13 The Characterisation of Gold Layers on Copper Artifacts from the Piura Valley (Peru) in the Early Intermediate Period

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Abstract

Investigations of gilded copper metalwork from the Moche cemetery at Loma Negra have shown that the gilding method used differs significantly from that observed on Moche metalwork from centres further to the south. A comparative analysis of gold layers on copper sheet artifacts from Loma Negra, and those attributed to the Vicús people, their neighbors in the Piura Valley (north coast Peru), was carried out at The Metropolitan Museum of Art using metallography, energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM). The results suggest that the local Vicús population and the Moche at Loma Negra shared some aspects of their metallurgical traditions.

Introduction

Various techniques for altering the surface appearance of metals were widely employed by metalworkers of pre-Columbian South America, particularly in the northern and central Andean regions of Peru, Ecuador and Colombia. One feature of great interest was surface colour, and many of the sophisticated metallurgical techniques developed in these regions were applied to the production of gilded or silvered surfaces on metal substrates (Bergsøe 1938; Scott 1983, 1986a,b; Lechtman 1988).

In 1969, a large group of Moche metal objects, most of which were made of gilded or silvered copper sheet, was found by *huaqueros* at Loma Negra, located in the Vicús area of the upper Piura Valley on the northern coast of Peru (Disselhoff 1972) (Figs 13.1–13.3). The discovery was of great importance not only because it increased the small number of metal objects at that time assigned to the Moche culture (*c.* AD100–800), but because it deepened our understanding of the Early Intermediate Period in Peru (*c.* 200BC–AD600) as one of intense innovation in metal technology (Jones 1975; Lechtman 1979; Lechtman *et al.* 1982; Schorsch 1998). Loma Negra is, in fact, situated among habitation and burial sites attributed to the Vicús culture (*c.* 250BC–AD650) and separated from the main sphere of Moche occupation to the south by the Sechura Desert.

Recent discoveries of Moche metalwork at the centrally located sites of Sipán (Alva 1988; Alva and Donnan 1993) and La Mina (Donnan 1990: 32; Naváez 1993) provide further support for our high estimation of Moche metallurgical achievements, as well as parallels for many of the finds at

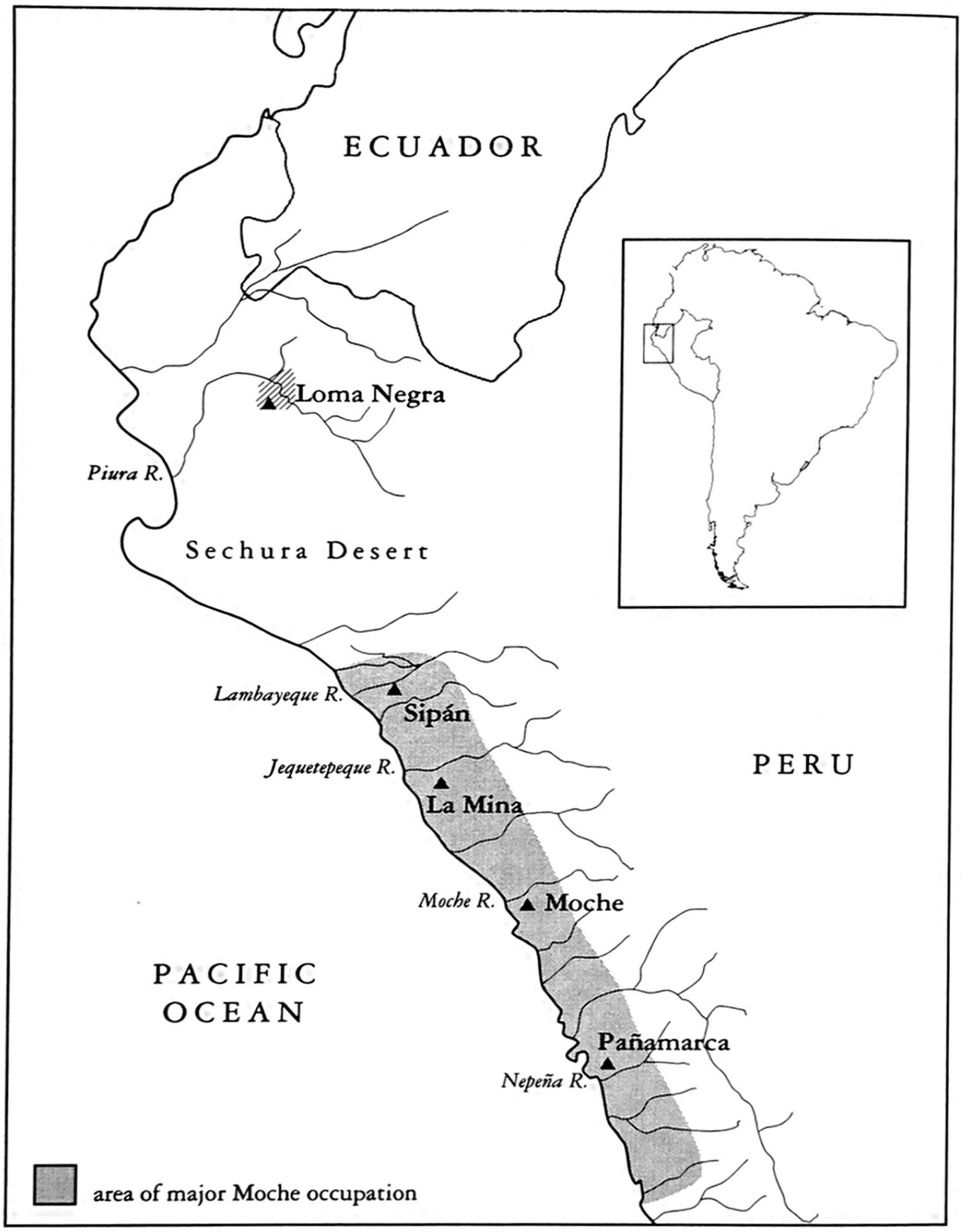


Figure 13.1 Map of the north coast of Peru, showing the major area of Moche occupation and locations of selected Moche sites (▲). The area where Vicús culture sites have been discovered so far is also indicated (courtesy of Adam Hart).

Loma Negra, and at the same time suggest that some innovations employed there may be local developments of the Piura Valley rather than characteristic of Moche metalwork as a whole.

Looting of archaeological sites in the Piura Valley in the region of Cerro Vicús had long preceded the discovery of Moche metalwork at Loma Negra (Murro Mena 1994). In the mid 1960s several archaeologists were sent to the area to investigate reports of widespread illegal excavations. The distinctive finds from these burials could not be attributed to any known Andean culture and were assigned the name Vicús by Matos Mendieta (1965–66). Guzman Ladrón de Guevara and Noriega (1964) subsequently excavated 41 tombs at Cementario Yécala, but their results, except for a preliminary report, were never published. A few of the hundreds of metal finds from Tomb 11 of their excavation were studied by Ríos and Retamozo (1993). Disselhoff (1969, 1971) carried out a series of small excavations that yielded Vicús ceramics but few metal objects. He published the first radiocarbon dates from charcoal samples, placing the Vicús culture (*c.* 250BC–AD650) within the Early Intermediate Period, and more or less contemporaneous with the Moche. In 1988, as part of the Upper

Figure 13.2 Gilded copper warrior figure, Moche, from Loma Negra. The Metropolitan Museum of Art, Gift of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1981 (1981.459.32). (Photograph: E. G. Howe). (See Plate 71.)

