that were modelled with wax threads and cast as part of the artefact. Although pink shades predominate, some cast objects also show remnants of what seems to have been a more golden surface layer that was subsequently polished off. These gilding remnants are typically confined to the crevices between object bodies and their applied decoration (Figure 6), although in a few cases they appear to cover the bulk of the object.

<FIGURE 6, 13.5cm colour>

Cross-section and chemical analyses

SEM-EDS and EPMA results show the use of gold-copper-silver (Au-Cu-Ag) alloys of varied compositions, but always rather copper-rich (EPMA results: mean±SD Cu 62.9±9.5%, Ag 5.6±1.2%, Au 30.4±7.8%; n = 5). While there is no evidence for pre-Hispanic silver extraction technology in the area, an abundance of naturally argentiferous gold in Colombia is well known. We infer, therefore, that these alloys were made by combining metallic copper with argentiferous gold, rather than alloying three separate metals. All other elements are present in concentrations lower than 0.03%, and hence near the detection limits of the EPMA (Sáenz-Samper 2015). Most interesting, however, are the chemical and microstructural gradients observed when some artefacts were examined in cross-section. The back surfaces of flat objects frequently show a very thin and porous layer that is much richer in gold than the substrate, similar to those reported elsewhere as resulting from depletion gilding (Figures 7 & 8) (e.g. Lechtman 1988; Hörz & Kallfas 2000; Schlosser *et al.* 2012). This layer is sometimes found on the front surfaces too; here, it is thinner and often discontinuous, and barely perceptible when the object is seen from the surface (maximum layer thickness on front 2.0±1.6µm, mean layer thickness on back 4.2±0.8µm, based on two measurements per layer on five objects). Consistent gilded surfaces on both sides are seen in only a very few cases. These observations appear to support the proposition that many objects would have been wholly covered by gilding, but that the golden layer was often removed from the front surfaces. The single cast object that we analysed in cross-section did not show any traces of a gilded layer.

<FIGURE 7, 13.5cm colour>

<FIGURE 8, 13.5cm colour>

Cross-section analyses also showed the metallographic structure of the objects. Flat artefacts display a tight, fibrous texture resulting from intense hammering; intergranular corrosion reveals small recrystallised grains that denote episodes of heating between hammering cycles, to ensure the alloy retained its malleability (Figure 7). The cast object analysed metallographically showed a dendritic structure, indicating the lack of mechanical work after casting.

We carried out non-invasive pXRF analyses of a larger number of objects to compare alloy choices between flat, hammered objects and three-dimensional cast ones, and pooled these new analyses with legacy data (overall mean±SD: Cu 52.4±15.9%, Ag 7.4±3.2%, Au 39.9±13.9%; n = 36; see OSM). Figure 9 confirms that, for all types of object, preferred alloys were those with relatively high proportions of copper, corresponding with pinkish and orange colours. No significant compositional differences were found between cast and hammered artefacts (the fact that the two artefacts of nominally pure copper are cast may simply reflect a sampling bias). When the XRF results as measured from the back and front of the same hammered objects are compared, the back analyses tend to show higher gold levels. But this is not always the case, and the differences are much smaller than what might be expected, considering the very noticeable contrasts in colour between back and front surfaces. This may be explained by the exceptional thinness of the gilded back layer (mean 4.2±0.8µm) and its inherent porosity, meaning that much of the X-ray fluorescence detected is produced beneath this layer (effective X-ray-penetration depth in a gold alloy is around 10µm for Cu Kα, and higher for Ag Kα and Au Lα; cf. Gigante *et al*. 2005; Troalen *et al.* 2014). This comparison demonstrates that non-invasive XRF may provide a reliable indication of bulk major element concentrations in gold alloys, even when surface phenomena are present (cf. Blakelock 2016).

<FIGURE 9, 13.5cm colour>

Discussion

Visual examination of Nahuange gold work reveals a preference for pinkish hues and highly polished surfaces. Microscopic analysis, however, shows that often these surfaces had been previously covered by a gilded layer, which was subsequently removed from the visible side of these objects. We propose that, in many of these cases, depletion gilding was an inevitable side-effect of the manufacturing sequence by hammering and annealing copper-rich tumbagas. Crucially, however, this golden appearance would not always be desired. This would explain why the front surfaces of diadems, breast plates and nose rings were meticulously polished to return them to their former pink colour. The removal of the gilding is not consistent with use-wear: the polish is generally too thorough and uniform, appearing only on the front of objects (the front being less exposed to use-wear through contact with the individual wearing the object).

