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NOESIS
ΚΕΝΤΡΟ ΔΙΑΔΟΣΗΣ ΕΠΙΣΤΗΜΩΝ & ΜΟΥΣΕΙΟ ΤΕΧΝΟΛΟΓΙΑΣ

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Οι εργασίες είχαν γίνει αντικείμενο κρίσεων και σχολιασμού από την Επιστημονική Επιτροπή. Επι πλέον, έγιναν κι άλλες παρατηρήσεις και σχόλια κατά την συζήτηση που ακολούθησε μετά την προφορική τους παρουσίαση στο Συνέδριο.

Οι εργασίες αναρτώνται όπως κατατέθηκαν από τους συγγραφείς μετά την ολοκλήρωση του Συνεδρίου. Οι συγγραφείς φέρουν την ευθύνη του περιεχομένου της εργασίας τους, τόσο ως προς τις απόψεις τους όσο και ως προς την ακρίβεια και την ορθότητα των στοιχείων που παραθέτουν.

The Board of Directors of the Association for Research on Ancient Greek and Byzantine Technology (EDAByT) undertook the posting on its website (www.edabyt.gr) of the papers presented at the 3rd International Conference on Ancient Greek and Byzantine Technology (Athens, November 19-21, 2024).

The papers had been subject to reviews and comments by the Scientific Committee. Additionally, further observations and comments were made during the discussion that followed their oral presentation at the Conference.

The papers are posted as submitted by the authors after the conclusion of the Conference. The authors are responsible for the content of their work, both in terms of their views and the accuracy and correctness of the data they present.

METHODS OF GILDING IN LATE CLASSICAL AND HELLENISTIC GREECE

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Abstract. The technology of gilding in the fourth and third centuries BCE is an important part of the study of gilded jewellery, figurines and many other items from the late Classical and Hellenistic periods. Several different methods were used at that time in Greece, which varied according to the underlying surface. Most gilding was done with leaf rather than the thicker foil, and with gold of very high purity, probably because it was easier to work.

During the period in question, four main ways are discussed in the academic literature for adhering gold to substrates: (i) using heat, (ii) using mercury, (iii) using an adhesive directly on the surface and (iv) applying the gold leaf above a coating or ground. According to Pliny, on surfaces which could not be heated, such as marble, gold was laid with white of egg and on wood it was laid with *leucophorum*, made of ochre and Melian earth.

The method of using a coating or ground has been found by other researchers and by the present author to have been used on many occasions and to be made of kaolin, calcite or gypsum, sometimes coloured with yellow ochre. It has been found on all types of surface, including copper, bronze, wood, clay, bone and marble. This method provided a level substrate and allowed the thin gold leaf to be attached securely.

Keywords: gilding, gold, Hellenistic, gilt

1 Introduction

Gold foil, which can support its own weight, was used in Ancient Greece to cover many different objects, in a technique known as plating (Giumlia-Mair 2020,2). Many examples of plating with gold foil survive from Minoan Crete, the Mycenaean mainland and Iron Age Greece.[1] The gold was generally attached mechanically to the object, but could be made more secure by using adhesive or by overlapping and burnishing pieces of gold foil (Oddy 1981, 75-76). Gold leaf is thinner than gold foil, ranging from 1 μm to 10μm thick and cannot support its own weight. It has to be adhered securely to a substrate as it is so light. It was obviously more economical than foil, and this doubtless explains the preference for its use once refining methods became available. The main part of this article will look at methods of gilding with leaf, as opposed to plating with foil.

Examples of several methods of gilding survive dating to the periods leading up to the Late Classical, from Greece and other places beyond which were in contact with the Greek world. There are many gilded silver items such as a phiale mesomphalos described as ‘Greek’ now in the Metropolitan Museum of Art (**Fig. 1**) (MMA 2015.260.3). Silver could be gilded relatively

[1] Examples from Greece and elsewhere are given in Giumlia-Mair, 2020, 2 and for Iron Age Greece see for example some pins from Lefkandi dated to approximately 950BC (Kosma 2012, 62).

easily with heat in a process generally known as diffusion gilding[2] but copper and copper alloy objects were difficult to gild using heat as will be explained below. A rare surviving example however is a gilded bronze plaque representing Athena which was found to the north of the Erechtheion in Athens in 1887 (Stais 1887) (**Fig. 2**). It is not clear how the gilding was originally done but heat may have accidentally helped to preserve part of it since this fine piece was damaged by fire (Stais 1910,283). Pottery was sometimes decorated by applying gold leaf over a coating with an adhesive: an early example, dated to around c.460 BCE, is on a kylix now in Boston discussed by Cohen.[3] Gilding or plating using an adhesive (perhaps birch sap) was used on objects found in Celtic graves near Salzburg dating to the late Hallstatt period.[4] There are many examples of gilding above a ground in Egypt on a variety of surfaces including wood (see for example Hatchfield and Newman 1981 and Oddy et al. 1988).

Figure 1 (left). Phiale mesomphalos MMA 2015.260.3. The Metropolitan Museum of Art, New York. Figure 2 (right). Gilded bronze figure of Athena, NAM X6448, c.530. ©Acropolis Museum.

This article addresses gilding methods in the Greek world during the late Classical and Hellenistic periods, from the second quarter of the fourth to the second century BCE. Gilded objects have been found in Northern Greece and elsewhere on the mainland and islands, as well as in Southern Italy and Greek cities such as Naukratis and Ai Khanoum. Gilding was used to adorn many small and large objects on a base of metal, terracotta, wood, marble or pottery. In Greece and the wider Greek world, many gilded objects were buried in graves, and gilded terracotta jewellery may well have had a particularly funerary use[5], but there was no doubt much more gilded material which has not survived. The adhesives in particular, being organic, have deteriorated over the centuries, so the gold has detached.