Piura Archaeological Project of the Pontificia Universidad Católica del Perú co-directed by Kaulicke and Makowski (1990), a metallurgical survey of the region was undertaken by Shimada (1988). No mines or smelting sites were found in the area of Cerro Vicús, but a furnace found at Pampa Juarez was later reported by Makowski (1994).

The quality of interaction between the Moche at Loma Negra and their Vicús neighbors, and between the inhabitants of the Piura Valley and those of the Moche heartland, remains to be clarified (Bawden 1994; Kaulicke 1994; Shimada 1994). A preliminary examination of gilded and silvered surfaces on copper artifacts from the Piura Valley suggests that the Moche at Loma Negra and the local Vicús population shared some aspects of their

Figure 13.3 Gilded and silvered copper disk, Moche, from Loma Negra, obverse. The Metropolitan Museum of Art, Bequest of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1986 (1987.394.56). (Photograph: B. J. Schwarz). (See Plate 72.)

respective metallurgical traditions, though their visual repertoires are quite distinct (Figs 13.2-13.7).

Whereas cast artifacts have been attributed to both cultures, most Moche and Vicús metalwork was made from hammered metal sheet of gold, silver, copper, silvered gold and gilded or silvered copper. As a rule, Vicús artifacts of gold and those that combine silver and gold, are nose ornaments; objects entirely of silver are rare. The copper sheet used for Vicús artifacts, both with and without precious metal surface layers, is usually somewhat thicker than that produced by Moche metalworkers. Moreover, unlike the elaborate three-dimensional objects constructed from multiple sheets of metal often favoured by the Moche (Fig. 13.2), most Vicús metal objects consist of a single sheet and have only shallow relief or superficial linear decoration. 'Plaques' made in a limited number of geometric and organic shapes, as well as crowns, discs and pectorals, are the most typical products of Vicús metalworkers (Figs 13.4–13.7)

In common with much ancient Peruvian metalwork, many of the Vicús copper sheet artifacts have dangles, usually circular or rectangular in

Figure 13.4 Gilded copper plaque, Vicús, obverse. The Metropolitan Museum of Art, Bequest of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1986 (1987.394.169). (See Plate 73.)

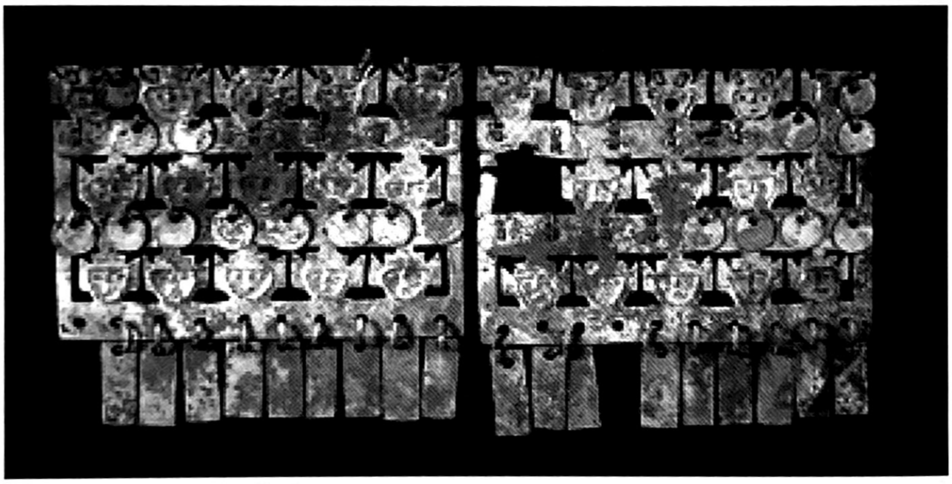


Figure 13.6 Gilded copper plaques,Vicús, obverse. The Metropolitan Museum of Art, Bequest of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1986 (left: 1987.394.252, right: 1987.394.251). (See Plate 75.)

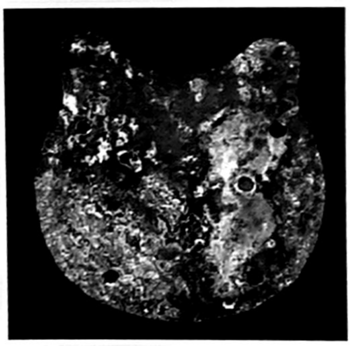


Figure 13.5 Gilded copper plaque,Vicús, obverse. The Metropolitan Museum of Art, Bequest of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1986 (1987.394.599). (See Plate 74.)

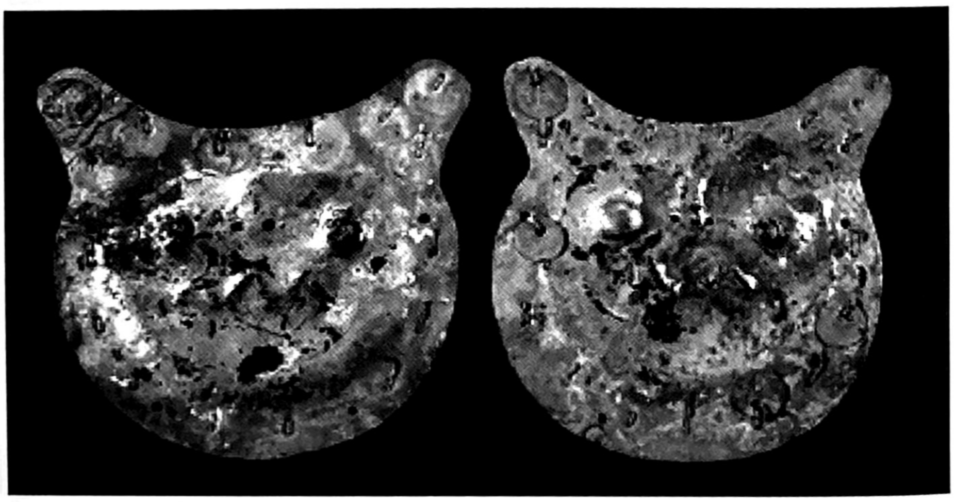


Figure 13.7 Gilded copper plaques,Vicús, obverse. The Metropolitan Museum of Art, Bequest of Jane Costello Goldberg, from the collection of Arnold I. Goldberg, 1986 (left: 1987.394.598, right: 1987.394.596). (See Plate 76.)

shape, that were attached to the substrates using rectangular-section wires, and that jingled and shimmered when the objects were moved. All of the plaques have small holes that allowed their attachment to textiles or other substrates. We often lack specific archaeological contexts for the various artifacts, and due to the general paucity of scholarship in the field of Vicús archaeology, it cannot be said how the plaques and disks might have been used or displayed.

