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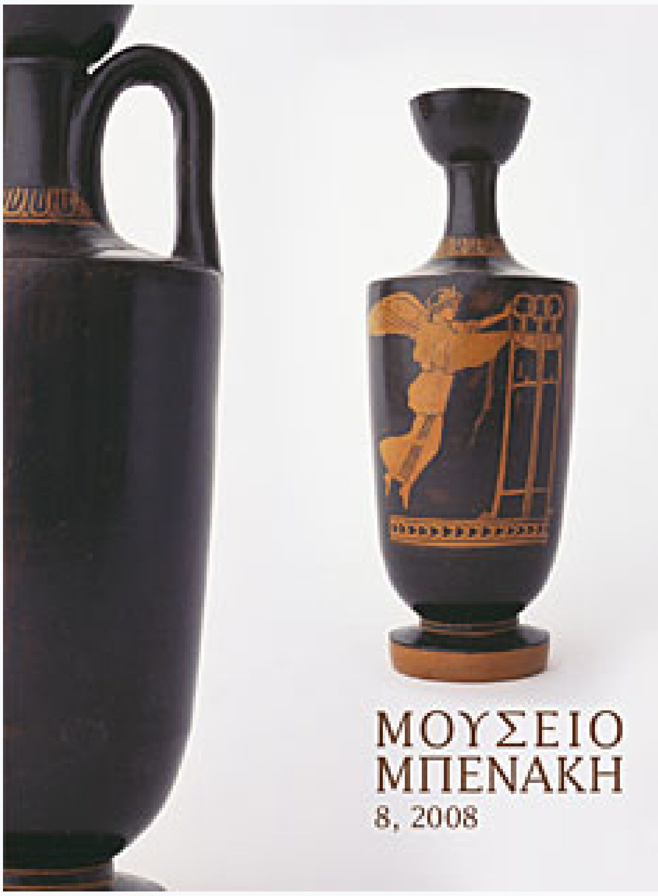

The golden kylix inv. no. 2108 of the Benaki Museum: Technical report

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Because of Irini Papageorgiou's study[1] on the Benaki golden kylix (henceforth called footed cup or cup) (figs 1, 3), it is now considered essential to ascertain its authenticity and establish a more precise dating for this object, which, on the basis of some of its features, is dated to the Mycenaean period.

It is well known that the dating of metal artefacts presents difficulties[2] and that answers to questions about their authenticity cannot be found in isolation. The answers to such questions usually lie in a combination of factors, ascertained after investigation of the technology used to make and decorate them, the chemical composition of their metal and corrosion products, as well as the object's overall state of conservation.

Various methods of analysis were used to investigate the specific characteristics of the cup. In the laboratory of the Conservation Department of the Benaki Museum the overall surface of the object was examined with a stereoscope and of a sample there under an optical microscope. The same sample was also observed under a scanning electron microscope (SEM) at the Athens Technological Educational Institution (TEI) and in the Archaeometry Laboratory of the Institute of Materials Science, 'N.C.S.R' Demokritos. It was subjected to X-radiography and the elemental composition of the alloys was determined by using X-Ray Fluorescence (XRF) analysis, in the Radiography Laboratory and the Institute of Nuclear Physics respectively of 'N.C.S.R' Demokritos.

Crucial to this whole process of investigation was comparing the technical and chemical characteristics of the footed cup with other objects of similar metal composition and shape, which could be dated to the probable period of its production. Four gold footed cups were chosen (inv. nos 959, 957, 656 and 427) and a golden cup from the Mycenaean period (inv. no. 8743) from the Athens National Archaeological Museum; and also seven pieces of gold jewellery from the Thebes 'Jewellery Ensemble' (inv. nos 2063, 2070, 2075, 2079, 2069a, 2080 and 2068), together with two gold items (Imre Somlyan donation) from the Benaki Museum, dated to the same period. All the artefacts from the Archaeological Museum were examined macroscopically and three cups were also examined microscopically. X-Ray Fluorescence was used to analyse their composition and this was carried out in the Metals Conservation Lab of the Archaeological Museum. The same method was used to ascertain the composition of the Benaki Museum jewellery.

Macroscopic observations

Macroscopic examination of the cup determined that it is made up of four separate pieces of gold, appropriately hammered into shape and joined together. The three main parts (body, foot and base) are attached to one another using a hard solder (chemical attachment), whereas the handle was attached with rivets (mechanical attachment). The body was decorated with three hounds in relief, while the handle had stamped ivy leaves. On the base of the body a very small, round centre mark can be seen on both inside and outside.

The metal used in its construction is hard.[3] Its overall surface displays irregularities – possibly the result of its being shaped by hammering – and has an 'orange-peel' appear-

Fig. 1. The golden kylix. Athens, Benaki Museum, inv. no. 2108 (photo: M. Mathios).

ance. Smaller areas of the surface, mainly on the outside of the body, present a fish-scale appearance. In fact, some irregularities seem to have been entirely smoothed out in the process of grinding and polishing. The overall surface has a reddish tint which is more intense on the inner and outer surfaces of the handle, particularly around the riveted joints. Finally, traces of soil were found inside the foot, near the base of the body.

Microscopic observations – analysis

Construction

The initial evaluation of the way in which the cup was

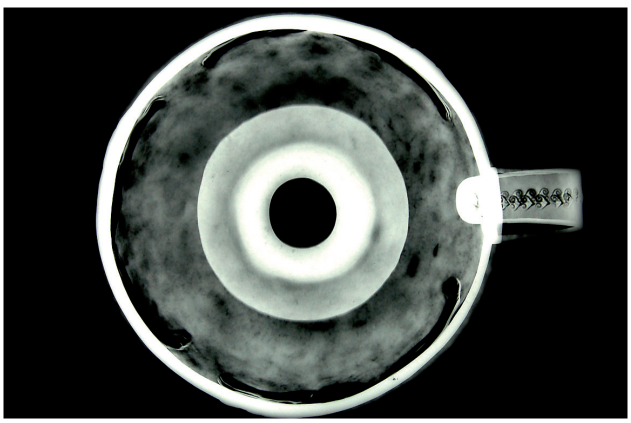


Fig. 2a-b. X-ray image of the kylix, showing a) the marks left by the tool used for the hammering process; b) the attachment areas between body, foot and base; c) the way the foot was formed from a coiled sheet of gold hammered into shape (the joining of its edges is visible); d) the circular centre mark on the base of the body. Athens, Benaki Museum, inv. no. 2108.

crafted was confirmed using microscopic observation and by examination with X-radiography. The object was examined under an Olympus SZX9 stereoscope at magnifications ranging from 20x - 100x. Irregularities were observed, which can be attributed to the way the metal was formed, while radiography showed up the impressions left by the tool the metalworker used in the hammering process (fig. 2b).

Microscopic examination also confirmed the presence of the two round centre marks on the base of the cup's body. One is visible on the inside of the body (fig. 3a) and the other on its outer surface through the tubular foot (fig. 3b).

The external centre mark is the impression left by the punch.[4] Its presence can be explained by the fact that the body of the cup is hollow and this sort of mark was often used as a reference point for different measurements[5] in the various stages of production of objects of this shape.[6] Indeed according to Untracht,[7] it was traditional for the mark to remain intact in such products.

However, the presence of the centre mark on the inside of the body raises some issues. Usually the co-existence of the two impressions indicates the polishing or even decorating of metal objects on a lathe,[8] practices which were more widespread from the fifth century BC onwards,[9] in cast wares.[10] Perhaps the internal centre mark had exactly the same function as that identified on the outer surface of the body.

Decoration

The upper part of the body of the cup is decorated with three hounds in relief. These figures (fig. 3c) might first have been worked in repoussé and then chased. But, because of their great similarity and the fact that it is difficult to find traces of hammering on the inside, it seems possible (although it is a more difficult technique) they were created on a cast former, a way of decorating metal surfaces which was relatively widespread in antiquity for relief designs and repeated motifs.[11] The technique dates from the second millennium and possibly earlier.[12]

If a cast former was used, it would have been applied to the interior of the body. Yet there are visible traces of hammering on the outer surface (fig. 3d-e).

A pattern punch with the ivy leaf design on the end has been used for the repeated motif on the handle which is applied by stamping, so as to impress the design onto the surface of the metal. The embossed leaves are in relatively low relief (fig. 3f).