The reasons for burying valuable items with the dead are complex, but honouring the deceased seems to be one of them, as well as demonstrating the wealth of the family who

[2] Oddy et al. 1979, 233-4 discuss a dagger sheath (?), BM 1885, 1213.46.
[3] Boston MFA 00.356, Cohen 2006, 108 and 126.
[4] Grave 202 item 27 Kammelhöhe, Moser et al. 2012, 39 and 239; grave 44/2, Dürrnberg, Penninger 1972, 38. The latter is dated a little later than the former. Vases from Attica have been found in some of the graves, but the gilded/gold plated objects are likely to be locally made.
[5] Manetta and Pisani 2012.

chose to honour them in this way. Gilding is traditionally thought to have been used as an economy measure, because it would have been much cheaper than solid gold, but the position may have been more complicated than this suggests. Gilded objects are found in some of the graves of the super-wealthy in Macedonia, such as Derveni A and B, indicating that there may have been other reasons for use of gilding since the people buried in these graves and their relatives could obviously afford both. Bourgeois and colleagues suggest that it may have been used on marble statues to make them look like bronze (Bourgeois et al. 2011, 654). The saline air on Delos is, they suggest, one possible reason for the choice combined with the fact that bronze was more expensive than marble for statues, probably even when gilded (ibid). Objects such as the famous Derveni crater were cast in a high-tin bronze which looks like gold and indeed was believed to be gold until the analysis was done, so gilded marble would have looked like one type of bronze favoured at the time, but whether the bronze was imitating gold or the gilding imitating bronze is unclear.

The author studied gilded wreaths from mainland Greece and the islands, as well as Southern Italy, for her doctoral thesis, and looked at the method of gilding used on all elements of these wreaths,[6] so many of the examples given in this article will be wreaths. The results of the analytical work relevant to this article are in Tables 1 and 2 and a note on the methodology is in the Appendix. Sampling permission was not sought, as the timing for the doctorate did not allow for this, and although hand-held XRF was used on all the objects studied, it was only possible to use an SEM with EDS or µXRF on material in two museums. The uneven surface of the material and its porosity mean that no reliable quantitative analysis could have been done even if permission had been obtained to sample. SEM/EDS and µXRF do show reliably the proportions of the various elements, but the HHXRF results are best used to detect whether a particular element such as mercury was present. The proportions of the elements present found with SEM/EDS and µXRF are given in weight percent and normalised in the Tables, but it must be emphasised that even these results are only semi-quantitative.

2.Working of Gold

Native (non-alloyed) gold can range in purity from less than 76% to more than 90%[7] and its composition varies a great deal even in gold from a single source (Craddock 2009, 370). It can be refined to remove other substances present, including silver and copper, and although this is not essential to hammer it into leaf[8] it does make the gold easier to work. The colour is also affected by the presence of other metals: it is whiter if alloyed with silver, and redder with copper.

There is evidence that gold was refined at Sardis in the mid-sixth century BC and by about 50 years later, gold refinement had become common in Egypt.[9] Base metals such as copper could be removed by cupellation, and silver separated by cementation: when heated slightly, silver forms a chloride with the salt and parts from the gold.[10] Platinum group inclusions are sometimes present in alluvial gold; they are described as small, hard and silver-coloured, from 5 to 50µ in size.[11] The inclusions are so hard they would have been a cause of difficulty in

[6] Jeffreys 2019. The main conclusions are summarised in Jeffreys 2022.
[7] Hatchfield and Newman1991, 30.
[8] Hatchfield and Newman pointed out that leaf can be made from less pure gold. See also McArthur et al.2015,114.
[9] Ramage and Craddock 1999, 95; Hatchfield and Newman 1991, 30.
[10] Remains of parting vessels were found at Sardis (Ramage and Craddock 1999, 100, 120, 124).
[11] Vavelidis *et al.* 1997, 88; Dagi 2011, 11.

making fine gold jewellery or leaf, so either gold was selected for leaf which did not have many inclusions or these were removed.[12] After refinement, the gold would have been beaten in a process using a hammer with the gold placed between pieces of leather or parchment (Nicholson 1979, 163). The gold leaf would then have been cut into small pieces on a leather cushion with a sharp knife and carefully transferred to a prepared surface.

The gold leaf analysed by the author from gilded wreaths was found to be technically pure, with at least 96% gold where it was possible to quantify and very little silver or copper (**Table 1**). On none of the material analysed using μXRF or SEM/EDS was any more than 2% of silver found, and very small amounts of copper. Analytical work on further wreaths from other parts of Greece and Southern Italy was done with a hand-held XRF where the absence of silver was striking. It was of such consistently high purity in the items analysed as to suggest that the silver and any copper had been deliberately removed. The author's results are consistent with those obtained by other researchers on both gilded and gold items.[13] She was not able to analyse for trace elements but many platinum inclusions would have been visible had they been present. It is theoretically possible that if copper had been present in the original gold alloy, it may have diffused in a process of surface enrichment and formed soluble corrosion products which leached out into the soil.[14] However, the gold on elements of well-preserved gilded wreaths, such as those from Phoinikas Cist Grave 5 which were not buried in soil but in a dry, sealed grave, gave similar analytical results to those from other graves, so it seems unlikely that there was any such enrichment followed by leaching.

3 Techniques Used for Gilding in Classical and Hellenistic Greece

3.1 The Four Main Methods

Pliny mentions a method of gilding using a substance known as *leucophorum* in his *Natural History* and as will be explained below it appears that this was in fact the main method used in Classical and Hellenistic Greece, although he was writing a few centuries later. He describes how gold was applied to materials such as marble and wood which could not be heated (NH XXXIII, XX): 'On marble and other materials incapable of being raised to a white heat gold is laid with white of egg; on wood it is laid with glue according to a formula; it is called *leucophorum*'. He also refers to coloured ochres being mixed with *melinum* (Melian earth) to make a coating for gilding (*leucophorum*): 'half a pound on Pontic *sinopis* [a red pigment, almost certainly hematite], ten pounds of bright *sil* [yellow ochre], and two pounds of Greek *melinum*, well mixed and triturated together for twelve successive days, produce l*eucophorum*, a cement used for applying gold-leaf to wood' (NH XXXV, XVII).