Previous studies of gilding techniques in the Piura Valley

Studies to determine the methods of gilding and silvering used on copper-based metalwork found at Loma Negra were undertaken by Lechtman (1979) and by Lechtman *et al.* (1982). On the basis of their investigations, the authors proposed that the gold and silver layers had been applied using an electrochemical replacement plating technique, suggesting the following sequence of steps. First, plating solutions were prepared by dissolving gold and silver in aqueous solutions of corrosive minerals available in the arid coastal environment of northern Peru. The availability of the raw materials alone, however, can not explain how this sophisticated technology took root and developed. Precious metal layers of varying compositions were deposited onto the copper substrates by dipping them into the solutions, which had been neutralised by the addition of sodium carbonate. Under these conditions a redox reaction takes place, in which some copper atoms from the substrate are oxidised and gold or silver ions in solution are reduced and deposited on to the copper surface. The authors proposed annealing to secure the layers to the substrates and burnishing to increase their lustre as final steps. Modern replication samples prepared by Lechtman and her colleagues reproduce the macroscopic characteristics observed in the ancient samples, including the extreme thinness and uniformity of the precious metal layers, as well as some features of their microstructures.

Several studies of Vicús gilded copper objects have been undertaken. Ríos and Retamozo (1993) examined some of the metalwork found in Tomb 11 at Cementerio Yécala by Guzman Ladrón de Guevara and Noriega in 1964. Among the finds are a number of gilded copper artifacts, including plaques, crowns and feather-like attachments that may have functioned as plumes. Based on the examination of samples taken from two copper artifacts that appeared to have gilded surfaces, Ríos and Retamozo report that the layers average 10 μm in thickness and are composed principally of copper containing 'only traces of gold, silver and silicon'. It is not indicated how the elemental analysis was carried out, but, in any case, it is likely that most of the copper detected in the surface layers is due to the proximity of copper corrosion products from the copper substrate, and that the surfaces were fully intended to appear golden. Ríos and Retamozo suggest that a fusion gilding technique had been used.[1]

In a general survey of Vicús metalwork, Diez-Canseco (1994), mentions the examination of one sample from a Vicús site at Pampa Juárez, excavated by Makowski (Kaulicke and Makowski 1990) in 1988 and 1989. Unfortunately no metallographic sections or analytical data are presented, but the sample is described as an unalloyed copper substrate supporting an irregular gold layer averaging 8 μm in thickness. The author proposes the use of an electrochemical replacement plating technique although surface layers thought to have been applied using such methods are generally much thinner.

Lechtman *et al.* (1982: 29) and co-workers describe the preliminary examination of some Vicús gilded copper plaques with pierced openwork designs. They report the gilding layers to be 'quite thick', and otherwise lacking features observed on the Loma Negra samples, and suggest that the plaques had not been gilded using an electrochemical replacement process.

Studies of extremely thin gold and silver layers on copper artifacts from archaeological contexts have proven to be difficult, in part because the lateral resolution of most conventional electron microprobes does not allow the compositional analysis of the layers without interference from signals originating in the metal substrate. In addition, the ubiquitous presence of archaeological copper corrosion products both on the surfaces of the artifacts and within the precious metal layers, and the solid state diffusion of elemental gold, silver and copper across the interfaces, add to uncertainties in establishing the original compositions of the gold and silver layers.

Loma Negra gilding layers

Presented here are the results of visual, radiographic and metallographic examinations carried out on samples of Vicús and Loma Negra gilded copper sheet at the Sherman Fairchild Center for Objects Conservation at The Metropolitan Museum of Art. These examinations were supplemented with scanning electron microscopy (SEM) and elemental analyses using conventional as well as high resolution energy-dispersive X-ray spectroscopy (EDS).[2] The results are compared to those reported by Lechtman and co-workers (Lechtman 1979; Lechtman *et al.* 1982), and to observations and data obtained from many of the Loma Negra artifacts examined previously at the Sherman Fairchild Center (Howe *et al.* 1993; Schorsch *et al.* 1996).

Gold and silver layers on artifacts from Loma Negra examined in the course of the present study were found to be of the same order of magnitude in thickness as those studied by Lechtman *et al.*, that is 0.5–2 µm (Fig. 13.8). Each layer is quite uniform in thickness and covers the entire surface of the substrate, including the inner walls of perforations and the edges of the thin hammered sheet, as well as all surface irregularities. The layers show no evidence of having been applied using metallurgical methods

Figure 13.8 Loma Negra unassociated dangle, backscattered image of metallographic section. Original magnification: 500× (Photograph: L. Carapia).

known to have been used in the New World, such as fusion or diffusion gilding,[3] or strictly mechanical methods involving the application of leaf or foil (Scott 1986b). Furthermore, as the samples contain no mercury, amalgam gilding was ruled out.[4] Depletion gilding, a method often observed on Andean metalwork that has been reported for gilded copper artifacts from the Moche site of Sipán (Eckmann 1993),[5] was also eliminated as a possibility because copper was the only metal detected in the Loma Negra substrates that were analysed at the Sherman Fairchild Center.[6]

EDS elemental analysis using an electron microprobe with a high lateral resolution (*c.* 0.5 µm) was carried out on samples removed from two representative artifacts. The beam was focused directly on the gilding layers, avoiding excitation of adjacent copper substrates and surface corrosion. The first object is a large disk that displays an owl (MMA1987.394.56) (Fig. 13.3). The owl itself is made of gilded copper, as are the border applied to the circumference of the disk, the dangles and the dangle wires. The disk itself is silvered copper. All of the various components were joined mechanically using tabs and slots.[7] The sample was removed from a tab that holds the owl to the disk. The second sample was taken from an unassociated Loma Negra dangle.

The analytical results for the two Loma Negra samples are shown in Table 13.1. Precious metal surface layers ranging in composition from 100% silver to 98% gold with 2% silver have been observed on the other Loma Negra artifacts examined (Schorsch *et al.* 1996).[8] Based on results of plating experiments carried out at the Sherman Fairchild Center, it can be stated that the ratio of gold to silver in a given layer is not necessarily identical to the starting ratio in the solution used for its deposition.

Table 13.1 Thickness and weight percent compositions of precious metal layers on Loma Negra objects. The weight percents Au, Ag and Cu were normalized to total 100.

accession number	wt %	Ag : Au wt %	thickness (µm)
1987.394.56	Au: 85.6 Ag: 11.0 Cu: 3.4	1 : 7.8	1–1.5
unassociated dangle	Au: 63.5 Ag: 18.8 Cu: 17.7	1 : 3.4	0.8–1.2

EDS point analysis was also used to study the compositional variation across the gold/copper interfaces. The distance to which gold and silver had diffused into the substrate was determined to be 2–4 µm on the two Loma Negra artifacts examined. The presence of a diffusion zone indicates that the artifacts – which had been repeatedly hammered and heated during their fabrication – were heated for the last time during or after the gilding had been applied.