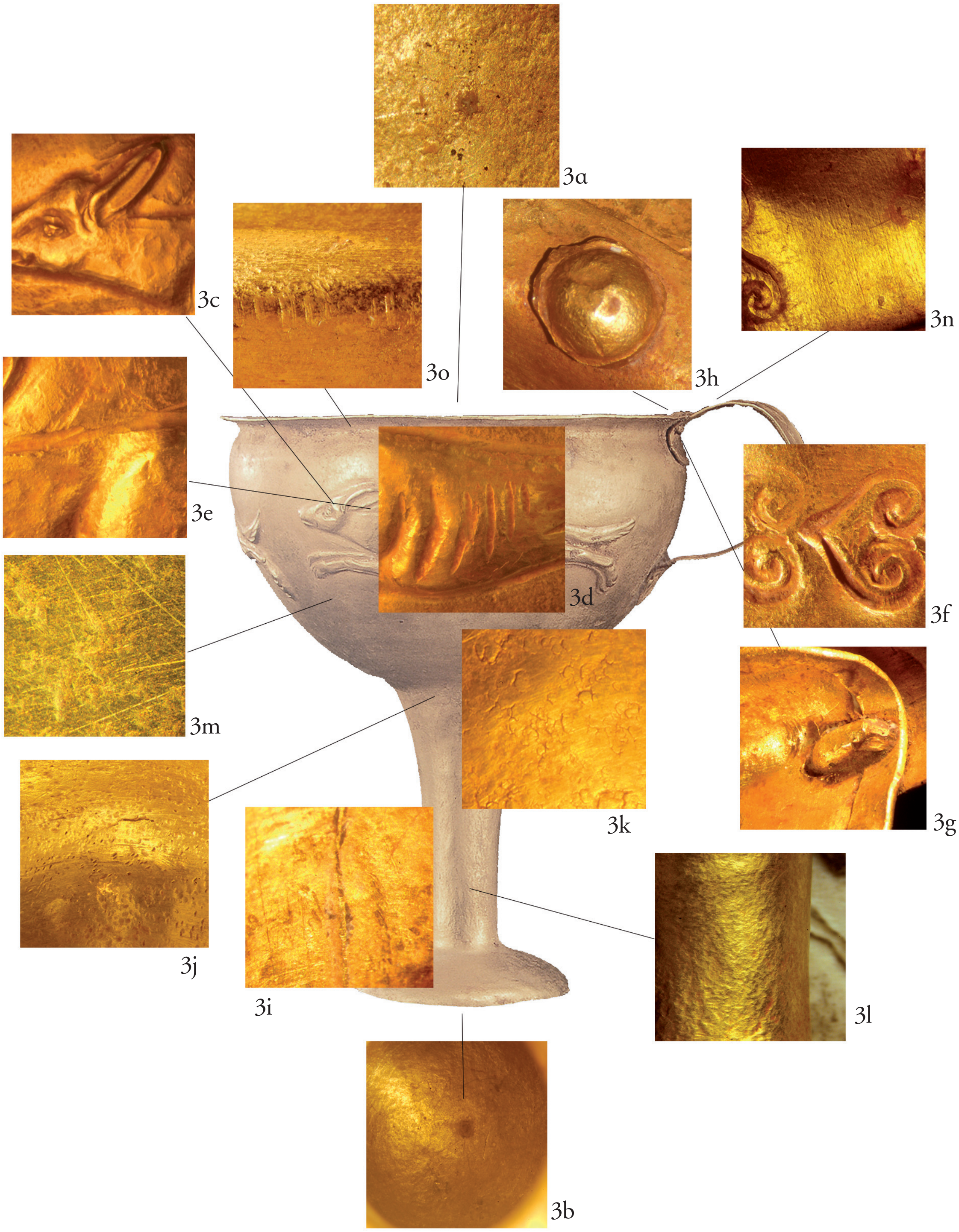


Fig. 3. Stereoscopic image of the golden kylix. Athens, Benaki Museum, inv. no. 2108. 3a-b: The circular centre marks on the inside and outside of the body. 3c: The figure of a hound, traces of working. 3d-e: The traces of 'working' on the outer surface. 3f: The ivy leaves in relief. 3g: The way in which the rivets have been attached with a simple turn. The cut at the end was made with scissors. 3h: The cutting and filing of the heads. 3i: The area of the joint on the inside of the foot. Faint colour difference. 3j: The attachment between the foot and body with signs of grinding and indentations. 3k: The patterns on the surface which recall the crystal structure of the metal. 3l: The 'orange peel' effect. 3m: The irregular scratches from the use of sandpaper. 3n: The parallel ridges left by the use of a rolling mill. 3o: The grooved impression left by a modern nipper.

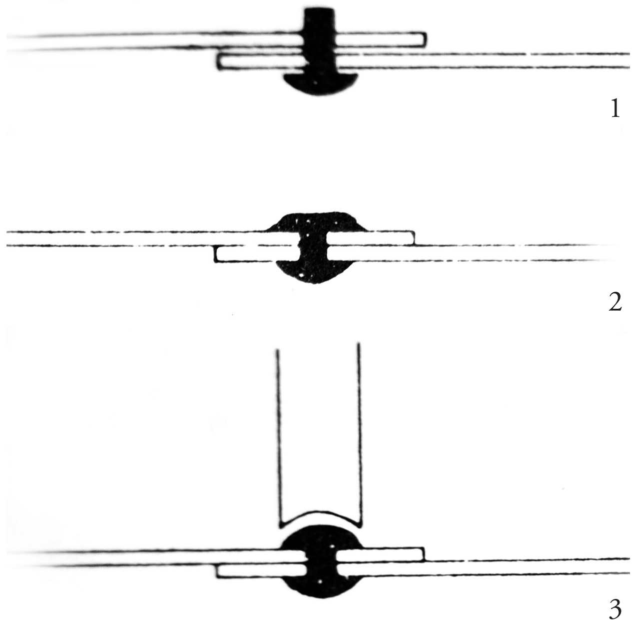


Fig. 4. The usual manner of manufacturing, fitting and fixing rivets as shown in H. Hodges, *Artifacts: An Introduction to Early Materials and Technology* (London 1976) 77.

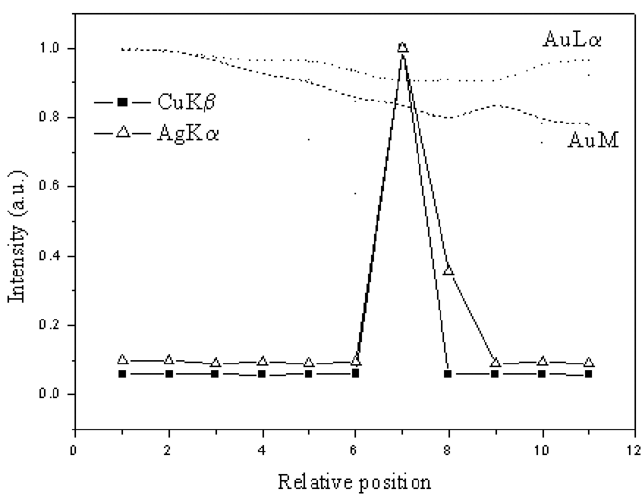


Fig. 5. μ-XRF spectrum, from scanning an area on the foot of the cup, where, according to the X-ray (fig. 2a), there was a join. Substantial ratios change of the characteristic Ag, Au, and Cu X-rays intensity in the areas with solder.

Attachment

As was mentioned at the beginning, the cup is made up of four parts joined together. Of these only the handle was fitted using mechanical means, i.e. using 4mm-diam. domed rivets – a popular way of joining metal constructions in antiquity from the third millennium.[13] The way they were made and fixed is shown in fig. 4. A thin, short rod was used, its two ends being hammered into place so as to join the metal parts.

The manufacture of two out of three of the rivets used on the cup, and more particularly their attachment, do not seem to follow the well known ancient techniques. The way they are attached and fixed, with a simple turn of one end – once they have passed through the body of the cup and then the hammered sheet forming the handle so as to end up on its inner side – is not consistent with the usual way of constructing rivets (fig. 3g).

They are domed rivets with a ridge formed by a snap. This way of forming made the attachment stronger, at the same time giving a more pleasing appearance, as rivets also had a decorative function in antiquity.[14] However, this method of constructing the rivets is not entirely acceptable from a chronological point of view. The cutting and filing of the ornamental, domed heads (fig. 1h) and the use of scissors to cut the end of the rod (fig. 3g) are more reminiscent of relatively modern methods.[15]

A chemical means of attachment (i.e. soldering), also known in antiquity from the third or perhaps the fourth millennium,[16] was used to join together the body, the foot and the base of the kylix. The foot, a cylindrical construction made from a sheet of gold which had been beaten into a coil by hammering, was joined using the same solder before being attached to the body of the cup. Under microscopic examination the four joints were identified, and displayed a slight difference in colour (being more yellowish) from the colour of the main metal (fig. 3i). The contact points were confirmed by X-raying the object (fig. 2a). Of particular interest was the contact surface between the body and the foot, where heavy scoring and small indentations were identified in the solder (fig. 3j). These are usually observed in joints where the alloy of the solder has been overexposed to high temperatures – called burning by goldsmiths – and afterwards efforts would be made to iron out the irregularities left by the careless soldering.

The difference in colour found in the solder, i.e. more yellowish than the gold of the cup, is often due to an alloy

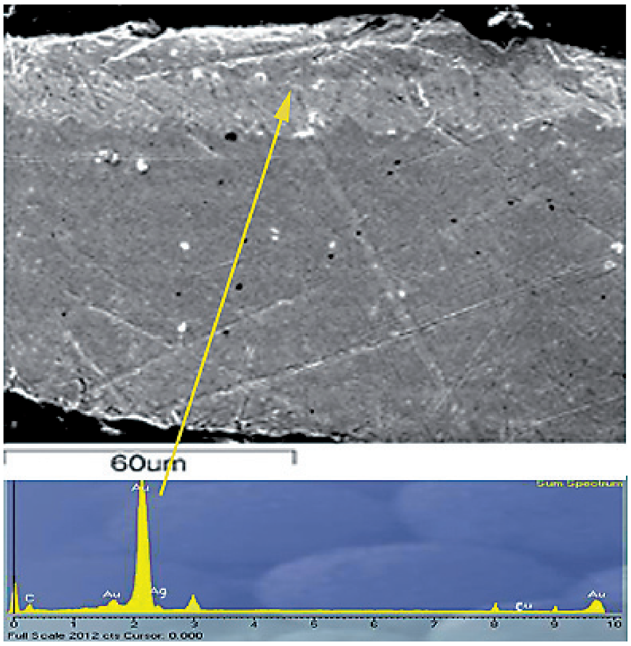


Fig. 6. SEM image of the area of the sample on which solder is likely to be present. Two zones can be distinguished. The upper one (tonally weaker than the lower) is attributed to the solder (see chemical cartography). Clear image without internal hairline stress or intergranular corrosion.

containing silver. Indeed, by using qualitative scanning with the micro X-ray fluorescent method (μ-XRF)[17] on an area of the foot (fig. 5), where, according to X-radiography, there was a join, it was possible to estimate the gold alloy as containing *ca*. 10.10% silver and *ca*. 0.72% copper.[18]

The composition of the alloy used in the solder was confirmed by quantitative and qualitative analysis of a small sample extracted from the foot of the cup[19] using Jeol JSM-S310 electron microscope scanning (fig. 6). In general the sources refer to the use in antiquity of gold alloys containing silver or copper, whether naturally occurring products selected on grounds of practical experience or produced by deliberate alloying.[20] Indeed the silver and copper content varies according to their provenance,[21] the period of manufacture[22] or the colour of the gold used to make an object.[23] Nevertheless any solder, whatever the composition of the alloy, had to achieve an acceptable aesthetic result (i.e. to be invisible to the naked eye) and it was essential that its melting point should be lower than that of the metal to be joined.[24]

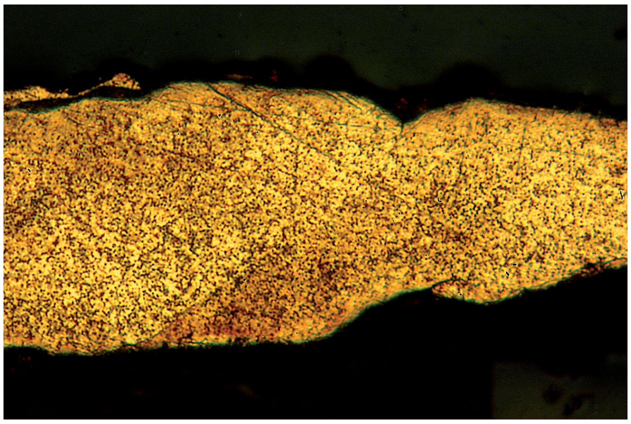
The melting point of the solder used on the cup was indeed lower than that of the gold used to make the cup. Given its composition, it is calculated that the temperature required to melt an alloy of this type would be of the order of 1050° C,[25] while the melting point of the cup's gold, because of its great purity (see the section on *Composition*), is about 1064° C. The temperatures used for the solder on the cup are extremely high. Usually in antiquity mention is made of the use of gold alloys with high silver content and very little copper,[26] or with high levels of copper and little or no silver which has a more drastic effect on the melting point of the gold reducing it to 910° C.[27] A kind of a flux was always applied during the joining procedure.[28] Copper salts or minerals[29] with some sort of flux – as in the case of the hard solders mentioned above – were also used to attach gold and require more reduced melting temperatures of around 850° C[30] even lower, between 800° and 700° C.[31] Perhaps this is why such compounds were especially used for fine work.[32]

Surface Appearance

As was ascertained by microscopic examination, almost the whole surface of the cup (both inside and out) resembles orange peel. Microscopy also identified irregular scratches and cracks, which were more obvious on the outer surface and above all on the concave part of the body of the cup. Indeed some of these cracks have joined up in such a way that the resulting shapes on the surface of the metal recall the metal's crystal structure (fig. 3k). This accounts for the fish-scale patterning observed macroscopically. These details are not recorded clearly in X-radiography.