Four main methods of gilding in Classical and Hellenistic Greece are referred to in the literature: the discussions by Oddy and Giumlia-Mair are particularly helpful.[15] These methods include i) diffusion gilding, ii) gilding using mercury, iii) applying gold directly to a surface using an adhesive and iv) gold leaf applied above a coating (sometimes called gesso and also bole or more generally a ground). Techniques iii) and iv) are sometimes run together. Technique

[12] Meeks *et al.* 1996, 480 suggest gravity separation was used. Rammage and Craddock observed that there were no inclusions on the gold foil found in Sardis (1999, 242).

[13] See for example Asderaki-Tzoumerkioti 2001, 28 (gilded wreaths from Thessaly); Katsifas and Ignatiadou 2017 (gold wreaths from Macedonia); Bourgeois et Jockey 2007, 185 (terracotta and marble sculpture from Delos).

[14] Blakelock 2016, 913.

[15] See in particular Oddy 1979, Giumlia-Mair 2020 and Giumlia-Mair et al. 2002.

iv) because of its importance will be discussed separately in the next section.

3.2 Diffusion Gilding

The first method i) diffusion gilding relies on heat and was most appropriate for gilding silver. The gold leaf was laid on the silver surface, smoothed with a burnishing tool and adhered with the application of heat. Gold forms a strong bond with silver with heat but the method was rarely used for gilding copper or copper alloys because they do not form a strong bond with gold even when heated owing to surface oxidation of the copper if it is heated above about 300ºC.[16] Pliny may have been aware that gold leaf was applied to silver using heat but seems not to have known of the difficulties of using it with hot copper or bronze. Examples were found on two wreaths from Southern Italy, but gilded silver wreaths went out of fashion here by the end of the 4th century BCE (Jeffreys 2019, Vol. II, 328-9 and 345-6).

3.3 Mercury

Method ii) involving mercury is generally referred to as fire or amalgam gilding. Suggestions of a method known as cold mercury gilding have been put forward by Vittori and Oddy, but if they were used at all, it was at a later period. Amalgam gilding is done by mixing mercury and fragments of gold into a paste, smearing it onto a cleaned substrate and applying heat at between 250 and 300ºC.[17] The surface then has to be burnished. Mercury gilding is a form of plating since the thickness of the gilding is between 2 and 10μm;[18] this method was not suitable for delicate material like the leaves for wreaths, which were made of sheet copper about 0.5mm thick and sometimes had fine veins. Mercury gilding became the main method of gilding on copper, bronze and silver from Roman times until the invention of electro-plating.[19] It was known in China from the third century BC and perhaps before (Jett and Chase 2000 148-9), and also in pre-Roman times in Spain (Giumlia-Mair 2020, with references, 5-6) and in Britain by about the first century BC (Northover and Anheuser 2000, 111). There is however a question about whether it was used in the Eastern Mediterranean before that and if so, how commonly.

Two objects from the first half of the fourth century BC in Greece which are sometimes cited as examples of mercury gilding are from Tomb II at Vergina/Aigai, believed by many scholars to be that of Philip II: a silver diadem and a gold *gorytus* (quiver). Assimenos analysed these two items using atomic absorption and SEM/EDS. He found that the silver diadem had about 0.3% gold applied on the surface and that the *gorytus* was made of 16 carat gold on which a layer of higher carat gold had been applied (Assimenos 1988, 287). His table of SEM/EDS results does not show any mercury in either the quiver or the diadem, and he says in the text that he found 'traces' (ίχνη) of mercury, from which he deduced that both items had been mercury gilded but it would seem there was very little mercury. He does not discuss the possibility of diffusion gilding. Anheuser was sceptical that this material had been mercury gilded and suggested contamination (Anheuser 1996, 21; Anheuser 1999,19). Might the explanation for there being only a small amount of mercury in the material analysed by Assimenos be that the mercury was a natural component? Mercury can be found in gold,

[16] Anheuser 1997, 58-9, Anheuser 1996, 8 and Giumlia-Mair 2020,7.

[17] Anheuser found that some heat was necessary to avoid a grey film being left on the surface; but heating it beyond about 350º (Anheuser 1999, 62) spoiled the gilding and as noted above, temperatures above 300º caused oxidation of copper in the substrate.

[18] Anheuser 1997, 59.

[19] Giumlia-Mair 2020, 5.

sometimes as much as 10%.[20]

A second article cited as authority for mercury gilding during the Hellenistic period was published in 1977. Hellenistic material was amongst the bronze material analysed by Craddock, for which he used emission spectroscopy (qualitative) and atomic absorption (quantitative) (Craddock 1976, 97). He mentions in particular a ring depicting Eros (BM 1888,0601.1, Marshall 1907 no. 1258) dated to 300 BCE and said to be one of the earliest examples of mercury gilding[21] and also two bracelets of Achaemenid design from Amathus in Cyprus (BM 1894,1101.228 and 229). These latter pieces are dated to the 4th century BCE by comparison with similar bracelets found in Susa.[22] Craddock does not say how much mercury was found in any of this material. However, Andrew Oddy, a conservator at the British Museum, states that the ring and the two bracelets were found not to contain mercury when re-analysed using emission spectroscopy (Oddy 1993, 179-180).[23]



Figure 3 (left). Gilded bronze ring with figure of Eros BM1888,0601.1 (Marshall 1907 no. 1258) © Trustees of the British Museum. Figure 4 (upper-right). Ring BM1888,0601.1 seen from side. © Trustees of the British Museum. Figure 5 (lower-rught). One of the Amathus bracelets, BM 1894,1101.228 ©Trustees of the British Museum.

Judging by the photographs on the BM website (**Figs 3 and 4**), the Eros ring was covered with a thicker layer of gold than leaf, which would be consistent with mercury gilding, but on the Amathus bracelets (**Fig.5**) much of the gold has gone and it seems more likely that they

[20] Patterson 1971, 301-2; Lins and Oddy 1975, 2, 370.
[21] Williams and Ogden 1994, 253; https://www.britishmuseum.org/collection/object/G_1888-0601-1, consulted 20.12.2024. See also Thomas and Acosta 2018.
[22] Marshall 1911, items1993 and 1994.
[23] Oddy goes on to say that seven further rings referred to by Craddock as being mercury gilded were subsequently re-dated to the Roman period and two more were bought from Castellani, who frequently retouched antiquities.

were gilded with heat (diffusion), despite the difficulties of doing so on bronze.[24]

The author would welcome restudy of the ring and bracelets with optical microscopy and re-analysis with XRF or SEM/EDS. Both are surface techniques, but if done in a suitable location XRF or SEM/EDS should reveal mercury since at least 3% will remain in the amalgam after gilding and sometimes as much as 25% (Giulia-Mair 2020, 7; Anheuser 1997,58). It would also be helpful to see whether there were other elements present with the gold, such as silver or copper. As mentioned above (footnote 13) the gold on material from the Hellenistic period from Greece studied by the author and many other scholars has been found to be technically pure. It would also be helpful to look for any evidence of regilding of the seal ring, since it would have been subject to wear.