Lechtman and co-workers noted pores in the precious metal layers in sections of replication samples prepared following the electrochemical replacement plating method they proposed. They suggested that the pores might result from the oxidation of copper atoms from the substrate during deposition of the precious metal layer but had difficulty in locating analogous pores in sections prepared from the ancient specimens because the interfaces between the copper substrates and the gold surface layers are invariably heavily corroded (Lechtman 1979: 159–60; Lechtman *et al.* 1982: 25). They also suggested that the extreme thinness of the ancient gold layers would make it difficult to locate pores that might be present.

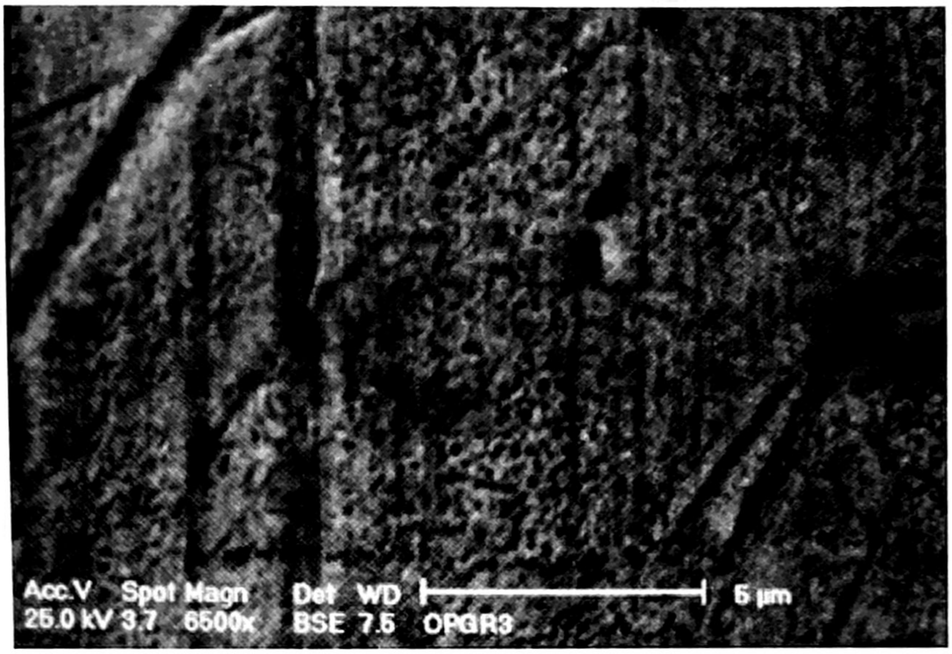


Figure 13.9 Replication sample (100% gold layer on a copper sheet substrate), prepared according to the electrochemical replacement plating technique proposed by Lechtman *et al.* (1982), backscattered image of the surface. Original magnification: 6500× (Photograph: L. Carapia).

An even distribution of pores (*c.* 0.1 µm in diameter) on the surfaces of replication samples prepared at The Metropolitan Museum of Art was observed using SEM(Fig. 13.9). Similar pores, though larger and less uniform in diameter (*c.* 0.2–0.4 µm), were seen on the surfaces of ancient samples (Fig. 13.10). The degree of porosity and the size of pores present in corrosion-free films formed by electrochemical replacement processes are affected by a large number of interdependent factors, including the initial condition of the metal substrate surface, in particular its cleanness and texture, and stirring conditions during the deposition process. Both the temperature and the duration of thermal treatments after deposition are also important variables (Visco 1974). With ancient artifacts it is very difficult to evaluate quantitatively the size and density of pores in the gilding layers at the time of application, especially because of physical alterations associated with the subsequent formation of corrosion. The three-dimensional morphology of the surface pores formed by electrochemical replacement processes differs markedly from that of channels and islands common in layers formed by depletion gilding tech-

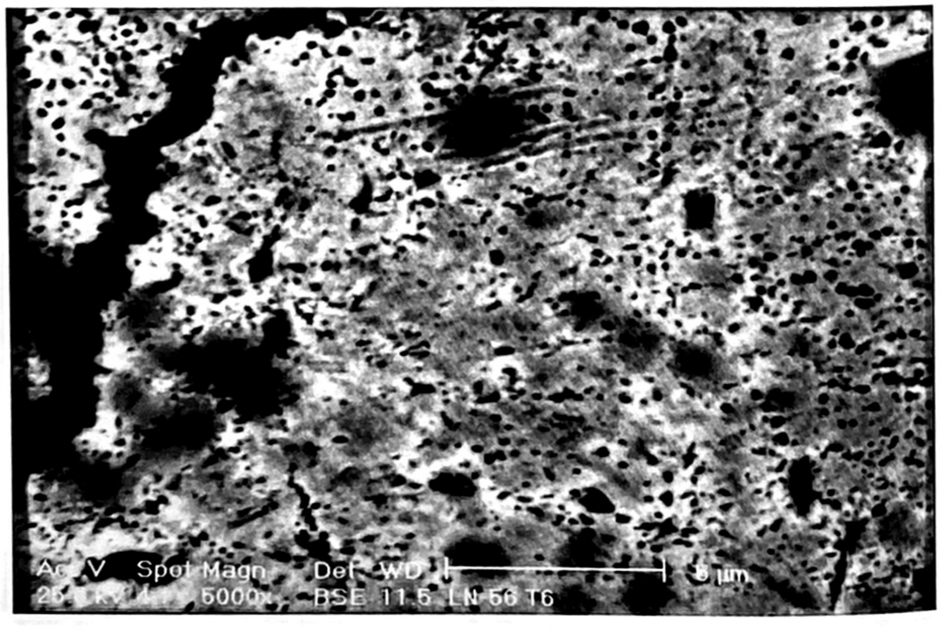


Figure 13.10 Loma Negra gilded copper sheet (MMA 1987.394.56), backscattered image of the surface of a sample. Original magnification: 5000×. (Photograph: L. Carapia).

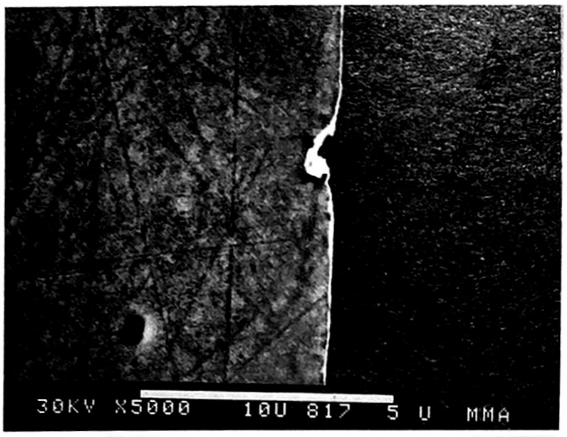


Figure 13.11 Replication sample (100% gold layer on copper sheet substrate), prepared according to the electrochemical replacement plating technique proposed by Lechtman *et al.* (1982), backscattered image of metallographic section. Original magnification: 5000× (Photograph: M.T. Wypyski).

niques, which also appear pit-like when the surface is viewed from above (Forty 1979; Forty & Rowlands 1981).