The cracks and more importantly the forming of the equiaxed grains on the surface of a metal and in particular of gold, usually indicate stress cracking corrosion, caused by internal tensions in the bulk metal, which have an increased rate of corrosion when combined with burial in the ground over a long period. These inner tensions are usually caused either by the hammering process and poorly controlled annealing,[33] aimed at removing them,[34] or by the process of grinding and polishing the gold.[35] However, the degree of stress exerted in the hammering process is much greater than that caused by the grinding and more particularly the polishing process.[36] The level of stress is affected by two basic factors: the humidity of the burial environment[37] and the relative purity of the gold alloy.[38]

According to Rapson,[39] the second factor is especially significant. He considers that stress cracking corrosion rarely occurs in gold alloys of over 14 carats, in which concentra-



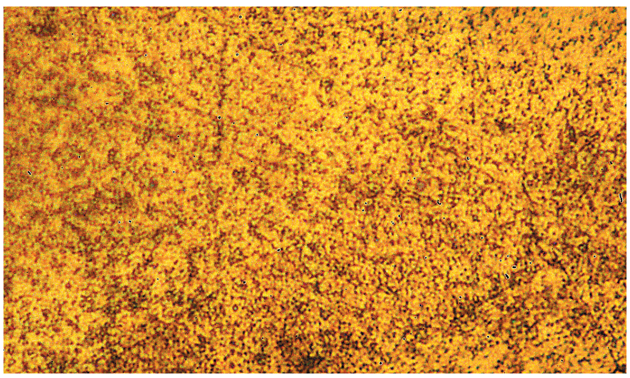


Fig. 7. Optical microscope image of the sample with the area of solder (top). Annealed dendritic crystal structure (100x).
Fig. 8. Same sample. No internal stress or intergranular corrosion is visible (200x).

tions of silver and copper are small and which are much less vulnerable when in a corrosive environment.[40] The gold of this cup is of this type according to the results of the chemical analysis of the cup's metal, as given in the *Composition* section.

In order to ascertain the causes of the tiny cracks and the 'crystals', the sample from the foot of the cup[41] was mounted in Epofix epoxy resin and examined under Olympus AX70 reflected polarized light microscopy and electron microscope scanning at magnifications of between 100x and 500x and 750x and 2000x respectively .

From examination of the sample's microstructure (figs 7, 8), there seemed to be no sign either of internal hairline cracks or of intergranular corrosion, to confirm the initial hypothesis about stress cracking corrosion.

This evidence leads us to the conclusion that the signs on the surface are the result of stress caused by the techniques used on the cup, independent of any effects of burial (if it is assumed that the cup was indeed found buried in the earth).

In accordance with the foregoing an inadequately controlled level of hammering and excessive period of heating in the process of forming the cup could be the cause of the hairline cracks and the grains.[42] Something of the kind might be thought natural, given that these characteristics are mainly observed on the body and in particular on the concave part of the body, where deformation is most difficult. Poorly controlled hammering and annealing as well as heating during the soldering process, could also have caused the orange peel appearance known as the 'orange peel' effect (fig. 3l) observable more or less all over the surface of the object.[43] Hammering may have been excessively prolonged and relatively high temperatures may have been reached in these processes.[44] Certainly, as regards soldering, this effect is usually observed when the melting temperatures of the metal and the solder are relatively close to one another.

The structure of the solder area at the sample also leads to this conclusion.[45] Though one might expect to see dendrites as a sign of the solidification of the melted metal of the solder, the latter shows that the dendrites, which were originally present, have been replaced by more schematic grains, indicative of further annealing (fig. 7).

The hairline cracks and the grains on the surface could also have been caused by grinding and polishing.[46] But in that case they would have been less obvious, not only macroscopically but also microscopically, unless they had been done with tools such as modern motors, which reach temperatures capable of causing serious surface cracking.

The characteristic signs associated with the use of mechanized means of grinding and polishing the surface of the cup were not found. The irregular abrasions observed (fig. 3m) are more likely to be due to the use of emery paper in the grinding process in order to remove unwanted metal residue. This, of course, is not categorized as mechanically operated equipment but unfortunately neither is it an ancient grinding method.

For the polishing of the cup there is no clear evidence to confirm the way in which this process was carried out and the kind of polishing implements used. The surface presents very few polished areas, as if polishing had been selective because the craftsman had been unable to remove the many traces left by the grinding process which preceded it.

At this stage in the examination of the various indica-

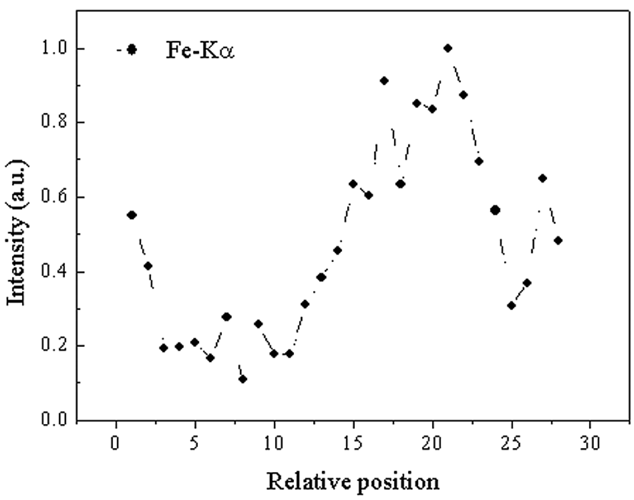


Fig. 9. μ-XRF spectrum, from scanning clean areas of the surface of the metal and areas with extensive presence of the reddish material, observed under the stereoscope. Ratio change of the characteristic Fe X-rays intensity where the reddish substance is thicker.

tions on the surface of the object, other forms of processing should also be mentioned, which may have damaged the surface and created such effects.

Poorly controlled chemical cleaning of the corrosion products, which might have formed on the surface of the cup as a result of subsequent attempts at conservation,[47] or alternatively treating it with acid (known as 'pickling')[48] are both techniques which inevitably leave the surface damaged and usually dull.[49] However, they rarely create such intense problems on the surface, unless the cleaning agent[50] used for the 'pickling' of the cup is so strong as to affect the metal,[51] which in this case, as mentioned above, is extremely pure,[52] to such an extent.

Yet the marks left on the surface as a result of poor craftsmanship could have been removed using the grinding process and with polishing, if the craftsman really wanted to get rid of them.[53] Although this process would have been much more time-consuming than usual and the cup – as was only to be expected – would no longer weigh as much, due to the reduction in its thickness, the appearance of the object would have been significantly improved.

As far as the reddish colouring of the cup is concerned (fig. 3h), this could be due either to iron (III) oxides from its burial environment or to the addition of iron or iron minerals to the gold metal for aesthetic effect.[54] Equally it could be attributable to traces of soil residues from the burial environment, or even to traces of some preparation containing colour which might have been used in the polishing process.[55]

Stereoscopic examination disproved the initial theory that this was an intentional addition for aesthetic reasons and the supposition as to the presence of a thin, superficial layer of the above-mentioned products. The greasiness of this material is another distinctive feature differentiating it from the texture of corrosion.

Ascertaining the composition of this product was effected qualitatively by scanning clean areas of the surface of the metal and other areas where this material showed a significant presence.[56] Micro XRF analysis revealed the presence of iron, an element which was not detected in the gold alloy used in the making of the cup. The peak of iron, which changes depending on the area in which it is analysed, is visible on the spectrum (fig. 9). According to these results the surface material could either be soil residue, which usually contains iron, or some modern tinted preparation used for polishing, containing iron oxides.[57] In the case of soil, the most likely source of the reddish material, its greasy texture may be due to its being intentionally or accidentally mixed with some organic or artificial substance.[58] It has not been possible to identify this material precisely.[59]

Besides the irregular striations (scratches), which were mentioned above as resulting from grinding, some other parallel striations were found but in a different arrangement. These striations are confined to the cup's handle, both on its inner, and on its outer surface, in the area where the handle meets the body of the cup. They run parallel to the length of the handle and are not incised like the scratches from grinding (fig. 3n). These marks might be attributable to a rolling mill used to produce sheet metal, though its use was unknown to antiquity.[60]

Finally mention should be made of some traces of grooves identified on the outer surface of the cup at the point where the lip curves. They recall the impression left by a modern nipper with grooves (fig. 3o), which could certainly be of modern manufacture.

Composition

The qualitative and quantitative analysis of the gold used in the making of the footed cup was carried out using X-ray fluorescent portable spectrometer (milli-XRF).[61] In table 1 the results of the chemical analysis of various areas of the surface of the object are presented.

	Analysis Position	Au (%)	Ag (%)	Cu (%)
	Body	98.9 ± 0.1	0.96 ± 0.10	0.14 ± 0.04
	Body	98.7 ± 0.1	1.07 ± 0.11	0.24 ± 0.07
	Handle	98.8 ± 0.1	0.99 ± 0.10	0.20 ± 0.06
	Rivet	98.6 ± 0.54	1.11 ± 0.06	0.34 ± 0.02
	Foot	98.8 ± 0.1	0.98 ± 0.10	0.20 ± 0.06
	Foot	98.8 ± 0.1	1.07 ± 0.11	0.15 ± 0.04
	Base	98.9 ± 0.1	0.90 ± 0.09	0.16 ± 0.04
	Lip abraded area	98.9 ± 1.41	0.28 ± 0.01	0.84 ± 0.12
	Base abraded area	99.4 ± 0.05	0.60 ± 0.06	0.11 ± 0.08
Average		98.8 ± 0.7	1.01 ± 0.08	0.19 ± 0.04

Table 1. Chemical analysis of the metal used in the making of the gold kylix from the Benaki Museum by micro-XRF in different areas.

The average gold content is 98.8 ±0.1%, silver content 1.01 ±0.08% and copper content 0.19 ±0.04%. From these results it is obvious that the metal is extremely pure with very small amounts of silver and copper.

According to the four basic stages of man's exploitation of gold,[62] an alloy with these amounts could either be classified as native gold, or as refined gold.

If the metal of the cup is considered native gold, the levels of silver and copper are reasonable, because gold from a variety of sources[63] contains silver at levels ranging from less than 1% to over 50%,[64] and usually has a copper content of less than 2%.[65] Of course, these figures are not accepted by all scholars. Craddock, for example, notes that the level of silver in native gold ranges between 5% and 30%,[66] whereas for copper both he and Tylecote[67] note the rarity of detecting amounts above 1%. Nevertheless all scholars who have worked on the metallurgy of gold agree that there are other elements present in native gold, such as iron, tin and members of the platinum group.[68] In the case of the cup, no such elements were detected.

The silver content, recorded as lower than 1%, might be an exception by comparison with the normal amounts of silver in native gold. According to Ramage – Craddock,[69] this level of silver would tend to put the gold of the cup in the category of a refined metal.