No evidence of mercury was found in the gold leaf on the gilded wreaths studied by the author (Table 1) and it was thought unlikely that there would be any, given the thin leaf (about 1μm thick). Summing up, it would seem that there are few objects dating to the Hellenistic Period from Greece which so far have revealed mercury in the gold, and for at least two of these it is clear there was only a trace of it. Even if amalgam gilding was known in Greece in Hellenistic times, it seems that it was not commonly used, although of course evidence of it may come to light, as happened with material from Spain (see Martinón-Torres and Ladra 2011).

3.4 Direct Application of Gold

Technique iii) involving the direct application of gold to the surface with an adhesive was found by Asderaki and Rehren on some of the Hellenistic gilded wreaths from Thessaly which they studied, although in the majority of cases they detected a coating beneath the gold (technique iv) (Asderaki and Rehren 2008, 510-11). This latter technique was also found on a few marble sculptures from Delos (Bourgeois et Jockey 2007, 184). The gilding on a marble throne in the Tomb of Eurydike in Vergina was applied with gum arabic and no ground beneath (Kakoulli 2009, 35). It is difficult to detect even with a microscope.

4 Technique Involving the Application of Gold Leaf Above a Coating or Ground

4.1 Purpose of Coating

The fourth technique, which involved the application of gold leaf above a coating, was widely used in Greece during the period under study for surfaces other than silver. The technique is well documented; one of the first groups of scholars to study it was that formed of Oddy and colleagues at the British Museum, who found several examples of it on material from Egypt as well as on a leaf from Kamiros in Rhodes.[25] This leaf was from a wreath originally dated to the fifth century BCE but is more likely to be from the mid-fourth.[26] Bourgeois and colleagues from the Louvre have done some particularly interesting work recently. They found that several sculptures on Delos had been gilded using this technique and that some had been regilded using the same technique (Bourgeois et al. 2011).

The author discovered that a coating or ground was used on virtually all the surfaces making up the gilded wreaths: the clay berries, bone circlets and copper leaves and sometimes stems

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[24] The British Museum website entry https://www.britishmuseum.org/collection/object/1894,1101.228, consulted 20.12.2024, describes them as gold-plated and does not claim that they were mercury gilded.
[25] Oddy et al. 1988 and Oddy et al. 1979.
[26] Jeffreys 2019 Vol.II,259.

Figure 6. Gilded wreath from Aineia, MTh7570 ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports.

Figure 7. Leaves from Phoinikas grave 5, showing gold, coating and copper leave. ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports

(**Fig. 6**). It can be seen with a microscope or a macro lens (**Figs 7–9**) and indeed to the naked eye. The material she studied was in less than an ideal state of preservation, and she cannot rule out that there may have been some examples of technique iii) where the gold is applied directly to the substrate with an adhesive—although a coating was visible in the vast majority

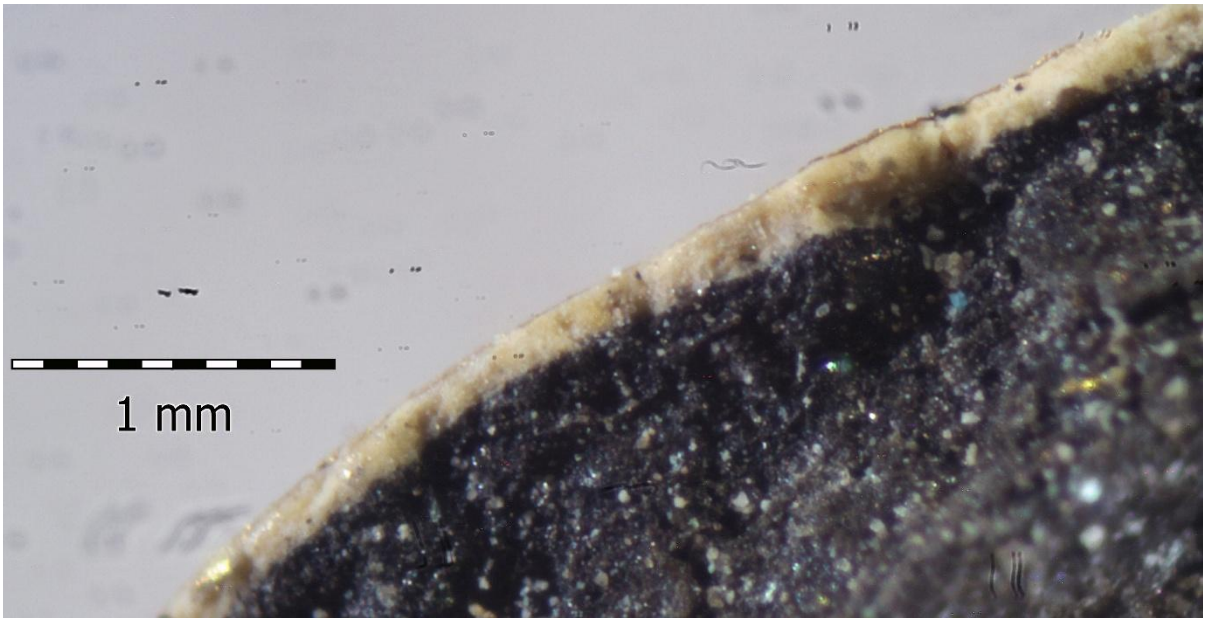

Fig.8 Detail of berry from cist grave 3 Phoinikas, showing gold, coating and clay fabric. ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports.