Of main concern to Lechtman and her colleagues (1982: 25) was sometimes finding ancient gold layers even thinner (*c.* 0.5 μm) than those on the replication samples they prepared. Following their technique, and varying deposition times and concentrations of the plating solutions, we were able to deposit, onto a copper substrate, uniform gold layers as thin as the thinnest layers observed on ancient specimens (*c.* 0.5 μm) (Fig. 13.11).[9]

Vicús gilding layers

The Metropolitan Museum of Art houses a small but representative collection of metal objects attributed to the Vicús culture (Figs. 13.4–13.7). Even though their provenance has not been established through scientific excavation, the artifacts have stylistic characteristics that make this proposed cultural association credible.

Preliminary metallographic studies of polished sections from several Vicús gilded copper artifacts indicate that the gilding layers are quite similar to those observed on objects from Loma Negra: they seem to be uniformly thin and cover all external and internal edges, including the inner walls of perforations, and surface irregularities entirely. As in the case of the Loma Negra materials studied, the gold and silver layers show no evidence of having been applied using any of a variety of mechanical or metallurgical methods known to have been used in the Old and New Worlds in ancient times.

More than twenty gilded or silvered copper Vicús artifacts in The Metropolitan Museum of Art and the American Museum of Natural History in New York were examined using an optical microscope. 'Wrinkles' were observed, particularly in areas of relief, on the surfaces of a number of these objects (Fig. 13.12). The wrinkles are due to a failure of the bond between the gold layer and the substrate but the exact cause of the failure is unknown. Similar wrinkles have not been observed on gilded and silvered copper artifacts from Loma Negra.

Three Vicús ornaments were selected for metallographic study and elemental analysis. The first is a rectangular plaque with pierced openwork (MMA 1987.394.252) (Fig. 13.6: left) with gilded copper dangles suspended from flat wires of gilded copper. A sample was removed from a dangle wire located in the second row from top on the proper right side of the plaque. Two other plaques (MMA 1987.394.596 & 1987.394.598) (Fig.

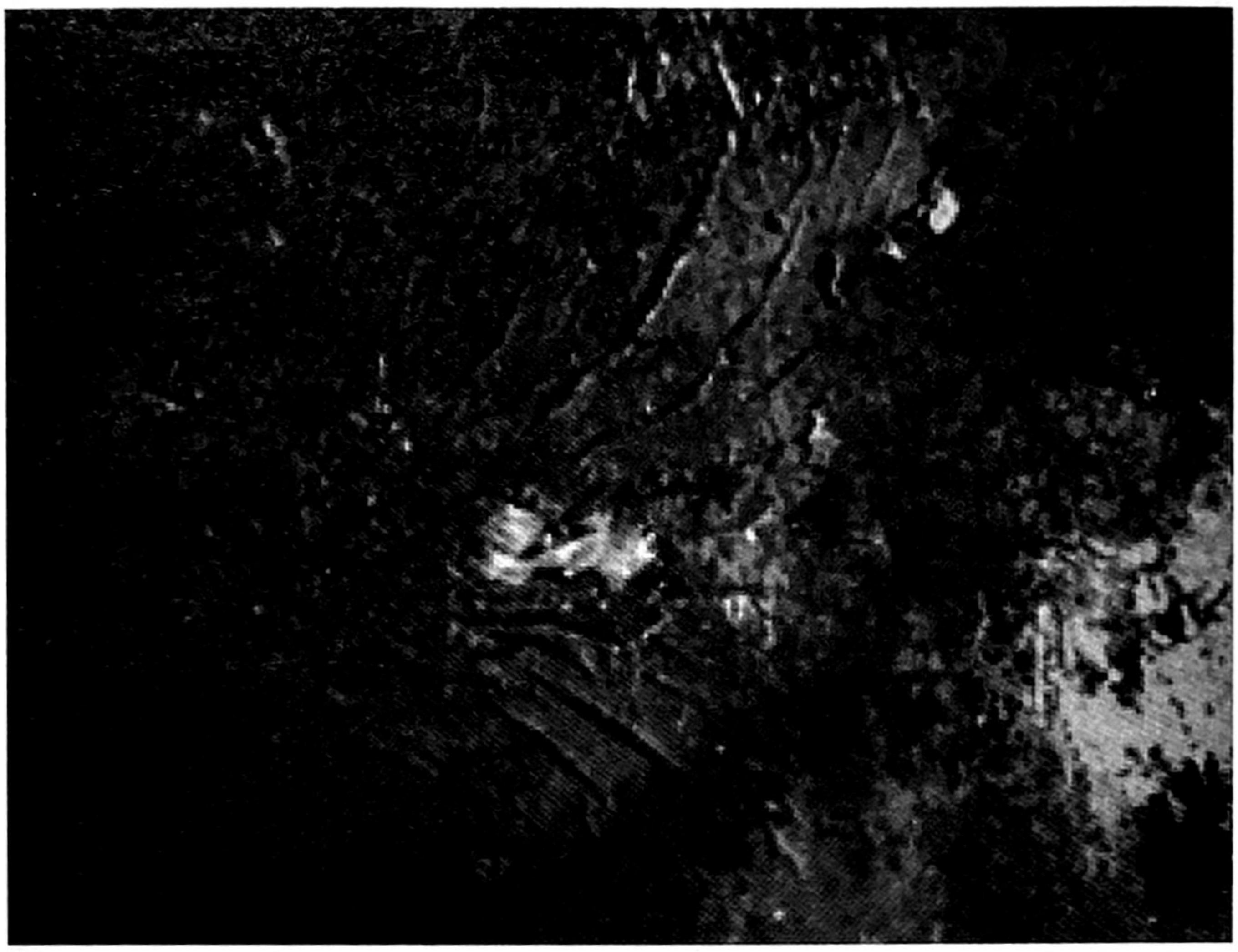


Figure 13.12 Gilded copper plaque, Vicús (MMA 1987.394.597), photomicrograph of the surface showing the presence of wrinkles. Original magnification: 35× (Photograph: E.G. Howe). (See Plate 77.)

13.7) were also sampled. Each depicts the head of a feline, with the contours of the face, as well as the eyes, nose and mouth, slightly raised from a flat sheet. Gilded copper dangles, almost all of which are now lost, were attached near the perimeter of each plaque using wires of gilded copper. Each plaque also has four holes distributed along its edges that served to mount it onto a supporting material. Two larger holes below each of the raised noses appear to represent nostrils. The samples were removed from a dangle wire on the proper right side of MMA 1987.394.596, and from a dangle on MMA 1987.394.598.