There are lots of references to the separation of copper from native gold using the cupellation process[70] and separation of silver by parting.[71] However there are a number of queries as to the exact time period in which this technology was acquired.

The cupellation process was known from the second or perhaps even the third millennium[72] in Mesopotamia and Egypt,[73] but the parting of silver, undoubtedly a more complex procedure, does not go back to such an early period.[74] There are, of course, references suggesting that it could have been used at that time, but there is no evidence for this.[75]

Fig. 10. Profile and view of the four goblets. Athens, National Archaeological Museum, inv. nos 656, 427, 959 and 957 (from left to right).

Our knowledge of the composition of gold in antiquity is incomplete. Studies and analyses carried out to date suggest that silver was not separated from gold alloys at any time prior to the introduction of coinage, i.e. before the seventh century BC.[76] Although the numismatic use of precious metals was already known from the third millennium BC in Mesopotamia and Egypt,[77] refining was not essential until the more widespread striking of coins made standardization essential.[78] Indeed Ogden says that the separation of silver from gold was mainly needed because of coinage.[79] It was not usually available for other types of products, such as tableware or jewellery. According to many scholars there was absolutely no reason for gold to be refined in such a time-consuming process, which moreover caused significant reduction in weight.[80]

By contrast there is evidence from the third millennium for the partial refining of silver and, of course, copper from the surface of gold.[81] This was what is called enrichment,[82] which improved the appearance of the gold in a very short space of time and without causing substantial loss of weight, as happened with parting.

Chemical analysis on two small areas, which had been slightly abraded with a dental tool on the lip and on the base[83] of the cup, showed absolutely no change in the amounts in the composition of the alloy between bulk and surface. Thus the likelihood of the enrichment of the gold being due to its being refined of its silver and copper content was rejected. The results have been recorded in table 1.

General observations on the vessels from the National Archaeological Museum

Four goblets were selected from the collection of the National Archaeological Museum of Athens (inv. nos 656, 427, 959 and 957) and one gold cup (inv. no. 8743),[84] which are considered typical as regards their state of preservation, their production techniques and decoration and the composition of their metal (figs 10, 11).

There follows a brief description of their construction, their decoration and the ageing of their surfaces, based on macroscopic observations and examination under the Euromex stereoscope[85] of the Museum's Metal Objects Conservation Laboratory. All the cups are made of separate

Fig. 11. The gold cup from Dendra, Argolis. Athens, National Archaeological Museum, inv. no. 8743.

sheets of gold, appropriately shaped using the hammering technique. The gold is relatively soft. It shows large areas with thin corrosion layers, which can be seen to come from the deposition of metal ions and the reactions of the less noble elements in the alloy of which they were made with the hydrogen sulphide present in the burial environment. In some the metal also shows mechanical strains. No signs of stress cracking corrosion were identified. The surface is perfectly worked with grinding and polishing (fig. 12).

They are each made up of three basic parts: the body, the foot and the handle. They are not all constructed in the same way. In goblets inv. nos 656 and 427 the body and the foot are a single unit made of one thin, probably conical, sheet of gold, which was later attached with solder along its vertical edges. The vertical joint is not discernible to the naked eye, while under the stereoscope the only area which seems to show some kind of join is on the vase with the lions (in one of the three spaces in between the lions) (fig. 13).

By contrast on goblets inv. nos 959 and 957 the body is separate from the foot. A thin, circular sheet of gold, formed into a hollow shape seems to form the body. The foot is constructed from a sheet of gold, wound round and hammered into a cylindrical shape, which has been joined with solder.

Only goblets inv. nos 656 and 427 have hammered handles. On the other two the handles were made by casting in a closed mould (i.e. using the lost wax technique). However, the way they are attached to the body is the same in all cases. Domed rivets have been used (figs 14, 15, 16).

Only footed cup inv. no. 656 is an open cup (see fig. 10). This differentiation in respect of any given object in this particular period may have been dictated by aesthetic preferences and practicality. The other three vases, which are closed, seem to have an additional part to their bodies, which is joined to the foot with simple, small-scale, domed rivets. The joint may have been reinforced with solder.

As regards goblet inv. no. 427 in particular, though it was originally constructed in the same way as inv. no. 656, it was later turned into a closed cup, as the lower part of its body has been completed with an extra sheet of gold cut in the form of a disc (see fig. 10). In the other two cases, the extra piece needs further investigation to determine how it was attached to the body (fig. 17).

Of the probable areas of contact mentioned above, none was detectable with the investigative tools available and thus it was not possible to ascertain precisely the type of solder used. Examination under a microscope did not reveal any perceptible difference in colour between the solder and the substrate, or any trace of a joint. Even the use of the milli XRF spectrometer on areas where solder was posited to be was either impractical or could not give reliable results on account of the specific form of these areas.[86]

Perhaps the only evidence which could be used, with some reservations, in respect of the type of solder used is the green-coloured copper corrosion products – most probably copper (II) carbonate hydroxide – which were identified around the body's bottom of vase inv. no. 427 (fig. 18), and the brownish-red copper (I) oxide at the contact points between the foot and the bases added to footed cups inv. nos 656 and 427. These could be explained by a gold solder with a high copper content or the presence of colloidal hard soldering (due to galvanic corrosion), as the latter is usually more susceptible to corrosive agents and mechanical strains.[87] The presence of the latter kind of solder might explain why it is so hard to identify it microscopically[88] and using chemical analysis, given that there is no gold alloy with a composition different from that of the substrate between the points of contact.[89]

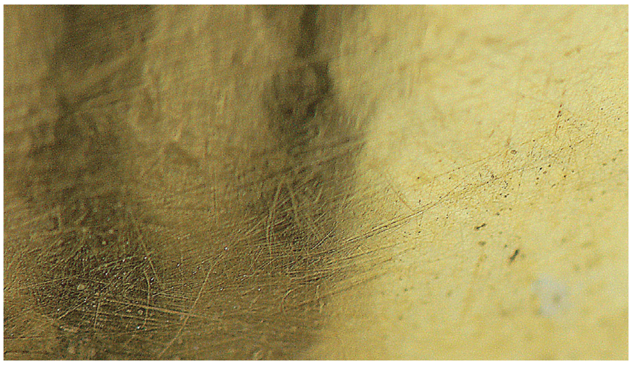
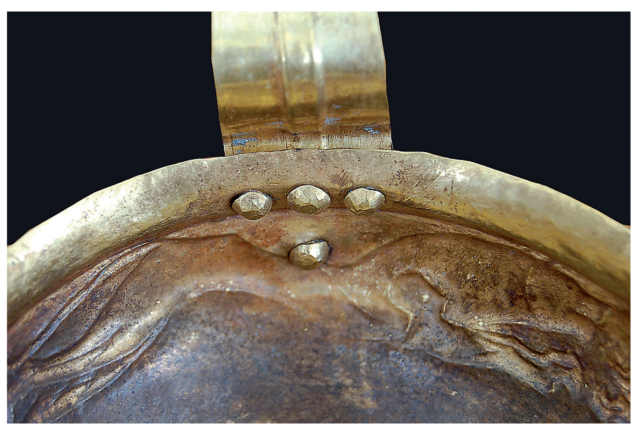


Fig. 12. Goblet. Athens, National Archaeological Museum, inv. no. 427. Detail of the surface of the metal, which has been thorough, grinded and polished.

Fig. 13. Goblet. Athens, National Archaeological Museum, inv. no. 656. Detail of one of the three gaps between the lions. There appears to be a joint in this area.



Figs 14, 15, 16. Goblets. Athens, National Archaeological Museum, inv. nos 427, 959, 656 (up to bottom). The domed rivets used for the artefacts and the way they were fitted to them.

Moreover in the closed cups from the Archaeological Museum a circular centre mark was identified inside the bodies (fig. 10). Unfortunately, it was not possible to see the outer surface in order to locate a possible second mark. However, a double centre mark was found on the gold cup decorated with stamped ivy leaves from Dendra in the Argolid (figs 19, 20).[90]

The lions on the only decorated goblet (inv. no. 656) were probably depicted by repoussé and chasing. The use of a cast former with the outline of a lion, applied to the inside of the body seems also possible since the marks left by the hammering, were restricted to the outer surface (see fig. 13).

The composition of these objects is presented in table 2 together with the chemical analysis of the seven pieces of jewellery from the Thebes 'Jewellery Ensemble' and the two

Fig. 17. Goblet. Athens, National Archaeological Museum, inv. no. 957. Detail of the attachment of the foot to the body.

gold items (Imre Somlyan donation) with dubious authenticity[91] belonging to the Benaki Museum.

From the results it seems that most of the objects (except from the two items with dubious authenticity) are made from gold with a silver content ranging from 9.6% to 28.9%, and more specifically in the goblets between 9.64% and 26.1% and copper content between 0.35% and 3.33%. In the goblets the copper content goes from 0.3% up to 2.40%, apart from vases inv. nos 656 and 427 which have less than 1% copper. The others have levels in excess of 1% and even over 2%.

The levels of silver can be accounted for by the use of native gold alloys[92] or gold alloys created by man, whether for aesthetic or economic reasons.[93] The levels of copper can also be attributed to native gold[94] or the practice of alloying[95] in order to improve the strength of the metal and to balance the pale colour caused by its high silver content.[96]

It was not possible to arrive at a precise identification of the provenance of the gold used in these objects. Unfortunately other elements which could have indicated something more specific and representative were either lacking or – if they existed – they could not be traced with the particular method analysis being used.

However a general assessment can be made. According to the ternary diagram (fig. 21) – which also includes the gold cup and the two gold items with dubious authenticity – the objects are categorized in two main groups due to their silver and copper levels. Exceptions to these two groups are the gold goblet (inv. no. 959) from the National Archaeological Museum which is nearly attached to the second group and the gold cup together with the gold item (inv. no. 27515) which significantly distiguish from the two main categories.