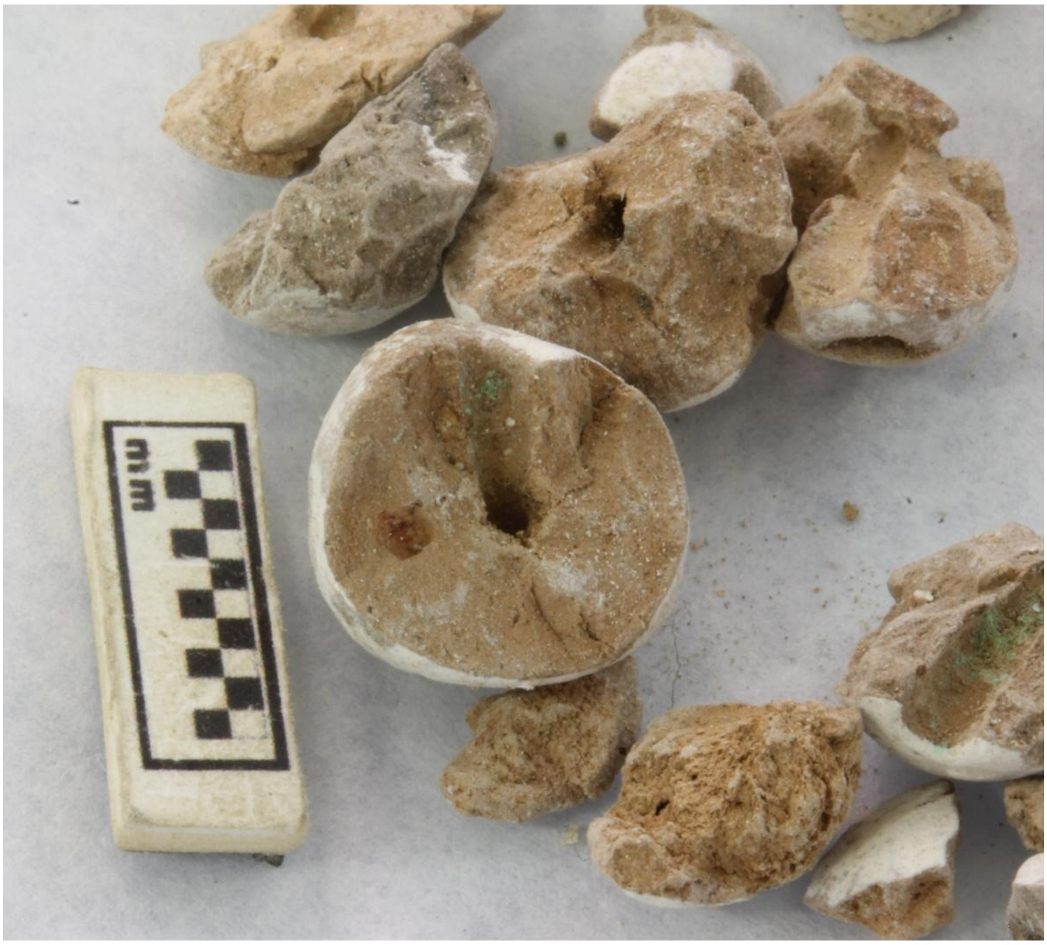

Figure 9. Detail of berry with lead white coating from Taranto Grave 10, Contrada Luppoli, MaRTA 15774.

of cases, in the remainder, it may once have been present but no longer visible. The technique of using a coating seems to have been introduced to Macedonia in the first half of the fourth century BC but was known in Attica as a means for fixing gold leaf to pottery earlier: as mentioned in the Introduction, an example is a kylix dated to c. 460 BC which has gold above a ground of gypsum and carbon.[27]

The purpose of a coating seems to be multiple: to help adhere the gold to the substrate, to provide a smooth surface for the gold, and in some cases to enhance the colour of the gold or to fill in gaps in the gilding, in others to make the underlying surface look like ivory. It may also have been used to allow burnishing. Coatings were used on many different surfaces, including wood, bronze, clay and marble. Kaolin and calcium carbonate, with a separate layer of yellow ochre and kaolin, were found on wood in Tomb II in Vergina (Assimenos 1988). Calcite and red bole were detected on various Egyptian objects (Hatchfield and Newman 1991, 34); gypsum and calcium magnesium carbonate or calcite on further Egyptian materials (Oddy *et al.* 1988, Oddy 1993, 175). Evidence of true gesso used for gilding has been found in Egypt and also of calcite.[28] Some examples of gilded marble statues have come to light fairly recently, on Delos, where Bourgois and colleagues found traces of gold remaining on ancient statues. They found a coating beneath the gold leaf on these too, made with lead white and coloured bole (Bourgeois and Jockey 2007, 184; Bourgeois *et al.* 2011, 648).

A really smooth surface might not have needed a coating, but it was no doubt more efficient to prepare the surface and add a coating than to achieve a completely smooth surface by polishing a surface such as marble. Every little imperfection in the surface beneath will show up when gold leaf is applied.

4.2 Details of Technique and Materials Used

4.2.1 Surface preparation and finishing

On marble statutes, a rasp or emery would have been used on the marble in order to assist adhesion beneath the coating (Bourgeois et al 2011, 647), but on metal surfaces no preparation may have been necessary (Oddy et al. 1988, 37). Above this was the coating and then gold leaf, approximately 1 micron thick. An agate tool may have been used for burnishing the gold, or a wolf or dog tooth.[29] Burnishing could only be done above a ground. Coatings were also used on metals including copper and its alloys. The substrate of the leaves and stems studied by the author was found to be copper, not bronze, since no tin was detected except on material thought to be from Pergamon, which is thought to be from the very end of the period (Table 1). Copper was probably selected in preference to bronze as it is easier to work.

4.2.2 One Layer or More?

On some figurines and other material there appears sometimes to have been more than one layer of ground, with a white layer beneath the coloured ground (Bourgeois and Jockey 2007, 184). Hatchfield and Newman make the same point, referring to the lower layer as a ground and the upper, coloured layer, as bole. Maier and colleagues found a single layer of coloured clay (bole) with a separating layer of a coloured adhesive above it and beneath the gold on a

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[27] Cohen says that it is the earliest example on a vase known to her (Cohen 2006, 108 and 126). A possible earlier example dated to c. 520 is a cup attributed to Psiax from which the gilding has now disappeared (ibid).