Heather Lechtman has previously proposed that depletion gilding could have been discovered by accident during the hammering work with tumbagas. As regular reheating was required to avoid fracture of the metal, smiths would have realised the progressive deposition of dark (copper oxide) scales on the surfaces. When removed, these would leave a more yellow appearance. In her own words, “there [was] essentially no way of preventing it” (Lechtman 1988: 354). This would have led to subsequent experimentation to optimise the method and apply it to cast objects. It has typically been assumed that this would have been an advantageous, desirable discovery, in that it required less gold and, more importantly, connected with broader Andean value systems as manifest in the symbolism of gold and copper. Our study has confirmed the association between depletion gilding and early hammered tumbagas at Sierra Nevada de Santa Marta, and hence supports Lechtman’s model of discovery. It has also demonstrated, however, that golden surfaces were not always immediately and preferentially accepted. If metals indeed had ‘essences’ to be displayed on the surface of artefacts, then the preferred essence for display was not always that of gold. The uptake and popularisation of depletion gilding in Sierra Nevada de Santa Marta did not take place until the Tairona period—approximately seven centuries after our documented earliest evidence of ‘polished off’ depletion gilding. This observation reminds us that even though a technological discovery can occur by accident, its widespread adoption does not—it requires a suitable social context in which the innovation may fulfil a utilitarian or cultural role. Nevertheless, the situation seems more complex than a wholesale rejection of depletion gilding in the Nahuange period, followed by a full adoption of the technique by the Tairona. Potentially contradicting this scenario are the few hammered objects from which the gilding was not removed and, especially, the cast objects with patches of gilding remnants. In the latter, the gilding is hard to explain as unintentional, as neither hammering nor annealing would have been required during manufacture; both the gilding and the subsequent ‘ungilding’ may represent deliberate practice.

To explain this diversity, a more detailed consideration of artefact life-histories may be required. It is possible that the removal of the golden layer did not take place immediately after manufacture. It may have been carried out at a later stage of the object’s life, perhaps as part of a ritual or to mark a particular moment in the life of an individual or the community. Similarly, the gilding (and subsequent polishing) of cast objects may represent different stages in the social life of the object, rather than all taking place at the beginning. The signs of extensive wear shown by some of these artefacts are compatible with relatively long life-histories of moderately intense use, which may have involved more than one person.

Ana María Falchetti (1999, 2003) has investigated the symbolism of metals in indigenous American societies, in which metal is often associated with ideas of transformation and the continuity of life. The yellow colour of gold, its immortality and incorruptibility are often connected with the male power of the sun, whereas the various reddish hues of copper and its capacity for transformation (through corrosion or other colour-changing processes) prompt associations with the human life-course. Among the present-day Desana people of Vaupés in south-east Colombia, different hues of red are classified as copper-like and related to female properties, to the corruptible and mortal essence of human flesh and blood (as opposed to the bones; Reichel-Dolmatoff 1981). Against this background, and notwithstanding the risks of using ethnographic parallels, we propose that the colour and sheen of Nahuange metal objects may have been adjusted in the course of their life-histories. Intentional alteration may, for example, have been carried out prior to deposition in a funerary context, where the removal of the gilded layer may have represented a form of ‘ritual killing’. This is perhaps comparable to the case of a Nahuange pectoral at the Gold Museum collection that was clearly folded before deposition, and also to similar practices documented elsewhere. This hypothesis could be tested by comparing the funerary *vs* non-funerary find contexts for Nahuange artefacts—a task made difficult by the scarcity of well-defined contexts. Another plausible scenario would be the alteration of the artefacts to mark important moments in life, such as the owner attaining puberty. Considering recurrent associations between reddish colours and females, it may be useful to further investigate the possible connections between women and metalwork. It may be significant that human representations in Nahuange metal, stone and ceramic artefacts are predominantly female.

A related question pertains to the origins and spread of this particular tradition of metal surface alterations. A small number of early Quimbaya artefacts (500 BC–600 AD, Uribe-Villegas 2005) appear to show the same front polish that removed an earlier gilded surface, thus providing potential directions for future research. This technical observation would be consistent with previous research that has highlighted a legacy of Quimbaya styles in the gold-making traditions of northern Colombia (Cooke & Bray 1985; Falchetti 1987, 1995; Bray 1992). Reddish hues are also used, although not exclusively, by the Zenú—the other notable gold-working tradition near the Caribbean coast of Colombia (Figure 1). Interestingly, female representations are abundant in Zenú and Early Quimbaya material culture (Sáenz-Samper 1993; Falchetti 1995), where connections between metalwork and the female have also been proposed (Uribe-Villegas 2005). Farther north, a preference for copper-rich gold alloys has been documented among the Taíno societies of the Greater Antilles. They called this metal *guanín* and were attracted by its supernatural associations, which materialised in a unique smell, reddish or purple colour, shiny quality and possible foreign origin. Guanín’s qualities contrasted to the paleness and lack of odour of local gold (Bray 1997; Oliver 2000; Martinón-Torres *et al.* 2007; Valcárcel Rojas & Martinón-Torres 2013). In the Cuban cemetery of El Chorro de Maíta, an indigenous female buried sometime after the conquest was accompanied by several guanín objects, including what seems to be a Tairona bird, probably transported by Europeans along with Colombian loot. This is the only object in the assemblage with evidence of depletion gilding and, as with the Nahuange objects, the golden layer appears to have been deliberately polished off (Martinón-Torres *et al.* 2012). Future work could, therefore, focus on the ethnography of colours and sheens (beyond metals), and possible associations with female and passage rites, with a particular focus on the Circum-Caribbean region. Furthermore, notwithstanding the frequent challenge of poor contextual data, future research should continue to study the diachronic development of gold-working traditions, trying to overcome oversimplified, atemporal narratives.