Thus thirteen out of the fifteen objects were not made of extremely pure gold. Such alloys, as the sources note, were widely used in antiquity and it was usual for them to be employed straight from the mine. Indeed they continued to be exploited without further processing up to the fifth century

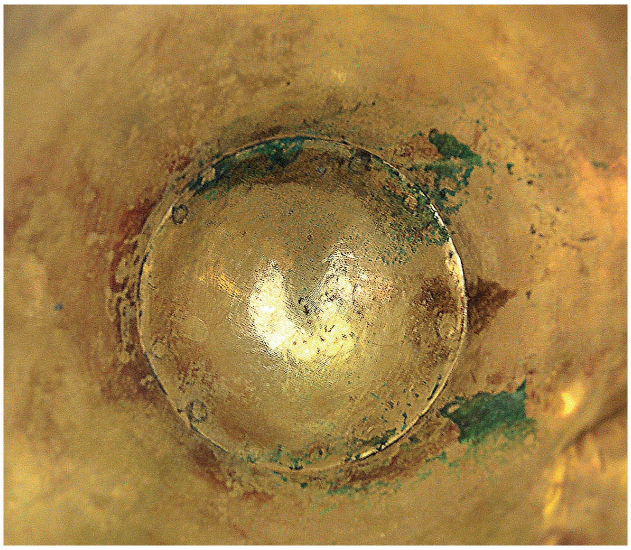
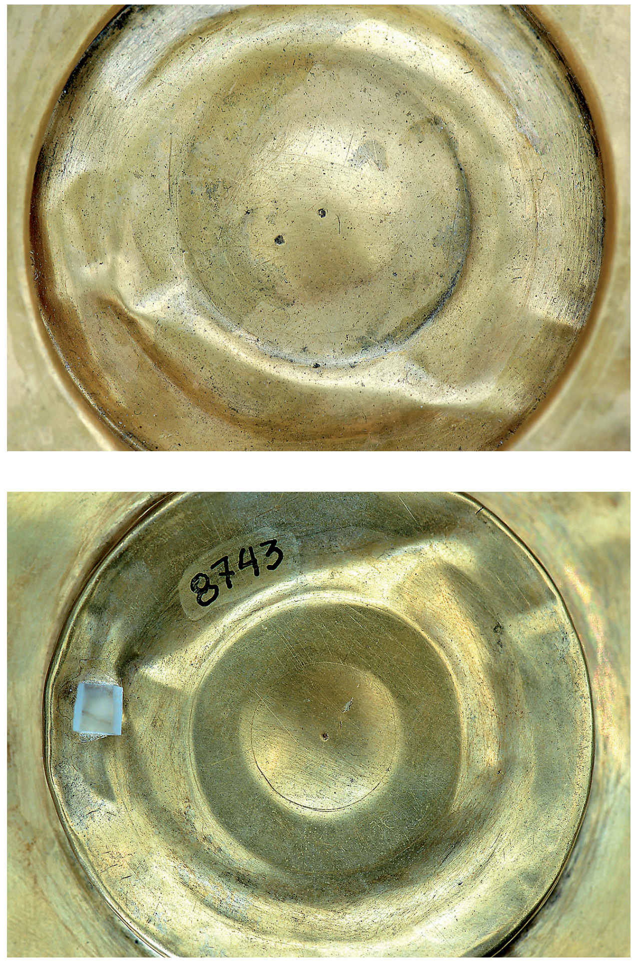


Fig. 18. Goblet. Athens, National Archaeological Museum, inv. no. 427. Copper corrosion products identified around the body's bottom.



Figs 19-20. Gold cup. Athens, National Archaeological Museum, inv. no. 8743. Detail of the inside and the outside of the body, at the base where the circular centre mark is visible.

BC.[97] According to this data, the metal used to make the objects could be judged not to be a product of alloying, at least as regards the level of silver.

This opinion is reinforced by bibliographical evidence regarding the location of deposits of such alloys in the Mycenaean period. Greece was on the whole too poor in deposits of gold to meet the demands of its large-scale domestic production of gold artefacts. The limited deposits in the islands of the Aegean were an exception.[98] Although they were workable, there was still not enough gold, and it was necessary to import it from other countries.[99]

Egypt and more specifically Nubia is referred to as the main supplier of gold in this period.[100] And it was gold with a high silver content, as the Mediterranean in general and more particularly Egypt, Nubia, Asia Minor, Spain and the Caucasus were extremely rich in deposits of such gold[101] and had even greater amounts of silver.[102]

If we assume that the gold of the objects which are the subject of this study is really native gold, then the level of concentrations of copper – at least in some of those objects (especially those from the National Archaeological Museum) – could reinforce this view. In the others, which do not have such low levels, it is likely that a native gold-silver alloy was used with the addition of some small amount of copper, for the reasons given above.

Conclusions

The techniques of working, decoration and attachment used on the kylix all date back to ancient times and it is no coincidence that they have also been identified in the other objects from the Mycenaean period. However, the significant differences more particularly in the manner of constructing and joining the initial sheets, the type of solder and mechanical attachment used and the indications of ageing and deterioration on the surface of the cup are elements which could call into question the authenticity of the object.

To be more specific, the parallel raised marks found on the handle indicate a more recent manner of producing the sheet gold. It could, of course, be maintained that a rolling

Acc.nos	Type of object	Analysis position	Place	Au (%)	Ag (%)	Cu (%)
656	Gold goblet	Body	National Archaeological Museum	81.6 ± 0.25	17.7 ± 0.11	0.71 ± 0.02
656	Gold goblet	Handle exterior surface	National Archaeological Museum	74.7 ± 0.51	24.6 ± 0.26	0.70 ± 0.04
427	Gold goblet	Handle exterior surface	National Archaeological Museum	83.4 ± 0.53	16.3 ± 0.21	0.35 ± 0.04
427	Gold goblet	Base	National Archaeological Museum	82.6 ± 0.55	16.9 ± 0.22	0.48 ± 0.04
959	Gold goblet	Body exterior surface	National Archaeological Museum	88.6 ± 0.54	9.64 ± 0.16	1.74 ± 0.06
959	Gold goblet	Body	National Archaeological Museum	90.0 ± 0.61	8.46 ± 0.18	1.54 ± 0.06
957	Gold goblet	Body exterior surface	National Archaeological Museum	71.6 ± 0.48	26.1 ± 0.25	2.40 ± 0.07
957	Gold goblet	Body	National Archaeological Museum	76.0 ± 0.61	22.4 ± 0.29	1.63 ± 0.07
8743	Gold cup	Body, exterior surface	National Archaeological Museum	75.1 ± 0.17	23.4 ± 0.09	1.42 ± 0.02
8743	Gold cup	Handle exterior surface	National Archaeological Museum	76.8 ± 0.54	22.1 ± 0.26	1.14 ± 0.05
2063	Embossed Rosette	Back	Benaki Museum	75.1 ± 0.15	21.8 ± 0.08	3.08 ± 0.03
2070	Pendant	Front	Benaki Museum	68.4 ± 0.15	28.9 ± 0.09	2.66 ± 0.03
2075	Ring	Bezel	Benaki Museum	84.3 ± 0.57	12.4 ± 0.20	3.33 ± 0.09
2079	Ring	Bezel	Benaki Museum	80.8 ± 0.19	16.4 ± 0.09	2.80 ± 0.03
2069α	Necklace	Back	Benaki Museum	65.5 ± 0.50	32.2 ± 0.30	2.35 ± 0.08
2080	Cylinder ceal	Exterior surface	Benaki Museum	83.1 ± 0.20	14.5 ± 0.08	2.4 ± 0.03
2068	Necklace	Back	Benaki Museum	79.1 ± 0.16	18.7 ± 0.08	2.24 ± 0.02
27516	Ring	Top	Benaki Museum	97.1 ± 0.17	1.82 ± 0.04	0.62 ± 0.02
27515	Cup	Lip	Benaki Museum	99.1 ± 0.20	0.65 ± 0.03	0.30 ± 0.01

Table 2. Chemical analysis of the four gold goblets and one gold cup from the National Archaeological Museum together with the analysis of the seven pieces of jewellery from the Benaki Museum and the two items (Imre Somlyan donation) with dubious authenticity.

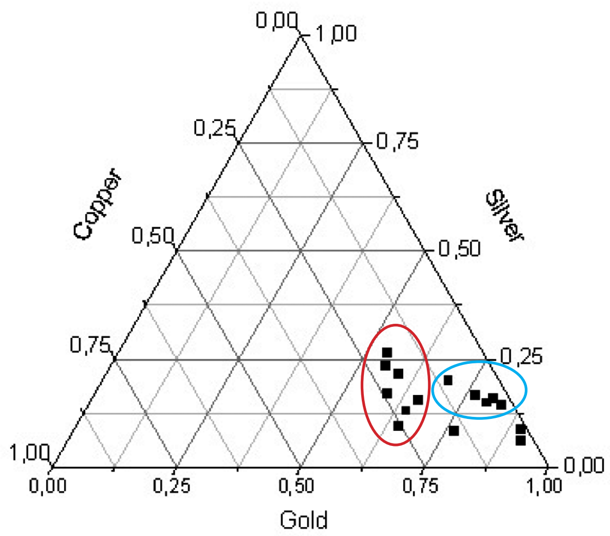


Fig. 21. Ternary diagram which shows the two main groups of the gold artefacts from the National Archaeological Museum and the Benaki Museum. The gold cup together with the gold item inv. no. 27515 from the Benaki Museum (dots near the edge of the triangle) significantly distinguish from the two main categories.

mill was used only on the handle, given that these marks were not found anywhere else on the cup. Or even that the cup was discovered without a handle or with a damaged handle, which was later replaced with a new one. However, the fact that the gold of the handle has the same composition as other parts of the object makes it rather difficult to argue for this hypothesis.

From the point of view of technique, the way in which the body of the kylix was produced is comparable with the construction of hollow objects in antiquity, but differs from that used on the closed goblets from the National Archaeological Museum, which have an extra part to the body.

As regards the marks found on the lip, most probably made by modern nippers, it is not altogether clear if they are due to some more recent repair or were the result of some modern production method.

As regards the type of rivets and the way in which they were attached, and especially the two together, they differ from those used on the four goblets from the National Archaeological Museum and from the way they were fitted. This difference could be attributed to poor workmanship in antiquity. On the other hand it could be atributed to some subsequent intervention, if for example the cup had been discovered with damaged links. However, the results of the chemical analysis of the links show no essential difference in their composition from that of the metal used to make the cup.

On the basis of its composition, the solder can be considered authentic. Moreover such solders were widespread in antiquity, and no other evidence was found which would point to the use of more modern solders.[103] This type does not seem to have been used on the other cups. It is most likely in their case that an alloy with a higher copper content or colloidal hard soldering was chosen.

In addition the metal is hard, unlike the cups from the National Archaeological Museum, where the gold seems more soft and floppy, which is characteristic of the natural ageing process in an originally hard metal (as a result of the repeated stages of cold working), and has thin corrosion layers.

The hairline cracks, the 'crystals' and the 'orange peel' appearance on the surface of the kylix, which were not observed on the artefacts from the National Archaeological Museum, incline us to conclude that either the techniques of working and refining were badly controlled or there was a deliberate attempt to imitate a metal with 'stress cracking corrosion' and to make the cup look old. If the aforementioned characteristics are the result of bad craftsmanship, then it is interesting to note that subsequent grinding and polishing did not remove them completely or even smooth them out and that they were entirely selective.

As regards the reddish material present on the surface, it could be attributable to traces of soil from the burial environment, though it goes without saying that the traces themselves do not constitute reliable evidence for the artefact having spent a long period of time in the earth. The greasy texture of the material remains to be interpreted.

The metal used in the construction of the cup suggests an alloy of high purity with small amounts of silver and copper. An alloy of this sort would be categorized as either native gold or refined gold.

The truth is that such levels are found more often in refined gold. Nevertheless, its gold and silver content could be categorized as native gold. It is no coincidence that, in the available research and analyses relating to artefacts made of alloys of native gold from the same area and period, similar levels of silver and copper as those identified in the cup have been observed.[104]

Moreover it is possible to find significant variations in composition even among native gold alloys coming from the same mining area.[105] However, this is a statistically small possibility.