[28] Examples are given in McArthur et al. 2015, 113-4.

[29] Perrault 1992, 168.

late wreath from Taranto (Maier et al. 1998, 202). About 20% of the items studied by the Louvre team had a yellow ochre layer, only, beneath the gold, whereas most had a white layer lying beneath it.[30] On the wreaths, there appeared to be only one layer of coating in most cases, but in some there were clearly at least two such as on some berries from Isthmia (IM5046) (Jeffreys Vol. II, 204 and Vol I. fig. 6.26). Practice may have varied. Those working on gilding elements of a wreath which was only to be used in the grave may have reached for the quickest technique, using a single coloured layer which would help in covering up any gaps in the gilding. More attention would have been paid to gilding the sophisticated figurines studied by Bourgeios and colleagues where two layers were more often used. The composition of the substrate may also have been a factor in some cases.

4.2.3 Composition of Off-White Layer

In some of the cases studied by the author the white coating was almost certainly kaolinite with only a trace of calcium and nearly equal and fairly high proportions of aluminium and silicon (including berries from Phoinikas and a circlet from Derveni D—**Table 2**), but in others it was more likely to be a marl (calcareous clay) judging by the constant presence of calcium. Asderaki-Tzoumerkioti using SEM/EDS found kaolinite in the coatings on berries from two graves at Demetrias and on two leaves but a calcareous clay on a wreath from a different grave (Asderaki-Tzoumerkioti 2001, 28-9). Oddy and colleagues referred to the coating on the leaf from Kamiros which they studied as 'kaolin' (Oddy et al. 1979, 237). Hatchfield and Newman studied many examples from Egypt now in American museums and found the ground to be mainly calcite with the occasional example of gypsum (Hatchfield and Newman 1991, 36 and their Table 1). Kaolinite makes a particularly good base for gilding because of its lamellar crystalline structure, and it can be mixed with chalk to ease application (Perrault 1992, 153). Calcite is commonly found in Greece.

The coating found by the author and other scholars including Oddy, Hatchfield and Asderaki, sounds as if it is the material described by Pliny as l*eucophorum* or *melinum*. (NH XXXV, XIX). He does not of course say what, precisely, *melinum* ('Melian earth') was. Photos-Jones and Hall have made a study of various clays from the Aegean including the volcanic islands of Milos and Lemnos. These clays often had medicinal uses. They suggest that although kaolin was the main constituent, 'Melian earth' also included some silica and alunite, which contains potassium, aluminium and sulphur. They found that this produced excellent results in terms of covering power and whiteness because of the high kaolin content[31]. With the techniques used by the author of this paper there was no way of knowing whether the white coating used on the Macedonian wreaths was 'Melian earth' or another clay but it would be a distinct possibility.

4.2.4 Coloured Layer

The coating beneath the gold on the wreath elements was generally pale yellow, from the pigment yellow ochre or goethite, judging by the iron content (**Table 2)**. Bourgeois and colleagues found mainly a yellow bole (Bourgeois and Jockey 2007, 184). The only Greek example studied by Hatchman and Newman had a yellow substrate (no. 17 in their Table 1), but many of their Egyptian examples had a red bole. Some of the cases studied by the author where a red coating was observed almost certainly involved use of a clay coloured with yellow ochre which turned into red hematite because the heat of the funeral pyre removed the water

[30] Bourgeois *et al.* 2012/3, 490.

[31] Photos-Jones *et al.* 1999, 397-8; Photos-Jones and Hall 2011, 83, Photos-Jones and Hall 2014, 188.

from the oxide to form a hydroxide (**Fig. 10**). A creamy colour may have been chosen for the substrate by the craftspeople in Greece to make the underlying surface look like ivory, a precious material often used with gold.