Finally, this study of Nahuange gold work emphasises not only the active role of social agents in adopting, adapting or rejecting innovations, but also the need to prove intentionality behind the actions recorded in archaeological material culture. While the removal of gilded layers among the Nahuange denotes a purposeful act, the intentionality behind depletion gilding in hammered and annealed gold-alloy artefacts, here or elsewhere, cannot be assumed. In gilded cast objects, if post-depositional treatments can be excluded, surface depletion is more probably the result of an intentional act (but see Martinón-Torres & Uribe-Villegas (2015: 144–45) for tumbaga cast figurines accidentally depleted-gilded by burning). The gilding of hammered tumbaga items may, however, have been simply unavoidable, irrespective of the intentions and expectations of goldsmiths and consumers. This should not only raise caution in South American contexts, but also in other regions where depletion gilding has been identified by archaeometallurgists.

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Supplementary material

To view supplementary material for this article, please visit XXXX

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Figures

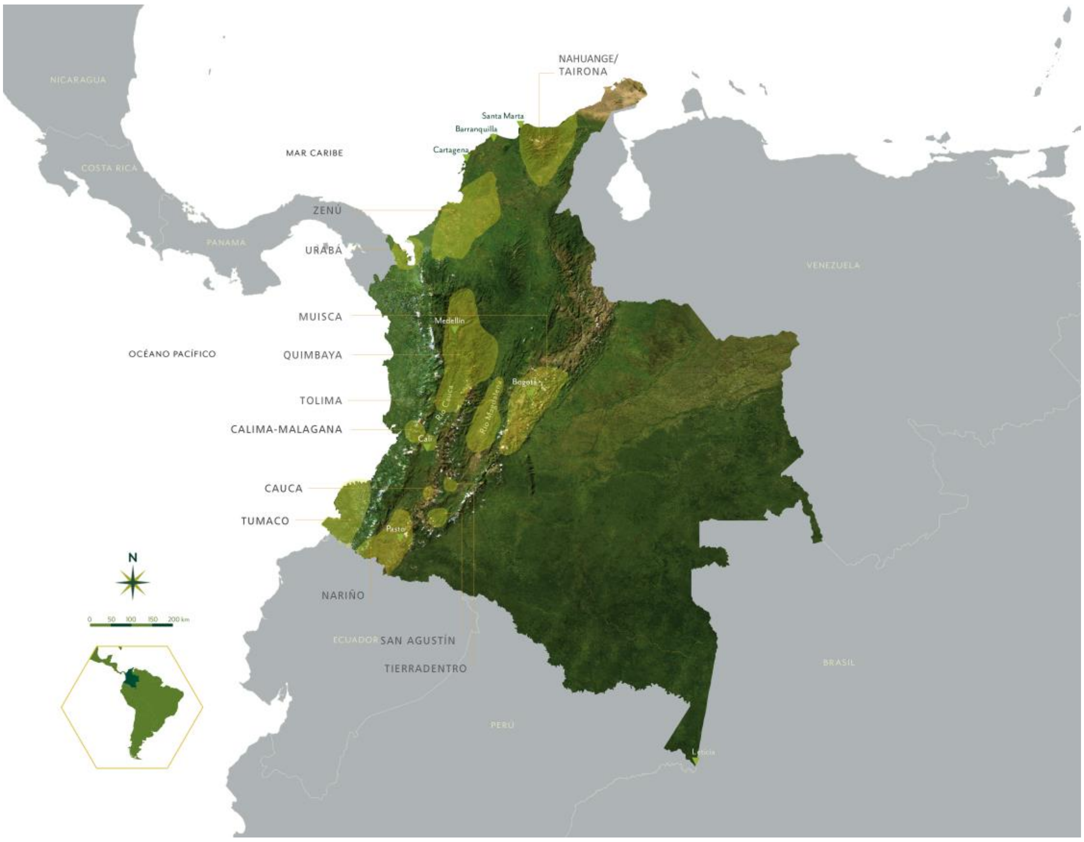

Figure 1. Map of Colombia indicating the main gold-working regions. The geographic span of the Nahuange coincides with the Tairona in the Sierra Nevada de Santa Marta, near the Caribbean coast.