Consequently, the gold of the kylix is either an exception among native golds or should not be included in this category at all, as to date most analyses of objects dating to periods before the age of coinage – including the artefacts from the National Archaeological Museum – differ from those relating to objects from later periods and indeed the modern period.[106]

Of course, the number of artefacts of certified provenance and dating to the period in question, which have been analysed, is too small for anyone to have a comprehensive idea of the composition of native gold.

However, up to now most results have shown that this gold contains either significant amounts of silver and small amounts of copper, or high levels of copper and silver. In both cases it was confirmed that the gold, on the basis of its silver content, was an entirely natural product sometimes with a little extra copper and sometimes with significant additions of copper for aesthetic, practical or perhaps economic reasons. In no case was the use of refined gold attested.

On the basis of the foregoing, the difficulty of finding a definitive solution to the question of the authenticity of the Benaki Museum's cup and of fitting it into a unified set of objects with common stylistic, technical and chemical characteristics is evident. In any case the wider arguments surrounding it and the many contradictory views which have been expressed in relation to this cup would seem to stress the need for caution in coming to any conclusions.

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Notes

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1. I. Papageorgiou, The Mycenaean golden kylix of the Benaki Museum: A *dubitandum*?, *Mouseio Benaki* 8 (2008) 9-37.

2. Unless, in addition to its metal component, an artefact has some clay, which has been subject to annealing at temperatures above 400° C. Dating is then possible using thermoluminescence, E. Aloupi – N. Zacharias – A.-G. Karydas, Το χρυσό αγαλμάτιο Αφροδίτης: ζητήματα γνησιότητας, *Mouseio Benaki* 1 (2001) 33-40.

3. The hammered gold, which is hard and inflexible at first due to the shaping process, becomes softer with time. These are characteristics of the natural ageing of the metal, which a modern metallurgist can, of course, imitate using the annealing process. See. J. Ogden, *Jewellery of the Ancient Word* (New York 1982). In the case of the cup the ancient metal does not display such properties. This raises questions as to its authenticity.

4. A chisel with a sharp edge.

5. A set of compasses, for example, was a tool used for marking out circular sheets of metal from the Mycenean period, E. Konstantinides-Syvrudes, Στο Εργαστήριο του Μυκηναίου χρυσοχόου: ανασύνθεση τεχνικών στα χρυσά κοσμήματα του Εθνικού Αρχαιολογικού Μουσείου, in: G. Kazazis (ed.), *Αρ-*

χαία Ελληνική Τεχνολογία, Αθήνα 17-20 Οκτωβρίου 2005 (= *Τεχνικό επιμελητήριο Ελλάδας* 1, Athens 2006) 98-106.

6. O. Untracht, *Metal Techniques for Craftsmen* (New York 1975).

7. *Ibid*., 294-95.

8. H. Hodges, *Artifacts: An introduction to early materials and technology* (London 1976).

9. K.S. Painter, Gold and Silver in the Roman World, in: W.A. Oddy (ed.), *Aspects of Early Metallurgy* (= *Occasional Paper* 17, London 1980) 135-58.

10. For the period in question there are no sources which even mention the use of some sort of rotating device for working metals. What evidence there is for the use of a lathe in even earlier periods relates to wood or bone and very particular constructions made from them. Evidence relating to the use of a primitive form of lathe has been found in the early 18th Dynasty in Egypt, only in relation to wood and bone, E. Simpson, Early evidence for the use of the lathe in Antiquity, in: P. Betancourt – V. Karageorghis – R. Laffineur – W.D. Niemeier (eds), Meletemata 3, Studies in Aegean Archaeology Presented to Malcolm H. Wiener as he Enters his 65th Year, *Aegeaum* 20 (1999) 781-85.

11. Ogden (n. 3) 37-39.

12. Ogden (n. 3) 37-39.

13. R.A. Higgins, *Greek and Roman Jewellery* (London 1980).

14. Snaps with various devices imprinted on their ends, which are stamped on the heads of the rivets as decoration, Hodges (n. 8); J. Lang – M.J. Hughes, Joining techniques, in: Oddy (n. 9) 169-78.

15. On the curved end of the rivets signs of cutting with scissors, a more modern method of cutting through a rod, can be made out. On the domed heads of the rivets the surrounding flange has been cut. The traces of cutting and finishing in these areas were not especially evident, due to their being covered by a reddish material, but they seem likely to have involved the use of some more modern tools.

16. Higgins (n.14); P.M. Roberts, Gold Brazing in Antiquity: Technical Achievements in the Earliest Civilizations, *Gold Bulletin* 6,1 (1973) 112-19.

17. The portable micro-XRF spectrometer consists of an X-ray Rh anode tube, a policapillary lens that focuses the emitted x-rays at about 100μm at the sample position, an X-ray Si-drift detector and the accosiated electronics, a CCD camera and a laser for the correct positioning of the samples, finally three spepping motors are coupled with the spectrometer head. The μ-XRF spectrometer is used to study the distribution of the intensities of the characteristic x-rays of the elements contained in selected areas of the surface being analysed, using line or surface scaning. The essential differences between the μ-XRF spectrometer and the m-XRF, which was used for the chemical analysis of the cup, the artefacts from the National Archaeological Museum and the jewellery from the Thebes 'Jewellery Ensemble' are: 1) their very different spatial resolution, with the analysis point in the m-XRF having a diameter of *ca* 3.000 μm (3 mm), while in the μ-XRF it is of the order of *ca* 70 μm (0.070 mm), i.e. 42 times smaller, thus allowing microscopic details of the area under examination to be analysed; 2) the stimulation beam in the μ-XRF is of much higher intensity, which ultimately, combined with the different technology of its X-ray detector, makes it possible to carry out analyses in a much shorter period of time; 3) the stepping motors can provide the possibility of advanced elemental mapping studies.

18. Only qualitative analysis was carried out in the area of the soldering. The intensities of silver and copper X-ray lines are higher in this area than the ones detected in the areas around the joint and with no solder.

19. The sample comes from a damaged area of the soldering between the foot and the base.

20. Roberts (n. 16) 114.

21. As, for example, electrum in the case of naturally occurring alloys, Ogden (n. 3) 18.

22. In the earliest civilizations the use of copper in solders was preferable, as a craftsman could achieve a very good solder, without knowing the composition of the alloys or their melting points, Roberts (n.16) 115. It is perhaps not by chance that the use of the more intentionally manufactured alloys made of gold and silver or even of gold, silver and copper, became more widespread from the Hellenistic period onwards, Ogden (n. 3) 59-67A.

23. The colour of the gold is more yellow or more red depending on the silver and copper content in the alloy. The greater the silver content, the more yellowish the gold will be. By contrast, the greater the level of copper, the more reddish the gold.

24. Ogden (n. 3) 58-67; Roberts (n. 16) 113. There is no doubt that these properties must be assumed to have applied to all types of solder used from antiquity up to the present day.

25. Roberts (n. 16) 114.

26. Electrum, for example, which they got straight from the earth for use in gold solders had over 20% silver content, Ogden (n. 3) 37-39. Such an alloy has seen to have a melting range of about 1000-1040^{o}C, Roberts (n.16) 114.

27. Roberts (n.16) 114.

28. Ogden (n. 3) 58-67.

29. This is what is called colloidal hard soldering. When soldering using copper salts or minerals, a very small amount of metallic copper is produced, which is diffused into the substrate in the area of the joint during thermal activation, Ogden (n. 3) 58-67.

30. Roberts (n. 16) 115.

31. R. Duval – C. Eluere – L.P. Hurtel, The use of Scanning

Electron Microscopy in the study of Gold Granulation, in: Y. Maniatis (ed.), *25th Symposium, Archaeometry, Athens 19-23 May 1986* (Amsterdam-New York 1989) 325-33.

32. Roberts (n. 16) 116.

33. D.A. Scott, *Metallography of the Ancient and Historic Metals* (Malibu 1991).

34. W.S. Rapson, Tarnish Resistance, Corrosion and Stress Corrosion Cracking of Gold Alloys, *Gold Bulletin* 2 (1996) 29.

35. D.A. Scott, The Deterioration of Gold Alloys and Some Aspects of their Conservation, *Studies in Conservation* 28 (1983) 194-203.

36. *Ibid.,* 198.

37. If a gold alloy remains in a naturally corrosive burial environment selective etching occurs on the less noble metals, resulting either in the corresponding corrosion products, the enrichment of the surface with gold and/or the appearance of cracks, Rapson (n. 34); N. Meeks, A Greek Gold Necklace: A Case of Dual Identity, in: D. Williams (ed.), *The Art of the Goldsmith* (London 1997) 127-38.

38. Where there is a higher gold content, the level of stress is reduced accordingly, Scott (n. 35) 198.

39. Rapson (n. 34) 63-64.

40. I.e. 58% gold, 30% silver and 11.5% copper.

41. This, of course, is not representative of the body area where the crystals were observed, though it can nevertheless give extremely important information about the way in which the cup was made, the various stages in this process and about its corrosion.

42. During cold working of the metal, when plastic deformation is not properly achieved (i.e. by less than a crucial amount) and the metal is submitted to annealing for the period of time usually required, recrystallization does not occur as expected in order for the metal to acquire its properties from the hammering process, because the metal is already considered recrystallized. The result is that large grains form, which is not desirable, and the surface of the metal presents irregularities, D. Ott – C.J. Raub, Grain size of gold and gold alloys, *Gold Bulletin* 14,2 (1981) 69-74; G.G. Antonopoulos, *Μέταλλα και κράματα* (Thessaloniki 1986) 120.

43. Ott – Raub (*op. cit.*) 69-74; Antonopoulos (*op. cit.*) 120.

44. Ogden (n. 3) 158.

45. In the process of joining two metal parts, the solder must be heated to its melting point. Then, to achieve the join, the molten metal gradually, or rapidly (depending on the manufacture) solidifies. The crystalline structure of the molten metal is dendritic, i.e. as it solidifies first of all primary, then secondary and tertiary arms develop.

On the sample of solder, whereas dendrites were anticipated – albeit in small amounts because of the relatively pure alloy – as a result of the melting process, these crystals are more schematic. The new crystalline structure leads us to conclude that the metal of the cup should have been subjected to more annealing. The artefact seems likely to have been heated in order to improve the metal's mechanical properties. Certainly a cross-section of the sample tends to indicate that the temperature used could have been higher than necessary, G.D. Chryssoulakis – D.I. Pandelis, *Επιστήμη και τεχνολογία των μεταλλικών υλικών* (Athens 2007).

46; T. Lyman, *The Metals Handbook* (Ohio 1948).

47. Scott (n. 35) 198.

48. This is a stage in the chemical refinement of gold traditionally used by goldsmiths on their metal constructions, in order to remove the traces of fusible matter used in solders, to dissolve the oxides created by heating and to give the metal a uniform colour, H. Maryon, *Metalwork and Enamelling: A Practical Treatise on Gold and Silversmiths Work and Their Allied Crafts* (New York 1971).