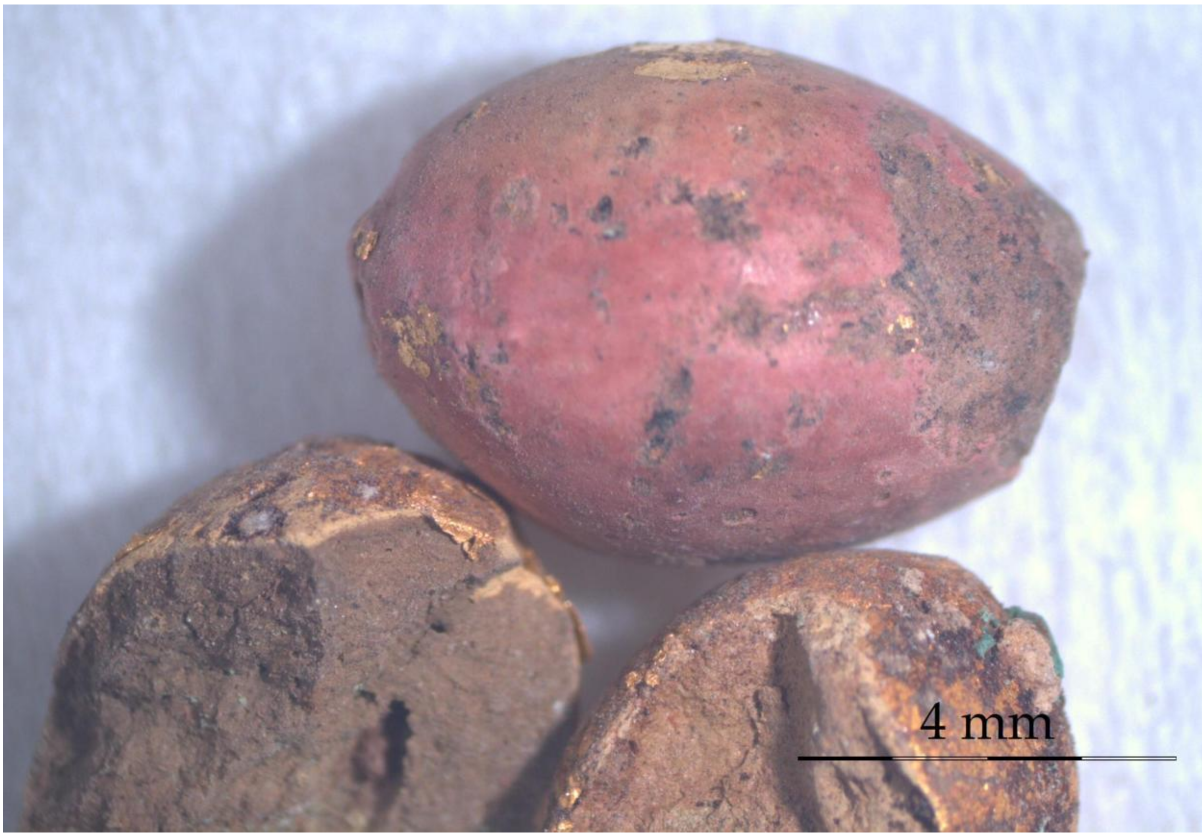

Figure 10. Berries with red and yellow coating from Derveni Grave A. ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports.

Some of the elements on wreaths from Southern Italy and Rhodes studied by the author, such as large rosettes, had a white coating which was found to contain lead, almost certainly lead white (**Table 2** and **Fig.9**). [32] Lead white was also used in the white coating on terracotta and marble sculptures on Delos studied by the team from the Louvre (Bourgeois et al 2011), and was found on figurines from at Myrina (Bourgeois et al. 2012/3, 504) and also on wood (Bourgeois et al. 2023). Quarta and Melica studied a coating on another partly gilded figurine from Taranto where the white substrate was kaolin and lead, and above this a yellow bole with aluminium, silicon, calcium and iron.[33] The original reason for the use of lead white in a coating may be that it was a particularly good base for painting. The practice may have been extended to elements of wreaths, some of which were polychrome. Lead white was not found on Macedonian wreaths, calcite being used instead. (**Fig. 11**) (**Table 2**).

4.2.5 Binders/Adhesives

An adhesive was necessary to attach the gold; this may have been mixed into the ground to act as a binder and then reactivated by water or applied as a further layer (Hatchfield and Newman 1991, 38). Animal glue and glair are often suggested as binders/adhesives, but gums

[32] Lead was also found by researchers on figurines from Taranto below gold leaf, as well as kaolin (Quarta and Melica 2014, figs 171 and 172).
[33] Quarta and Melica 2014, figs. 171 and 172.

are another possibility (see for example Bourgeois et al. 2011, 651). Analysis is particularly difficult because of the state of preservation.

Figure 11. Flowers from Phoinikas Macedonian Tomb 17442 showing polychromy and gilding. ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports.

Figure 12. Leaves with coatings of calcite (left), kaolinite and a mixture of fuller's earth and calcite on a copper base.

Figure 13. Berries, leaves and wooden circlet with gold leaf.

'Water gilding' is the term used nowadays where the adhesive (such as egg white or animal glue) is soluble in water. 'Mixtion' gilding strictly speaking involves use of a siccative oil, but the term has been used in relation to gilding from ancient Greece to refer more generally to gilding with use of an adhesive such as garlic juice (Assimenos 1988, 166). There do not seem to be any examples of a true siccative oil being used in ancient Greece, but it is not possible to be certain since the analytical methods do not generally include GCMS. Practice as to the type of adhesive used may have varied according to the effect desired and time available. Only water gilding for example permitted burnishing which allowed clever effects of contrast between brightly burnished gold and a matt finish (Bourgeois et al 2012-3, 502-6). In the case of the wreath elements it is unlikely that they were burnished.

4.2.6 Experimental Work

The author tested some possible adhesives and found that a slurry, formed of dry powdered calcite or kaolinite mixed with dried yellow ochre and to which animal glue or whisked egg white (glair) was added as a binder, worked well as a base for the gold leaf (**Fig. 12**) She also used glair beneath the gold to assist adhesion. She found that she needed to mix some calcite or kaolin with the lead white to make it adhere. She did not attempt to roughen the surface of the modern copper sheets which she used to make the leaves, nor did she burnish the gold on the various surfaces as she was looking for a quick and simple method which might have been used in antiquity.

5.Conclusion

The technique of using a coating beneath the gold on so many different types of objects, ranging from life-size statues to tiny elements of wreaths, shows how adaptable it was. The thickness of the coating and of the gold varied according to the type of object (both the gold and the coating were thicker on statues than on wreaths), but the technique seems to have been essentially the same.

The use of different substances to make the coatings beneath the gold on the various objects may have been a deliberate choice in some cases, but in others the craftspeople may have used whatever most easily came to hand. In a few cases, kaolin seems to have been specifically chosen, and in some cases white lead was used as part of the ground for aesthetic reasons. As Bourgeois, Jeammet and their colleagues in the Louvre have shown, gilders took the skill to new heights in the Hellenistic period when burnishing became an important element of finishing, with items such as folds highlighted to give depth and brilliance for which the bole was essential.[34]

Acknowledgements

I was privileged to study many gilded wreaths for the purposes of my doctorate (Jeffreys 2019) and wish to thank most warmly the curators and conservators in archaeological museums and staff in Ephorates who entrusted me with their material including in Thessaloniki, Athens, Isthmia, Kavala and Rhodes, as well as in the National Archaeological Museum in Taranto, the Archaeological Museum in Metaponto, the British Museum in London, the Musée du Louvre in Paris and the Antikensammlung in Berlin, whose material is discussed and in some cases illustrated in this article. In addition I must thank most sincerely the chemists at the Archaeological Museum of Thessaloniki, Christos Katsifas and Ioannis Nazlis, Professor

[34] Bourgeois *et al.* 2012/3, 499; Jeammet 2014, 219-220.

Ioannis Karapanayotis and Dr Dimitrios Lambakis at the Higher Ecclesiastical Academy in Thessaloniki for their assistance with the analytical work, and also Ina Reiche and her colleagues in the Rathgen Laboratory in Berlin. My heartfelt thanks go to my supervisors, Dr Maria Stamatopoulou and Dr Christopher Doherty (both University of Oxford), as well as to Dr Despina Ignatiadou (National Archaeological Museum, Athens), for their generous advice and encouragement throughout.