Figure 2. Examples of Nahuange metal artefacts. On hammered objects, note the difference between the highly polished, pinkish front surfaces (f) and the unpolished, yellow, matt back surfaces (b). Not to scale. All photographs by Clark Manuel Rodríguez. Main dimensions in centimetres: O16519—H: 6 × W: 51.8; O16195—H: 2.3 × W: 13.4; O16256—H: 1.6 × 7.6; O19707—H: 4.3 × W: 8.3; O33857—H: 6.7 × W: 6.2; O17123—H: 2.6 × W: 5.6; O17587—D: 10.

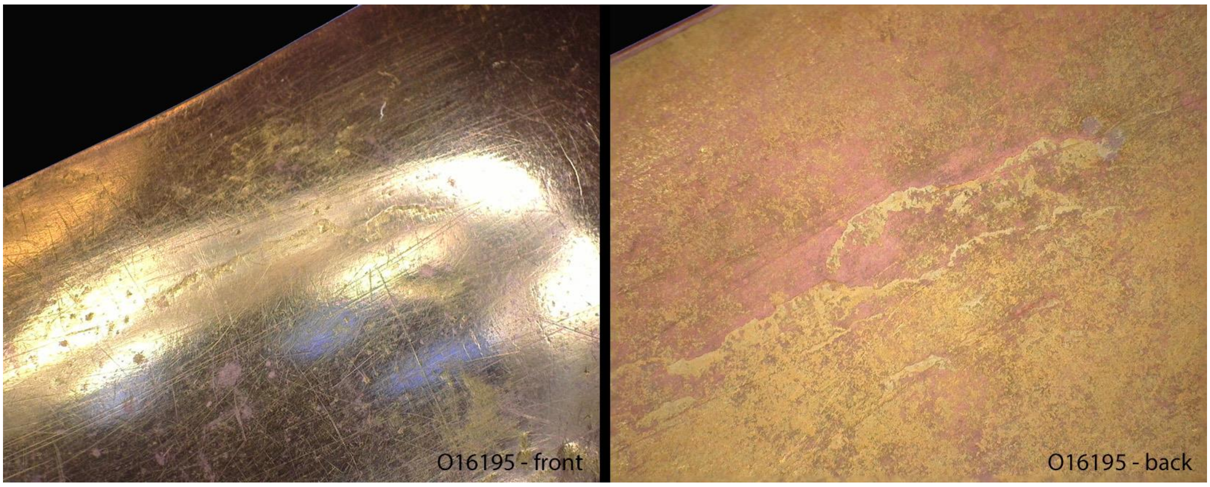

Figure 3. Comparison between the highly polished front surface and the matt, unpolished back surface of nose ornament O16195. Photographs by Marcos Martinón-Torres.

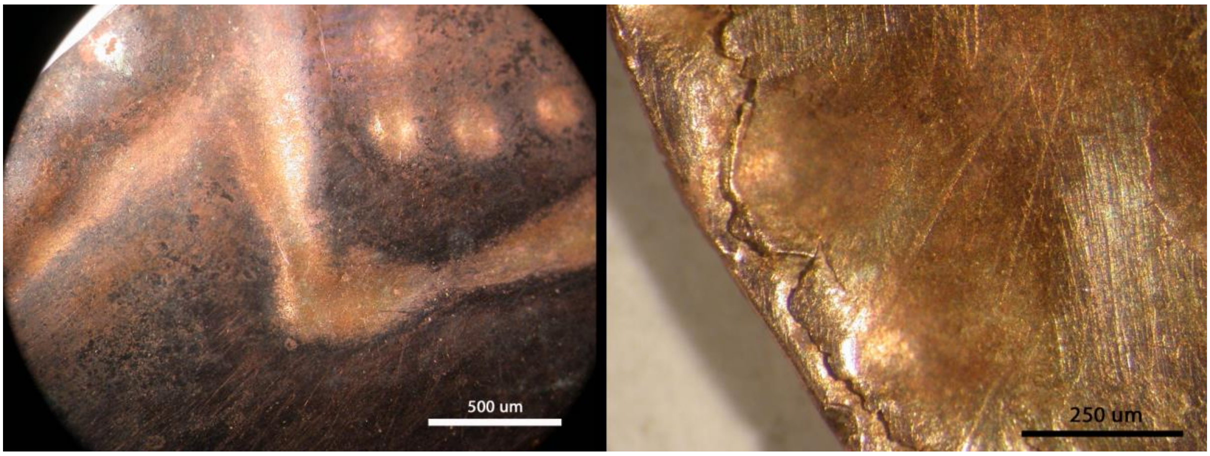

Figure 4. Details of decoration on metal artefacts. Left) detail of the punched and chased decoration on the front surface of nose ornament O18155a, showing remnants of a more golden colour inside the depression. Right) detail of metal displaced by the punched decoration on the back of nose ornament O19259. Photographs by Juanita Sáenz-Samper.