49. They leave a porous and pitted surface, Meeks (n. 37) 131-33.

50. Ogden (n. 3) 168.

51. Extremely pure gold alloys are much less susceptible to this sort of damage, Meeks (n. 37) 133.

52. Such a strong chemical constitutes one of the more modern 'pickling' solutions, or comes into the category of etching solutions, and according to Untracht's data (n. 6) 160, the former remove traces of prior working while the latter 'eat', i.e. remove, metal (usually for decorative reasons). Meeks (n. 37) 131-34, notes that in antiquity the 'pickle' was milder. He observed that this cleaning process did not have a very strong effect on the gold alloys of the period, despite the fact that they contained high amounts of copper and silver.

53. Ott – Raub (n. 42) 55.

54. The well-known reddish gold. The gold gives this impression superficially due to the introduction of iron. It has been noted mainly in Egyptian gold artefacts of the New Kingdom, such as those discovered in the tomb of Tutankhamen, see J. Ogden, Aesthetic and Technical Considerations Regarding the Colour and Texture of Ancient Goldwork, in: S. La Niece – P. Craddock (ed.), *Metal Plating and Patination* (Oxford 1993); J.H. Frantz – D. Scorsch, Egyptian red gold, *Archaeomaterials* 4 (1990) 133-52.

55. On modern metallic surfaces coloured preparations are used together with a lathe and a hair brush to remove the metal, giving a high shine.

56. Chemical analysis was carried out on the area around one of the two ornamental rivets which join the upper part of the handle to the body of the cup. The presence of the extra material there was more extensive.

57. Such as 'red rouge', for example, which is made of red iron oxide powder bound with grease and stearic acid.

58. It is possible that the recent impression taken of the cup,

in order to make copies for marketing in the Benaki Museum Shop, could account for the greasy substance mixed with the soil.

59. There was not enough of it to use any other method of analysis, which could trace any organic substance in it.

60. The rolling mill is used to reduce the thickness of the metal into sheet form. It can be hand operated. It came into use in the sixteenth century AD.

61. The spectrometer consists of a low power X-ray tube, a Si-PIN diode X-ray detector, a digital pulse processor PX4, finally two lasers are coupled to the spectrometer head for the proper positioning of the sample. For data on the m-XRF, see n. 17.

62. I.e. the use of native gold and of electrum in its natural state, intentional addition of silver and/or copper to native gold, the refinement of native gold with silver and copper to improve its value or for standardization, and the intentional addition of silver and/or copper to refined gold for functional, economic or perhaps even illegitimate purposes, Ogden (n. 54) 40.

63. Either from primary seams of quartz (SiO_2) or pyrite (FeS_2) or from secondary replacement deposits, created by the erosion of the primary deposits, H.G. Bachmann, On the Early Metallurgy of Gold, Some Answers and More Questions, *Der Anschnitt* 9 (1999) 267-75; Painter (n. 9) 135; R.F. Tylecote, *The Early History of Metallurgy in Europe* (London-New York 1987).

64. Bachmann (n. 63) 269; P.T. Craddock – N. Meeks – M. Cowell – A. Middleton – D.Hook – A Ramage – E. Geckini, The Refining of Gold in the Classical World, in: D. Williams (ed.), *The Art of The Greek Goldsmith* (London 1997) 111-21.

65. Bachmann (n. 63) 269; J. Ogden, Metals, in: P.T. Nicholson – I. Shaw (eds), *Ancient Egyptian Materials and Technology* (Cambridge 2000).

66. P.T. Craddock, *Early Metal Mining and Production* (Edinburgh 1995).

67. *Ibid.,* 111; Tylecote (n. 63) 74.

68. The platinum group includes platinum, palladium, osmium, iridium, ruthenium and rhodium.

69. Experiments carried out with the aim of recreating ancient processes of refining resulted in silver levels ranging from 0%-35%, A. Ramage – P. Craddock, *King Groesus' Gold Excavations at Sardis and History of Gold Refining* (London 2000).

70. In the beginning simple refining at high temperatures was used. Later this process was improved with the addition of lead, while the use of mercury has also been mentioned, Craddock (n. 64). Modern methods involve using a solution of nitric acid or electrolytic cleaning, D.J. Kinneberg – S.R. Williams – D.P. Agarwal, Origin and Effects of Impurities in High Purity Gold, *Gold Bulletin* 31,2 (1998) 60-61.

71. For the process of parting, they first used admixtures of sulphur or acidic salts, whereas later some strong metallic acids were used, *ibid.,* 60-61.

72. Bachmann (n. 63) 269.

73. Craddock (n. 64) 112.

74. Bachmann (n. 63) 269.

75. According to Ramage – Craddock (n. 69) there is no evidence for periods before the mid-first millennium BC and more specifically before the gold-producing centre at Sardis came into operation, which is dated to this period. Their report is based on evidence discovered by excavations in the region, on examination of residues of gold leaf or fragments of gold and other materials related with the processes involved in the production of gold and on experiments simulating the separation processes which are likely to have been used at that time. Forbes also gives an account of the first millennium in more general terms, see. R.J. Forbes, *Studies in Ancient Technology* 8 (Leiden 1971).

76. J. Williams – J. Cribb – E. Errington, *MONEY, A History* (London 1997); Craddock (n. 68) 112.

77. For all kinds of commercial, legal and/or social exchanges it was traditional to use metal bars selected by weight and not in the form of coinage, *ibid.,* 16-18.

78. D. Williams – J. Ogden, *Greek Gold, Jewellery of the Classical World* (London 1994).

79. Ogden (n. 54) 40.

80. Craddock (n. 64) 113.

81. Ramage – Craddock (n. 69) 28.

82. Reducing the amount of silver and copper on the surface could be achieved initially by heating the object, where copper would become coated with a copper oxide (Cu_2O) film. Then the oxides would be removed with organic acids, followed by grinding and polishing of the surface of the object. After analysis of the surface, the enrichment can result in a gold content up to 7% greater than that in the bulk, Bachmann (n. 63) 273.

83. The gold metal in these areas looks abraded as the metal from the surface has been removed.

84. Two gold cups (inv. nos 959 and 957) with cast handles with hounds' heads in relief (15th c. BC), a gold cup (inv. no. 656) with running lions and a gold cup with a handle (inv. nos 656 and 427 respectively, 16th c. BC) as well as a gold goblet from Dendra in the Argolid (inv. no. 8743).

85. Unfortunately it has not been possible to X-ray the objects, which could have revealed many details concerning the techniques of their manufacture.

86. In the quantitative analysis, the normalized factor which expresses the deviation in the unit when the surface being analysed has some curvature or if there is some localized lack of homogeneity in the alloy, showed some differentiation, though the results of the analysis cannot be considered reliable.

87. In many objects which had been joined with colloidal

hard soldering, it has been observed that the joints have very often deteriorated, been destroyed or been replaced by modern soldering alloys.

88. R.F. Tylecote, *Metallurgy in Archaeology* (London 1962).

89. This must have been the most prevalent form of soldering, as it has been observed from chemical analyses of solders found in earlier objects as well as much more recent ones (e.g. nineteenth century), that in ancient artefacts the composition of the attached areas shows no essential difference from the main alloy. The soldering area could not be chemically identifiable. It was also difficult to spot with the naked eye, Tylecote (n. 63) 85. By contrast the composition of the solder in modern manufactures shows some difference, Meeks (n. 37) 134.

90. Gold goblet (inv. no. 8743) decorated with ivy leaves (14th c. BC).

91. An embossed rosette (inv. no. 2063), an amulet (inv. no. 2070), two rings (inv. nos 2075 and 2079), an ornamental necklet (inv. no. 2069a), a cylinder seal (inv. no. 2080) and an ornamental necklet (inv. no. 2068) dated to 1450-1600 BC. The two gold items from the Somlyan donation are a ring (inv. no. 27516) and a gold cup (inv. no 27515).

92. And even over 5%, Craddock (n. 64) 111.

93. J. Ogden, *Ancient Jewellery* (London 1982).

94. Typically not more than 1%, Tylecote (n. 63) 69-79.

95. Ogden (n. 3) 18-19 reports a level of over 2.5%; and see Tylecote (n. 63) 74 for a level of over 3% and Scott (n. 36) 94 up to 5%.

96. Ogden (n. 54) 40; Tylecote (n. 63) 72.

97. Williams – Ogden (n. 79) 15.

98. Painter (n. 9) 136-37.

99. Williams – Ogden (n. 79) 14-16.

100. R. Shepherd, *Ancient Mining* (London-New York 1993).

101. C.C. Patterson, Native copper, silver and gold accessible to early metallurgists, *American Antiquity* 36,3 (1971) 286-321; Williams – Ogden (n. 79) 13.

102. Tylecote (n. 89).

103. P.T. Craddock – S. Bowman, Spotting the fakes, in: S. Bowman (ed.), *Science and the Past* (London 1991) 141-57.

104. Bachmann (n. 63); A.-G. Karydas – C. Zarkadas, Αναλύσεις επτά χρυσών δαχτυλιδιών Μινωικής προέλευσης που πραγματοποιήθηκαν το 1996 (unpublished); A. Lucas – J.R. Harris, *Ancient Egyptian Materials and Industries* (London 1962); A. Hartman, *Prähistorische Goldfunde aus Europa* 2 (Berlin 1982).

105. Ogden (n. 65) 162.

106. Kinneberg – Williams – Agarwal (n. 70); M.F. Guerra – C.O. Sarthre – A. Gordonneau – J.N. Barrandon, Precious Metals and Provenance Enquiries using LA-ICP-MS, *Journal of Archaeological Science* 26 (1999) 1101-10; G.P. Ferreira – F.B. Gil, Elemental analysis of gold coins by particle induced X-Ray Emission (PIXE), *Archaeometry* 23,2 (1981) 189-97; P.D.C. Brown – F. Schweizer, X-Ray fluorescence Analysis of Anglo-Saxon Jewellery, *Archeometry* 15,2 (1973) 173-82.

ΔΕΣΠΟΙΝΑ ΚΟΤΖΑΜΑΝΗ – ΒΑΣΙΛΙΚΗ ΚΑΝΤΑΡΕΛΟΥ – ΧΡΥΣΟΥΛΑ ΣΟΦΟΥ – ΑΝΤΡΕΑΣ-ΓΕΡΜΑΝΟΣ ΚΑΡΥΔΑΣ

Η χρυσή κύλικα του Μουσείου Μπενάκη αρ. ευρ. 2108: τεχνική μελέτη

Με αφορμή την πρόσφατη μελέτη της Ειρήνης Παπαγεωργίου για τη χρυσή κύλικα αρ. ευρ. 2108 του Μουσείου Μπενάκη, κρίθηκε απαραίτητη η διερεύνηση της αυθεντικότητάς της μέσω της εξέτασης της τεχνολογίας κατασκευής, της διακόσμησης, της χημικής σύστασης του μετάλλου και της συνολικής κατάστασης διατήρησής της, καθώς και η ακριβέστερη χρονολόγηση του έργου που τοποθετείται στη μυκηναϊκή περίοδο, με βάση ορισμένα χαρακτηριστικά του. Καθοριστικό ρόλο στην όλη αυτή προσπάθεια διερεύνησης έπαιξε και η συσχέτιση των τεχνικών και των χημικών χαρακτηριστικών της κύλικας με αντικείμενα συγγενή, όσον αφορά το μέταλλο, το σχήμα και την πιθανή εποχή κατασκευής της. Επιλέχθηκαν τέσσερις χρυσές κύλικες (αρ. ευρ. 959, 957, 656, 427) και ένα χρυσό κύπελλο (αρ. ευρ. 8743) μυκηναϊκής περιόδου του Εθνικού Αρχαιολογικού Μουσείου, καθώς και επτά χρυσά κοσμήματα από τον Θησαυρό της Θήβας (αρ. ευρ. 2063, 2070, 2079, 2069α, 2080, 2068), μαζί με δύο χρυσά αντικείμενα (αρ. ευρ. 27515, 27516, Δωρεά Imre Somlyan) του Μουσείου Μπενάκη.