Examination of the three sections revealed precious metal layers measuring in thickness on the order of those observed on artifacts from Loma Negra, that is 0.5–2 μm (Fig. 13.13a–c and Table 13.2). In each case the interfacial region between the copper substrate and the gold layer is corroded. The bulk of the copper substrate in the sample from the second feline plaque (MMA 1987.394.598) is completely mineralised and above the gilding layer a thick crust of copper corrosion products can be observed, averaging 20 μm in thickness (Fig. 13.13c).

Elemental analyses of the more well preserved gilding layers on the geometric plaque and the first feline plaque indicate that they are primarily gold, silver and copper with minor amounts (1–2 wt %) of impurities such as silicon, iron and aluminum (Table 13.2). The results of analyses of multiple spots along the highly corroded sample from the second feline plaque

Table 13.2 Thickness and weight percent compositions of precious metal layers on Vicús objects. The weight percents of gold, silver and copper were normalised to total 100.

accession number	wt %	Ag : Au wt %	thickness (mm)
1987.394.252	Au: 43.4 Ag: 12.0 Cu: 44.6	1 : 3.6	1–1.5
1987.394.596	Au: 48.0 Ag: 12.2 Cu: 39.8	1 : 3.9	0.5–1
1987.394.598	–	1: 3.0	0.8–1.2

(a)
(b)
(c)

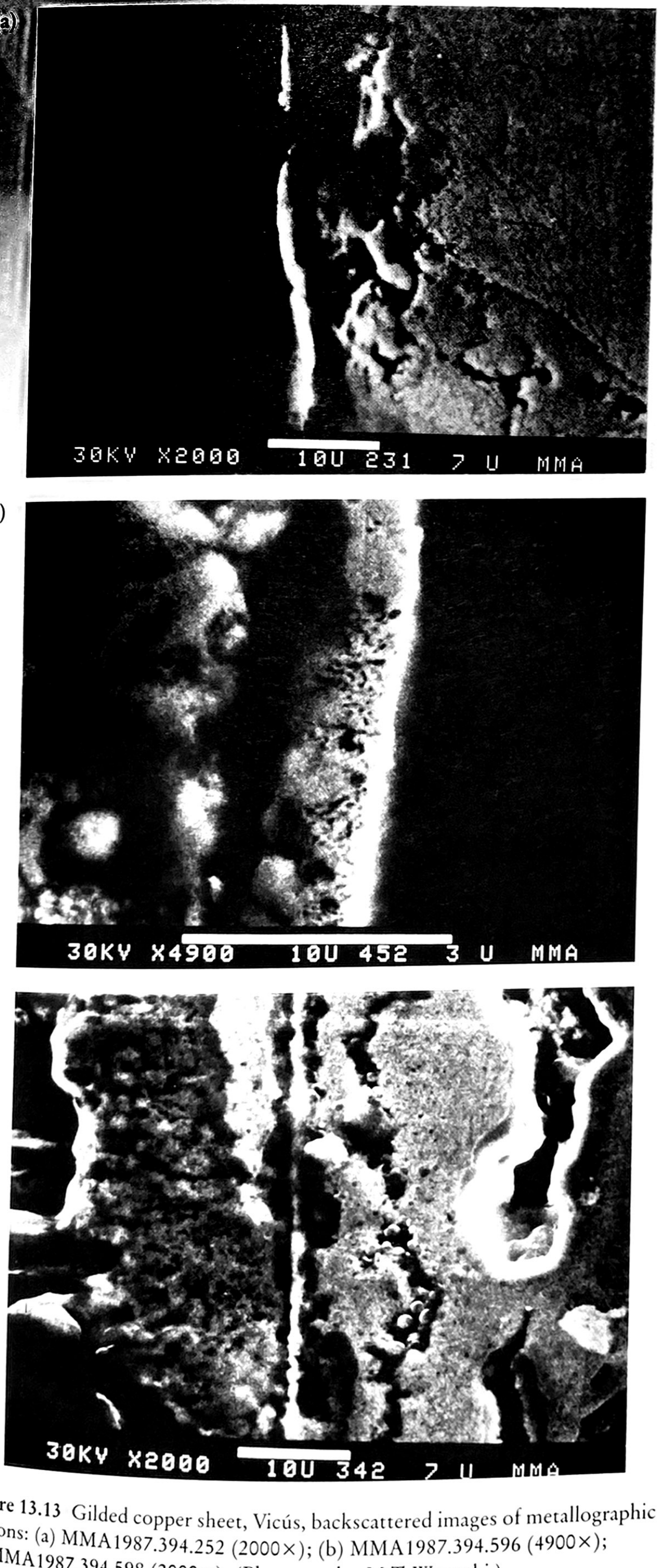
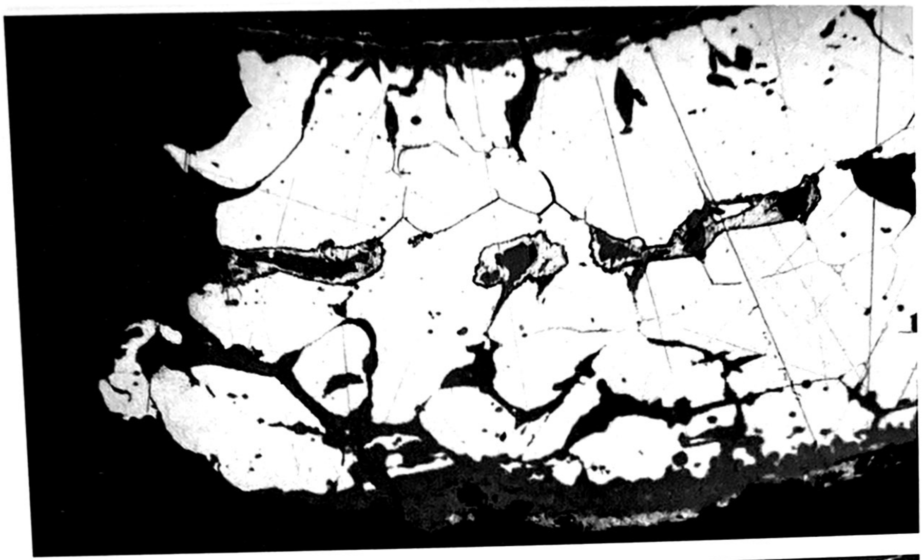


Figure 13.13 Gilded copper sheet, Vicús, backscattered images of metallographic sections: (a) MMA1987.394.252 (2000×); (b) MMA1987.394.596 (4900×); (c) MMA1987.394.598 (2000×). (Photographs: M.T. Wypyski.)