Figure 5. Front view of hammered nose ornament O19707 and detail of the raised decoration, showing remnants of the golden layer that once covered the whole surface. Object dimensions: 4.3 × 8.3cm. Photograph by Clark Manuel Rodríguez; detail by Marcos Martinón-Torres.

Figure 6. Front view of cast nose ornament O18124 and detail of the pseudofiligree decoration, showing remnants of the golden layer that once covered the whole surface. Photographs by Clark Manuel Rodríguez.

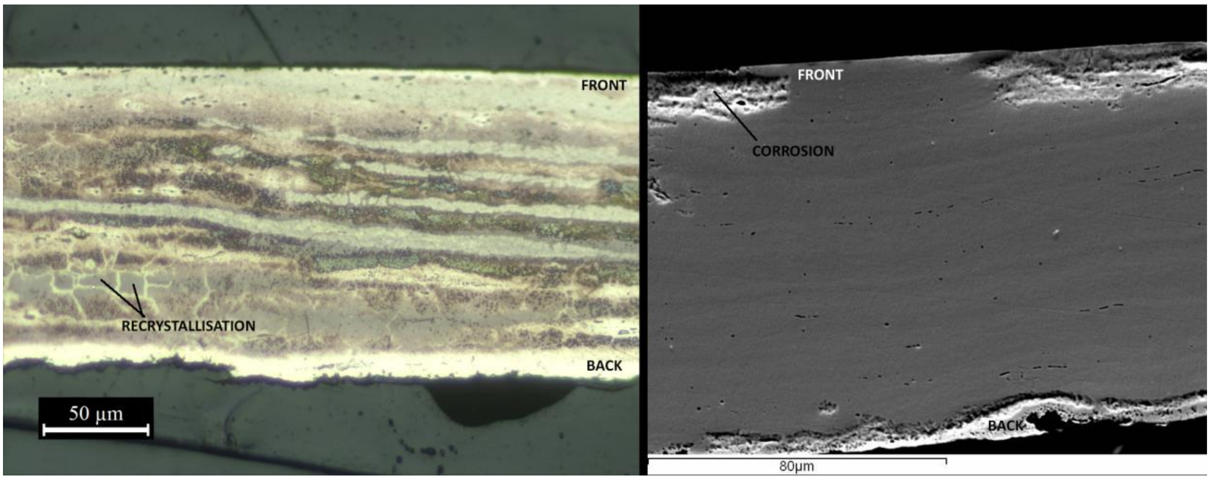

Figure 7. Polished cross-sections of hammered objects O16196 (left image: optical microscope, etched in alcoholic ferric chloride) and O26820b (right image: SEM secondary electron image). Note the straight surface on the front (top of the images), resulting from intense polishing, compared to the porous, golden layer on the back (bottom). The cavities are the result of corrosion. The metallographic image on the left also shows the fibrous texture resulting from intense hammering, as well as the recrystallisation achieved by annealing. Photographs by Nohora Alba Bustamante and Juanita Sáenz-Samper.