Η κύλικα είναι κατασκευασμένη από τέσσερα ξεχωριστά φύλλα χρυσού, κατάλληλα μορφοποιημένα με την

τεχνική της σφυρηλάτησης και ενωμένα. Τα τρία μέρη (σώμα, πόδι και βάση) είναι προσαρμοσμένα το ένα στο άλλο με σκληρή κόλληση, ενώ η λαβή με διακοσμητικά καρφιά (πλατιές εφηλίδες με πατούρα). Το σώμα κοσμείται με τρεις ανάγλυφους σκύλους, δουλεμένους κυρίως από την εξωτερική τους επιφάνεια, ενώ η λαβή με έκτυπα φύλλα κισσού, όπου έχει χρησιμοποιηθεί εργαλείο που φέρει στην απόληξή του το συγκεκριμένο σχήμα.

Οι τεχνικές μορφοποίησης, διακόσμησης και σύνδεσης στην κύλικα χρονολογούνται από πολύ παλιά και δεν είναι τυχαίο ότι αναγνωρίστηκαν και στα άλλα αντικείμενα της μυκηναϊκής περιόδου. Υπάρχουν όμως ορισμένες ενδείξεις που θέτουν κάποιο προβληματισμό για τη γνησιότητα του αντικειμένου. Οι ενδείξεις αυτές αφορούν ειδικότερα τον αρχικό τρόπο κατασκευής της λαβής και της σύνδεσής της με το σώμα της κύλικας, το είδος της κόλλησης, τη σύσταση του μετάλλου κατασκευής, καθώς και τη γήρανση και τη φθορά της επιφάνειας. Αποδίδονται είτε σε τεχνολογικές εξαιρέσεις για την εποχή, είτε σε μη προσεγμένες εργασίες κατασκευής (κακοτεχνίες), ή ακόμη σε πιο σύγχρονες επεμβάσεις με σκοπό άλλοτε την επισκευή και άλλοτε την ηθελημένη μίμηση αρχαίων τεχνικών.

Συγκεκριμένα, το πολύ μικρό κεντρικό ίχνος στην εσωτερική και την εξωτερική επιφάνεια της βάσης του σώματος υποδηλώνει, είτε τη στίλβωση επάνω στον τόρνο (διαδικασία όμως περισσότερο διαδεδομένη από τον 5ο αι. π.Χ. και μετά), είτε τη χρήση διαβήτη για λόγους αναφοράς σε διάφορες μετρήσεις κατά τα στάδια της μορφοποίησης.

Τα εξώγλυφα παράλληλα ίχνη που εντοπίστηκαν στη λαβή της κύλικας ίσως παραπέμπουν σε πιο σύγχρονο τρόπο παραγωγής μεταλλικών φύλλων, υποδεικνύοντας τη χρήση κυλίνδρου, ο οποίος είχε ευρεία χρήση από τον 16ο αι., ή σύγχρονη επισκευή του συγκεκριμένου τμήματος.

Ο τρόπος κατασκευής του σώματος της κύλικας από ένα ενιαίο φύλλο χρυσού είναι, από άποψη τεχνικής, συμβατός με την κατασκευή κοίλων αντικειμένων· όμως διαφέρει από εκείνο που χρησιμοποιήθηκε στις κλειστές κύλικες του Εθνικού Αρχαιολογικού Μουσείου, οι οποίες φέρουν πρόσθετο τμήμα στο σώμα τους. Το στοιχείο αυτό (το οποίο όμως μπορεί να θεωρηθεί ως εξαίρεση), μαζί με τον τρόπο κατασκευής του χείλους (στην εξωτερική επιφάνεια του οποίου εντοπίστηκαν ίχνη που αποδίδονται σε σύγχρονη πένσα και όχι σε σφυρηλάτηση), καλλιεργεί κάποιες επιφυλάξεις ως προς την αυθεντικότητα του αντικειμένου. Βέβαια, στην περίπτωση του χείλους τα ίχνη αυτά θα μπορούσαν να οφείλονται σε νεότερη επισκευή και όχι σε σύγχρονο τρόπο κατασκευής.

Η μορφή των καρφιών (πλατιές εφηλίδες ημισφαιρικού σχήματος με πατούρα), καθώς και ο τρόπος στερέωσής τους –ιδίως των δύο με γύρισμα του ενός άκρου τους στο τέλος– διαφοροποιούνται από τα καρφιά των τεσσάρων κυλίκων (πλατιές εφηλίδες χωρίς πατούρα) και τον τρόπο προσαρμογής τους (με μικρού μεγέθους και κυκλικού σχήματος εφηλίδες). Επίσης ο τρόπος κατασκευής των καρφιών (κοπή και λιμάρισμα των κεφαλών και του άκρου της ράβδου με ψαλίδι) είναι διαφορετικός και όχι τόσο διαδεδομένος τη μυκηναϊκή περίοδο. Η διαφορά θα μπορούσε να αποδοθεί σε μεταγενέστερη επέμβαση, εάν η κύλικα είχε ανακαλυφθεί με κατεστραμμένους συνδέσμους. Όμως η χημική ανάλυση του μετάλλου κατασκευής των συνδέσμων δεν απέδειξε κάτι τέτοιο.

Η κόλληση (κράμα χρυσού - αργύρου - χαλκού), βάσει της σύστασής της, μπορεί να θεωρηθεί αυθεντική, παρότι το χρώμα της διαφέρει από αυτό της κόλλησης που έχει χρησιμοποιηθεί στις άλλες κύλικες (πιθανότατα έχει επιλεγεί ένα κράμα με αυξημένο ποσοστό χαλκού ή η κολλοειδής σκληρή κόλληση). Άλλωστε τέτοια κράματα ήταν διαδεδομένα στην αρχαιότητα. Το υψηλό σημείο τήξης όμως, λόγω της χαμηλής περιεκτικότητας σε άργυρο και χαλκό, είναι στοιχείο που συμφωνεί με ένα πιο συμβατικό ίσως νεότερο είδος σκληρής κόλλησης.

Το μέταλλο κατασκευής της κύλικας είναι σκληρό σε αντίθεση με τις κύλικες του Εθνικού Αρχαιολογικού Μουσείου, όπου ο χρυσός φαίνεται πιο εύπλαστος, χαρακτηριστικό της φυσικής γήρανσης ενός σκληρού αρχικά μετάλλου από τα επαναλαμβανόμενα στάδια ψυχρηλασίας, με λεπτά στρώματα διάβρωσης.

Οι μικρορωγμές και οι "κρύσταλλοι" που παρατηρήθηκαν στην επιφάνεια της κύλικας, καθώς και το ζάρωμα του μετάλλου δεν εντοπίστηκαν και στα αντικείμενα του Εθνικού Αρχαιολογικού Μουσείου. Οι ενδείξεις αυτές συνιστούν μάλλον αποτέλεσμα είτε μη ελεγχόμενων τεχνικών μορφοποίησης και καθαρισμού, είτε επιδιωκόμενης προσπάθειας μίμησης ενός μετάλλου με "ρωγμώδη διάβρωση" και γερασμένη όψη.

Στην περίπτωση, πάντως, που τα παραπάνω χαρακτηριστικά οφείλονται σε κακοτεχνία, παρουσιάζει ενδιαφέρον το γεγονός ότι η λείανση και η στίλβωση, που προφανώς ακολούθησαν και ολοκλήρωσαν την κατασκευή, δεν τα εξάλειψαν –ούτε καν τα εξομάλυναν–, καθώς και το ότι ήταν καθαρά επιλεκτικές. Οι ακατάστατες χαράξεις που παρατηρήθηκαν ως ένδειξη τέτοιων διεργασιών, πρέπει πιθανώς να αποδοθούν στη χρήση γυαλόχαρτου – το οποίο βέβαια δεν κατατάσσεται στην κατηγορία των αρχαίων λειαντικών, αλλά ίσως συνιστά νεότερη επέμβαση.

Το κοκκινωπό υλικό που παρουσιάζεται σε κάποιες περιοχές της επιφάνειας, ενδεχομένως συνδέεται με ίχνη χώματος από το περιβάλλον ταφής, χωρίς τα ίχνη αυτά βέβαια να αποτελούν αξιόπιστα στοιχεία που να επιβεβαιώνουν την παραμονή του αντικειμένου για μεγάλο χρονικό διάστημα στο έδαφος. Η λιπαρή υφή του υλικού παραμένει ανερμήνευτη.

Όσον αφορά το κράμα κατασκευής της κύλικας είναι υψηλής καθαρότητας, με πολύ μικρά ποσοστά αργύρου και χαλκού. Ένα τέτοιο κράμα με αυτά τα ποσοστά εντάσσεται είτε στην κατηγορία του αυτογενούς χρυσού, είτε στην κατηγορία του εξευγενισμένου χρυσού. Η αλήθεια είναι ότι τέτοια ποσοστά ανιχνεύονται συχνότερα σε εξευγενισμένο χρυσό, καθώς οι περισσότερες μέχρι τώρα αναλύσεις της σύστασης αντικειμένων που χρονολογούνται σε περιόδους πριν από την εποχή της νομισματοκοπίας –συμπεριλαμβανομένων και αυτών του Αρχαιολογικού Μουσείου– διαφοροποιούνται από εκείνες αντικειμένων που ανήκουν σε μεταγενέστερες περιόδους, ακόμα και σε σύγχρονες. Παρά ταύτα, ο χρυσός της κύλικας και η περιεκτικότητά του σε άργυρο θα μπορούσε να καταταχθεί στις εξαιρέσεις για πρωτογενή χρυσό, εφόσον ο αριθμός των αναλυμένων αντικειμένων με πιστοποιημένη προέλευση και χρονολόγηση για την περίοδο που μας ενδιαφέρει είναι πολύ περιορισμένος, ώστε να έχει κανείς ολοκληρωμένη άποψη για τη σύσταση του πρωτογενούς χρυσού.

Με βάση τον γενικότερο προβληματισμό που υπάρχει, καθώς και τη διατύπωση τόσο πολλών αντικρουόμενων απόψεων γίνεται προφανής η δυσκολία τόσο ως προς την οριστική επίλυση του ζητήματος της γνησιότητας της κύλικας του Μουσείου Μπενάκη, όσο και ως προς την ένταξή της σε ενιαίο σύνολο με κοινά στυλιστικά, τεχνικά και χημικά χαρακτηριστικά.