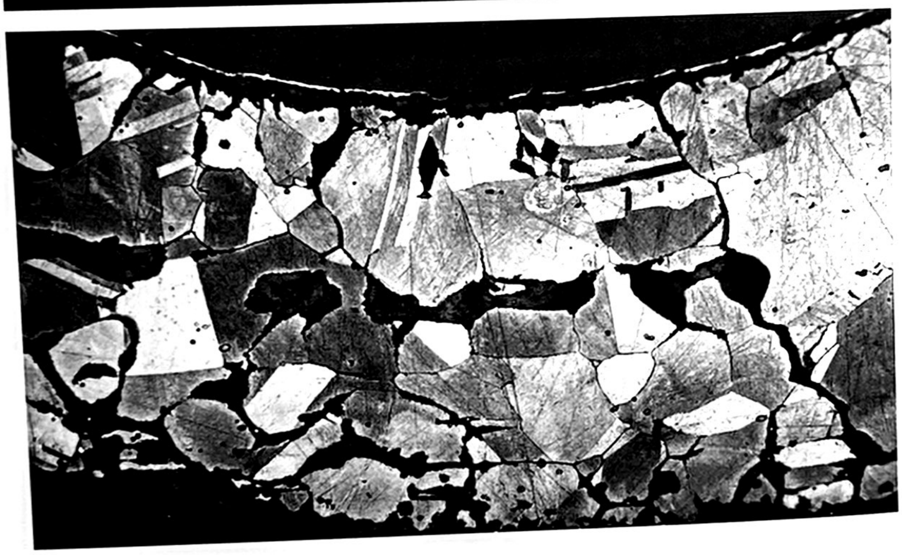


Figure 13.14 Gilded copper sheet, Vicús (MMA1987.394.252), metallographic section observed before (a) and after etching with an alcoholic ferric chloride solution (b). Magnification: 200×.

(MMA 1987.394.598) were so variable that only the average gold to silver ratio, which was found to be fairly consistent, is reported (Table 13.2). Copper is the only metal detected in the interiors of all three substrates.

The production of metal sheet from cast ingots requires repeated hammering and reheating. The presence of recrystallised grains with abundant twinning within the copper substrate of the openwork plaque (Fig. 13.14a,b) indicates that heating was the final step in its manufacture. EDS

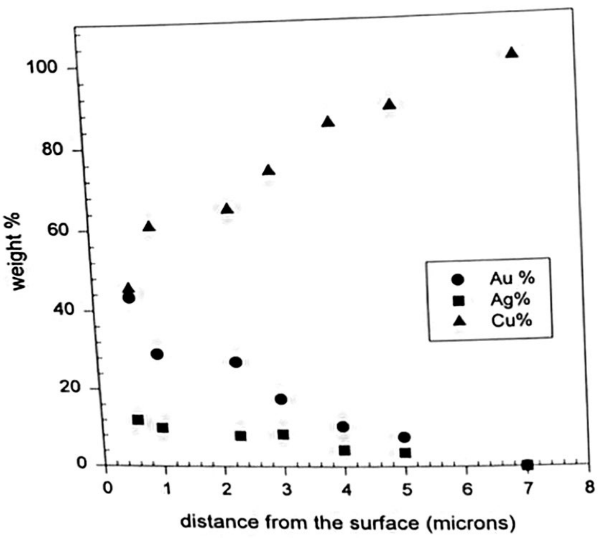


Figure 13.15 Weight percents of gold, silver and copper (normalised to total 100%), as a function of the distance from surface (MMA1987.394.252), as detected using EDS.

spot analyses were carried out on the two better preserved Vicús gilded copper sections in order to study compositional variations across the interface between the gold layer and the substrate, and the results for the openwork plaque were plotted in relation to the distance from the surface (Fig. 13.15). The diffusion of gold into both substrates to a depth of 5–6 μm suggests that, as in the case of the Loma Negra pieces, the gold was applied before the final reheating.

SEM was used to characterise and record the surface morphology of the Vicús samples before they were mounted for metallography (Fig. 13.16). In backscattered images of the gold layer on the openwork plaque (MMA 1987.394.252) a crack in the gilding and dark regions of corrosion can be

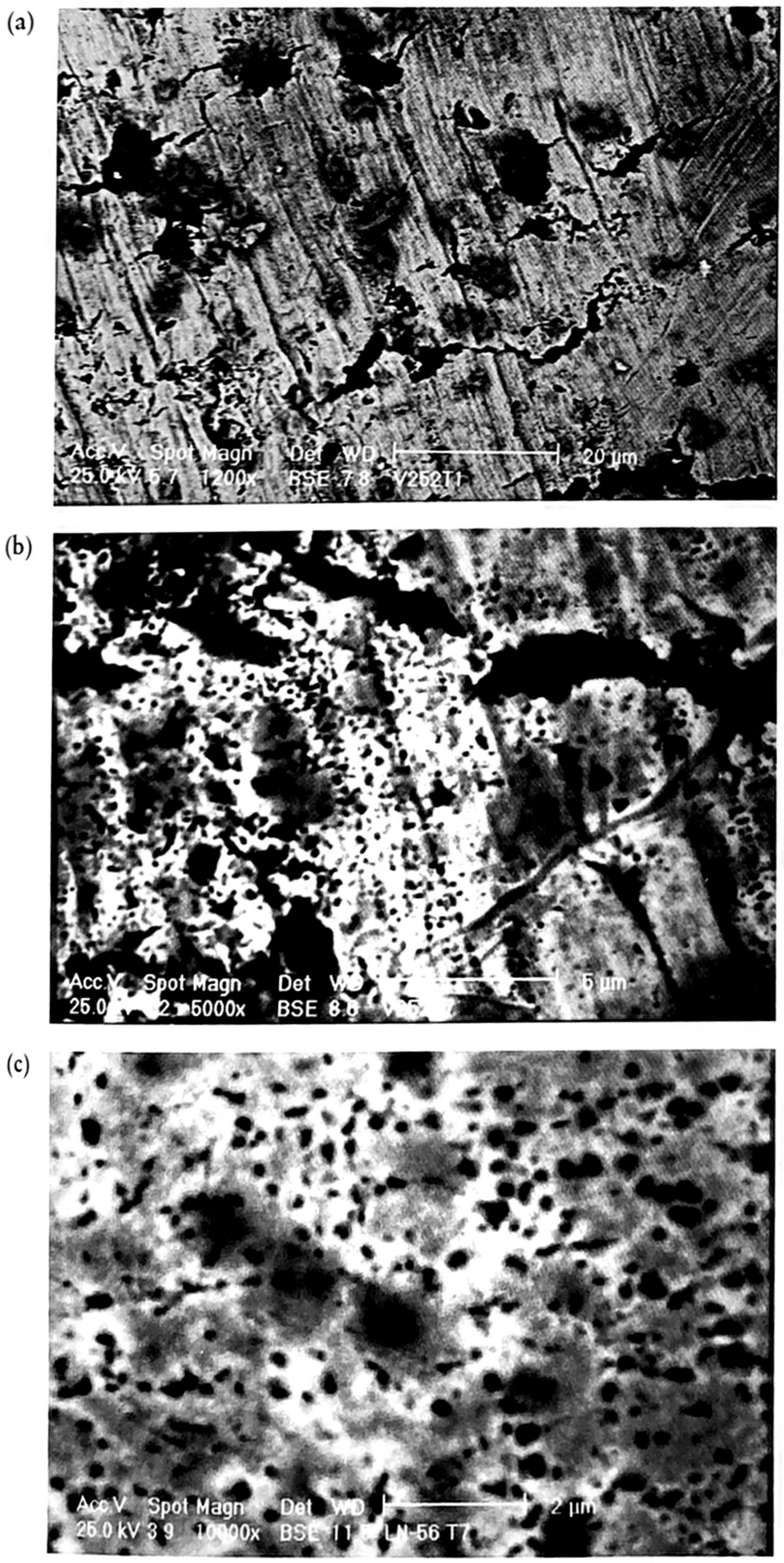


Figure 13.16 Gilded copper plaque, Vicús (MMA 1987.394.252), backscattered images of the surface: (a) 1200×; (b) 5000×; (c) 10 000×. (Photographs: L. Carapia.)

observed, as well as scratches on the surface. It was not possible to determine if these scratches were introduced during manufacture or subsequent to the removal of the plaque from its burial environment. The most important feature observed on the surface is a non-uniform distribution of pores (*c.* 0.1–0.2 μm) in diameter, similar to those observed on the Loma Negra surfaces (Fig. 13.10) and on the replication samples gilded using an electrochemical replacement technique (Fig. 13.9).