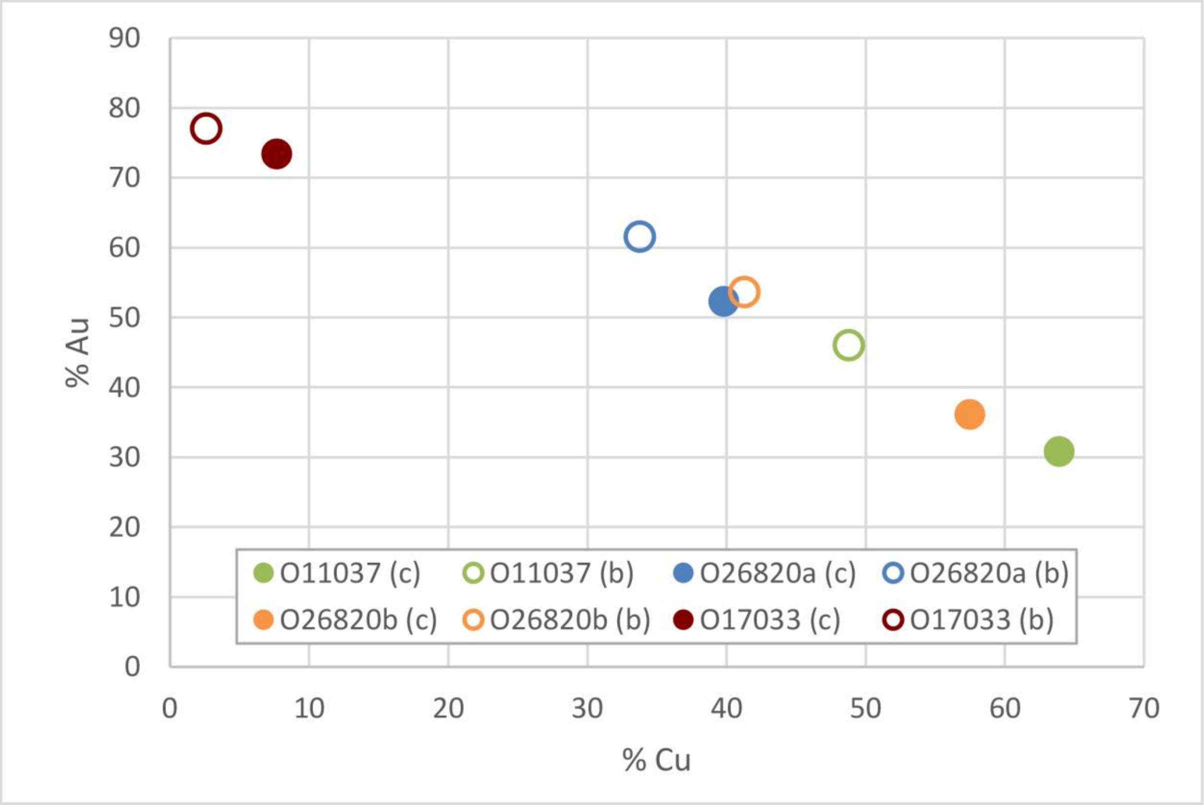

Figure 8. Scatterplot comparing the gold and copper levels on the core (c: full circles) and back layer (b: empty circles) in four hammered Nahuange artefacts, as measured by SEM-EDS on metallographic sections. Note the higher gold levels on the back surfaces, compared to the bulk.