Conclusion

Metallographic examination and SEM and EDS analyses have revealed that gold layers on Vicús and Loma Negra copper substrates share important features, such as surface morphology, including the presence of pores, as well as extreme thinness, uniformity, and the presence of an interdiffusion zone at the copper-gold interface. None of the gold layers on the Vicús or Loma Negra objects studied show any evidence of having been applied as leaf or foil, or using amalgam, fusion, diffusion or depletion gilding techniques.

Two differences in the precious metal layers on artifacts associated with Loma Negra and those assigned to the Vicús culture can be noted. 'Wrinkles' were observed only on the latter objects. The wrinkles result from local failure in the bonding between the gilded layer and the copper substrate, but whether this occurred at the time of manufacture, or developed subsequently during use or burial, is difficult to establish.

A second difference is the amount of copper detected in the gold layers of the Loma Negra and the Vicús samples (Tables 13.1 and 13.2). Far more copper, up to a maximum of 44.6 per cent, was detected in the Vicús samples; in the two Loma Negra gold layers analysed under identical operating conditions using the same high-lateral resolution electron microprobe, the copper content does not exceed eighteen per cent. It is probable that a significant contribution to the EDS signals comes from copper that has migrated into the gold layer as a result of corrosion processes.[10] In addition, copper atoms diffuse through the gold layers as a consequence of thermal treatments – the resulting bond being necessary to improve the adhesion of the gold to the substrate – both along grain boundaries and through defects in the film (Guillet *et al.* 1985).

As mentioned previously, gold and silver diffused 5–6 μm and 2–4 μm into the copper substrates of the Vicús and Loma Negra samples respectively, as measured from their surfaces. It is possible that longer thermal treatments were applied to the Vicús pieces, which would explain, although only in part, the higher copper content detected in the gold layers on Vicús objects. It should be noted that the composition of the precious metal layers and the approximate distances that gold and silver diffused into the substrates have been calculated for only two samples from each group; more representative values might be established using a larger number of samples.

In spite of these two differences, the evidence obtained thus far suggests that the same method was used in the manufacture of both Moche gilded and silvered copper artifacts from Loma Negra and those made by their Vicús neighbors. The experimental reexamination of the electrochemical replacement process proposed by Lechtman and her colleagues allowed us to recreate gilding layers as thin as the ones on Moche and Vicús objects from the Piura Valley, and to relate other properties, such as porosity, to features observed in the gilded surfaces of the ancient artifacts.

The method of gilding used on the Loma Negra artifacts differs from the depletion gilding process observed on Moche copper objects from Sipán, which was used by other Central and Northern Andean cultures as well. The use of the same method by both the Moche at Loma Negra and their Vicús neighbors suggests that the electrochemical replacement plating process is part of the shared metallurgical tradition of the Piura Valley during the Early Intermediate Period.

Further analysis using high resolution transmission electron microscopy and electron diffraction is in progress in order to determine crystalline structure, morphology and particle size in gilding layers from the Piura Valley and in the replication samples. [11]

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Notes

1. Fusion gilding describes a process of applying a molten gold alloy to metal or alloy with a higher melting point. The substrates can be dipped into a molten bath or, if only one surface or area is to be coated, the gold can be flushed on locally. The use of these techniques by pre-Columbian metalworkers at La Tolita, Ecuador and in the Nariño region of Colombia has been studied by Bergsøe (1938) and Scott (1986a,b). The thickness of gold layers applied in this manner are typically upwards of 100 μm (Scott 1986a,b).
2. Conventional EDS analysis was carried out by Mark T. Wypyski at The Sherman Fairchild Center for Objects Conservation, and analysis using a high resolution electron microprobe was carried out at Instituto Nacional de Investigaciones Nucleares (ININ), Mexico, by Leticia Carapia and Jesus Arenas.
3. Diffusion gilding involves the application of foil or leaf to a metal surface, followed by burnishing and heating. This technique has been reported for pre-Columbian metalwork from Ecuador (Scott 1986b).
4. Amalgam gilding has never been found on pre-Columbian metalwork from South America (Bray 1993: 183) although the use of cinnabar in a variety of Andean contexts , including the Vicús site at Cementerio Yécala, has been reported (Ríos & Retamozo 1993: 46).
5. Exceptionally, the backplates and shafts of a pair of Loma Negra earflares (MMA 1979.206.1245 and 1246) (Lechtman *et al* 1982: 7), as well as a pair of appliqués that were probably earflare frontal ornaments (MMA 1979.206.1234 and 1235), were gilded using a depletion gilding method (Schorsch *et al.* 1996: 153).
6. Lechtman *et al.* (1982: 12) reported finding approximately 1 per cent silver by weight in copper substrates of Loma Negra gilded and silvered objects that they

examined. Copper came into widespread use in the Central Andes during the beginning of the Early Intermediate Period (Lechtman 1980: 289), but arsenical copper did not appear until the subsequent Middle Horizon (*c.f.* Lechtman, 1975; Lechtman 1988, 1991)

7. For the construction of this object described in depth, see Schorsch (1998: 115–16).
8. Because of their inability to resist attack from the burial environment, silver-rich layers on the Loma Negra objects often survive only as isolated particles on the copper substrate. For this reason silvered copper samples were not chosen for detailed measurements of thickness or composition in this study.
9. The gold layer in the section shown in Figure 13.10 was obtained by dipping the copper sheet into the plating solution for a few seconds. Lechtman *et al.* (1982: 16) use a deposition time of five minutes in order to obtain a 1 μm thick layer. It is also possible to obtain thinner precious metal layers by lowering the concentration of gold and/or silver ions in the plating solution through the addition of water.
10. The oxidation of copper at the surface of the gilding layer has a direct effect in the extent of diffusion because it removes copper atoms, enhancing further diffusion from the substrate (Pinnel 1979).
11. This work is being undertaken in collaboration with M. José Yacaman and J. Rendón from the Universidad Nacional Autónoma de México and the Instituto Nacional de Investigaciones Nucleares (ININ), Mexico.

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