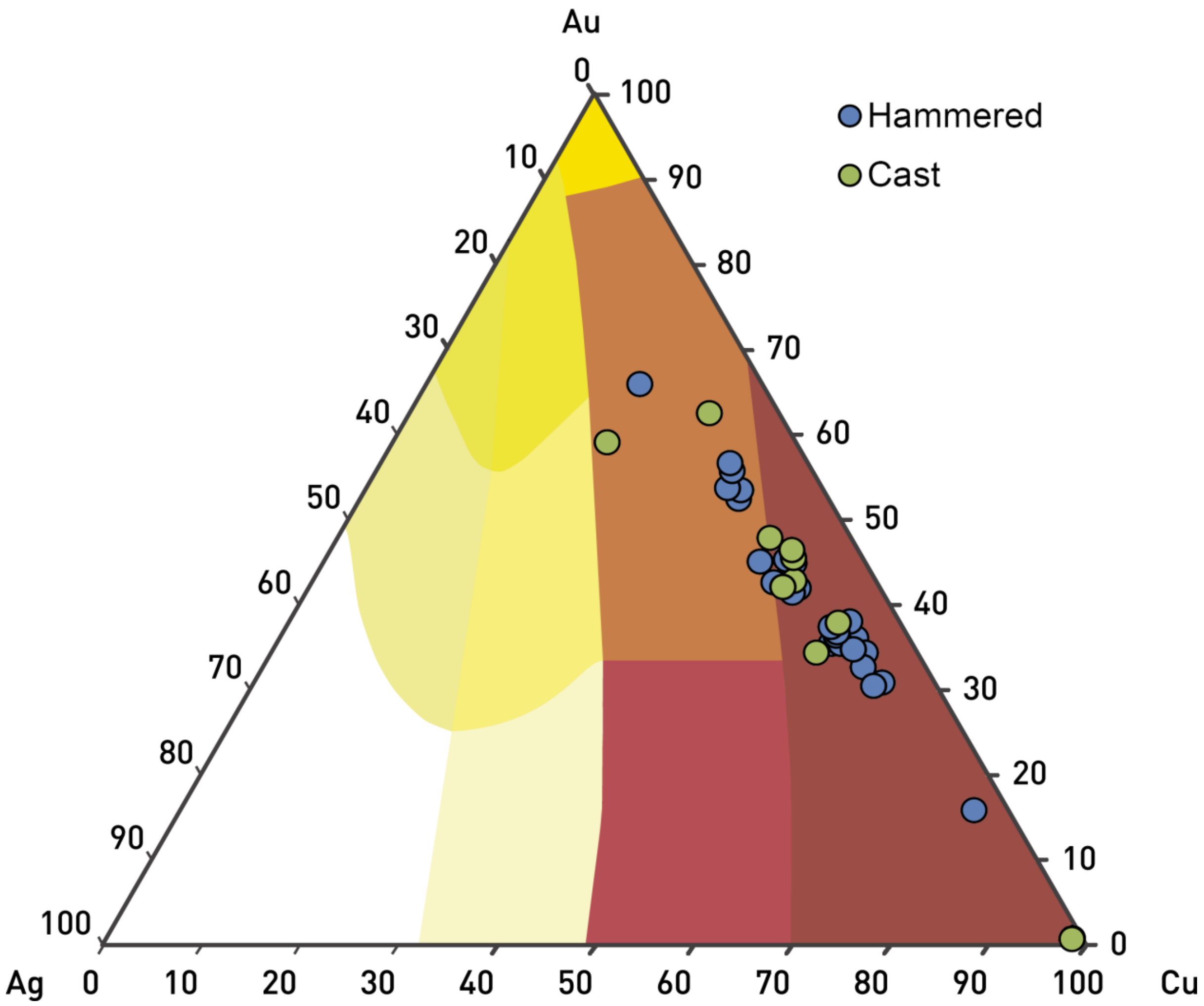

Figure 9. Plot of the chemical composition of Nahuange metal artefacts on a ternary colour diagram, using normalised values in percentage by weight (%). See OSM for data.

[supplementary material]

Depletion gilding, innovation and life-histories: the changing colours of Nahuange metalwork

Juanita Sáenz-Samper[1] & Marcos Martinón-Torres[2,*]

Analytical methods and results of chemical analyses

Full SEM and EPMA methods and results of the analyses performed at the UCL Institute of Archaeology are reported in Sáenz-Samper (2015), and therefore they are only succinctly summarised here.

SEM examination employed a Hitachi S-3400N and a Philips XL30. SEM-EDS was conducted on an Oxford Instruments EDS attached to the Philips, operating at 20kV, working distance of 10mm, spot size of 5.2 and acquisition time of 70s. Calibration with cobalt was carried out every 30 min. Analytical results always ranged between 95 and 102 weight percent (%), owing to small beam fluctuations and microporosity, especially in more corroded samples, but they were normalised to 100% to facilitate comparisons.

EPMA analyses were carried out on a JEOL JXA-8100 calibrated with pure standards, running at 20kV with a beam current of 5×10^{-8} and an acquisition time of 50s. Three crystals were employed (TAP, PET and LIF) and the following elements were sought: Si, S, Cl, Mn, Fe, Co, Ni, Cu, Zn, As, Ru, Rh, Pd, Ag, Cd, Sn, Sb, Os, Ir, Pt, Au, Pb and Bi. The results reported are averages of 8 to 10 measurements per sample, typically conducted on areas of ~80 by ~120µm, though sometimes smaller if the artefacts were severely corroded.

For portable XRF analyses we used an Olympus Innov-X Delta Premium portable X-ray fluorescence spectrometer (pXRF), with a Rh anode and equipped with a silicon drift detector (SDD), providing a typical resolution of 145-155 eV FWHM for 5.9 kV X-rays (on an AISI 316 standard). The factory-built Alloy Plus method was employed, which uses a fundamental parameters algorithm for quantification, optimised through the analyses of certified reference materials. Analyses were performed at 40kV with a beam current of 100µA and using the so-called Beam 1, which includes a 2mm Al filter in the X-ray path, for livetimes of 15 seconds. The X-ray beam was collimated to an analytical spot of ~3mm in diameter. Analyses of reference materials by pXRF are provided in Table S1 below, and these are a reflection of the data quality behind the values labelled as pXRF/UCL in Table S2.

The legacy data acquired by the Departamento Técnico Industrial (DTI) of Banco de la República includes two XRF instruments: a Bruker AXS SR3000 used directly on objects' surfaces (reported as 'surface XRF / DTI') in Table S2) and a Kevex Omicron micro XRF at the Getty Institute in Los Angeles, used on polished sections (reported as 'section XRF / DTI'). No analyses of relevant certified reference materials are available for these instruments, but we can trust their overall reliability based on experience re-analysing objects with the newer pXRF at UCL and comparing the datasets.

Table S1. Results of pXRF analyses of reference alloys using the UCL instrument. Values in percentage by weight (%).

		Cu	**Ag**	**Au**	**Sn**
MAC1	given	1	4.6	93.9	0.5
	mean (n=3)	1.0	4.4	94.1	0.5
	SD	0.01	0.02	0.04	0.01
MAC2	given	5.1	19.2	74.7	1.0
	mean (n=6)	4.8	19.1	75.0	1.2
	SD	0.04	0.12	0.14	0.05
MAC3	given	9.1	29.7	59.2	2.0
	mean (n=4)	8.5	30.6	58.7	2.2
	SD	0.07	0.15	0.07	0.02

Table S2. Chemical analyses of Nahuange metalwork, in percentage by weight (%). The front/core analyses are the values used for the ternary diagram in Figure 8 in the main article. Back analyses refer to XRF analyses conducted from the back (gilded) surface and are presented for comparison. Note, however, that considering the penetration depth of the XRF analyses and the thinness of some of the sheets, it is possible that the part of the fluorescence detected during a 'front' analysis comes from the 'back' of the object.

Museum ID	**Analysis / laboratory**	**Type**	**Technique**	**Front/core**			**Back**		
				Cu %	**Ag %**	**Au %**	**Cu %**	**Ag %**	**Au %**
O08647	section EPMA/ UCL	Breast plate	H	81.4	3.2	15.6			
O08678	surface XRF / DTI	Nose ornament	C	49.5	8.1	42.4			
O09502	section XRF / DTI	Bird shape pendant	C	96.0	<1	<1			
O10333	surface XRF / DTI	Nose ornament	H	39.0	9.0	52.0			
O10342	surface pXRF / UCL	Nose ornament	H	22.2	12.5	65.4	21.4	12.5	66.1
O10526	surface XRF / DTI	Nose ornament	H	64.5	5.0	30.5			
O10946	surface XRF / DTI	Nose ornament	H	57.0	8.0	35.0	57.0	6.0	37.0
O11037a	section SEM-EDS / UCL	Nose ornament	H	59.0	5.0	35.6			
O11140	surface XRF / DTI	Nose ornament	H	57.6	4.8	37.7			
O12278	surface pXRF / UCL	Nose ornament	H	38.7	8.3	53.0	40.3	8.1	51.6
O12611	section XRF / DTI	Bird shape pectoral	C	31.0	7.0	62.0			
O13706	surface pXRF / UCL	Nose ornament	H	37.2	9.5	53.3	41.5	9.2	49.3
O14580	surface pXRF / UCL	Nose ornament	C	44.5	8.1	47.4			
O14839	surface XRF / DTI	Nose ornament	H	61.0	5.0	34.0			
O14840	surface XRF / DTI	Nose ornament	H	61.6	6.1	32.3			
O14841	surface XRF / DTI	Nose ornament	H	48.5	7.1	44.4			
O15463	section XRF/ DTI	Bird shape pectoral	H	98.0	<1	<1			
O15612a	section EPMA/ UCL	Frog pendant	C	55.9	6.0	37.1			
O16195	surface pXRF / UCL	Nose ornament	H	47.4	7.7	44.9	42.8	7.5	49.7
O16196	surface XRF / DTI	Nose ornament	H	58.0	7.0	35.0			
O16197	surface XRF / DTI	Nose ornament	H	57.0	7.0	36.0			
O16519	surface pXRF / UCL	Belt	H	50.4	8.1	41.5	35.8	8.8	55.3
O16520	surface pXRF / UCL	Belt	H	47.5	10.3	42.2	46.2	10.7	43.1
O16971	section XRF / DTI	Bird shape pectoral	C	56.0	10.0	34.0			
O17033a	section EPMA/ UCL	Ear ornament	H	62.6	6.1	29.5			
O17116	section XRF / DTI	Bird shape pendant	C	22.0	19.0	58.0			
O17161	surface pXRF / UCL	Nose ornament	H	44.9	10.5	44.7	42.6	11.0	46.5
O17463	surface pXRF / UCL	Nose ornament	H	36.7	8.0	55.3	35.1	10.6	54.4
O18124	surface pXRF / UCL	Nose ornament	C	47.9	6.8	44.9	47.7	8.1	44.2

O19707	surface pXRF / UCL	Nose ornament	H	36.0	7.8	56.2	26.2	9.9	63.9
O22845	surface XRF / DTI	Nose ornament	H	50.0	9.0	41.0			
O26159	surface pXRF / UCL	Nose ornament	C	47.5	6.5	46.0			
O26820a	section EPMA/ UCL	Breast plate	H	58.5	5.9	33.7			
O26820b	section EPMA/ UCL	Ear ornament	H	56.3	6.7	36.0			
O29603	surface XRF / DTI	Nose ornament	H	56.0	7.0	37.0			
O33857	surface XRF / DTI	Frog shape pendant	C	48.7	9.6	41.7			
			Mean	**52.4**	**7.4**	**39.9**			
			Median	**50.2**	**7.0**	**41.3**			
			SD	**15.9**	**3.2**	**13.9**			
			Max	**98.0**	**19.0**	**65.4**			
			Min	**22.0**	**<1**	**<1**			