Appendix: Methodology of scientific investigations by the author

Chemical analysis

The first requirement of the scientific investigation was that the analysis should be non-destructive, since any sampling would have required a further permit, which even if granted would not have been within the time-scale of the thesis. Permission was sought for material to be studied with a hand-held X-Ray Fluorescence Spectrometer (HHXRF), and selected material to be examined with a micro-XRF (μXRF) and, in a few cases, a Scanning Electron Microscope with Energy Dispersive Spectrometer (SEM/EDS). In a few further cases involving pigments, a Raman and/or Fourier Transform Infrared Spectrometer (FTIR) was used.

A Bruker Tracer III-V handheld HHXRF (rhodium tube) belonging to the University of Oxford was taken to the museums in Athens, Rhodes, Metapontonto and Taranto, Thessaloniki and the British Museum on visits between 2014 and 2018. The analyses were carried out using an acquisition time of 90-120 seconds, with at least two iterations for each type of material analysed from each object. In the first instance, the instrument was used with an X-ray filter for copper alloys at 40KeV with preset calibration, which was tested against materials of known composition (modern coins). The lightest element which can be detected with a flat surface without vacuum is calcium. Use of a vacuum pump at 15KeV (with a card preset for aluminium) improves sensitivity towards the lighter elements, making it possible theoretically to detect aluminium and even magnesium providing the sample is in contact with or very close to the aperture,[35] but it was found that the instrument could only reliably detect these very light elements on modern purchased samples, not archaeological material, owing to degradation. The vacuum attachment was used with most of the material, but was not taken to Rhodes. Levels of accuracy for this type of instrument in relation to gold objects have been reported as being as good as 10% relative (±10%), and precision as good as 5% relative,[36] but this depends of course on the topography of the material. An HHXRF can be used for quantitative analysis providing it is properly calibrated and the data obtained are evaluated in terms of accuracy, precision and sensitivity, but only on flat material. The surfaces of all the items

[35] Bezur and Casadio 2012, 254.
[36] Guerra and Rehren 2009.

studied were uneven, and in some cases curved, and although the material was placed whenever possible at the optimum distance of 1-2mm from the instrument, there was some variation in the distance. Any assessment of the proportions of elements present requires averaging of several analyses performed on the same object (semi-quantitative analysis). The size of the peaks gives a rough indication of the relative proportions of elements present.

All the individual items, such as the berries and leaves, are small, and although the analysis is essentially a surface analysis, the beam penetrated through the coating into the body of the berry.[37] The depth of penetration of the beam through clay was found to be about 0.2mm - about the depth of the coating. The width of the beam is about 7mm—approximately the length of a berry, so it was not possible to analyze a precise area, such as a piece of coating or copper, without interference from adjacent material.

Permission was obtained to study selected material from Macedonia using the micro-XRF at the Archaeological Museum of Thessaloniki, a Bruker Artax 400, which was operated by the museum chemists Ioannis Nazlis and Christos Katsifas. This has a more highly focused beam, with a spatial resolution down to 70μm though the results obtained still showed some interference from adjacent material. By analyzing some of the same material with this instrument and the HHXRF it acted as a check on those results.

The results from the HHXRF and the μXRF were interpreted by comparing the line spectra obtained with the energies of the K and L X-ray lines characteristic for the relevant elements. Bruker software was used for both. The quantification of the analyses using the Archaeological Museum of Thessaloniki μXRF was done by the author, using calibration and standards provided by the Museum, but as explained above, because of the topography of the material this could only be semi-quantitative.

Selected items of material from Pergamon in the Antikensammlung in Berlin were analyzed by the Rathgen Laboratory with a micro-XRF and SEM/EDS. The results are summarized in an unpublished report by the Rathgen Laboratory (Rathgen 2017, Report no. 96_081517).

Permission was obtained to study a small selection of material with SEM/EDS, at the Higher Ecclesiastical Academy in Thessaloniki. The SEM used was a JEOL 5910 with Oxford Instruments Inca 300 software and was operated mainly at 20KeV but reduced to lower energy for clays. The SEM/EDS can detect elements down to carbon. Typical detection limits are about 0.08wt%, though only on flat samples.[38] The material, consisting of individual berries, fragments of leaf etc, was placed whole in the chamber of the SEM.

Raman analysis on some coloured items such as berries and flowers from Nikisiani and sites in Macedonia was done with a Renishaw InVia Spectrometer at the Higher Ecclesiastical Academy in Thessaloniki. A small amount of FTIR analysis was undertaken on a few items from Macedonia using a Perkin Elmer Spotlight 400 Microscopy System. The analysis was done on both instruments by Dr Dimitrios Lambakis. The Raman instrument was used in June 2017 with a red 785nm laser only, used at very low power (below 1mW/μm^2) to avoid overheating the sample and focused to a spot of 1-2 μm. Permission was obtained to use Raman on selected items from Macedonia and FTIR was used in reflectance technique in point mode. The wavelength range when used in this way was 4000 to 750 cm ^{1}. As with the SEM, the material was placed whole in the chamber of the respective instruments and returned unharmed to the museum. Dr Lambakis assisted the author with the interpretation of the results from both instruments.

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[37] The depth of penetration depends on the density of the sample as well as the energy used—Bezur and Casadio 2012, 277.

[38] Kuisma-Kursula 2000.

Photography

Photographs were taken using a Canon camera 400 with Canon macro lens (1 to 1) mounted on a tripod and generally using a lightbox and two lamps with daylight bulbs. They were processed with Canon, Microsoft and Adobe Photoshop software.

Optical microscopy

Optical microscopes belonging to the museums were used in Thessaloniki and Chania. In several further museums, a Meija binocular optical microscope belonging to the University of Oxford was used with the Canon camera described above, an adaptor, laptop and appropriate software. A USB digital microscope (x20) was used to examine material for which the more sophisticated microscopes were not available.

Experimental work

Some elements of a wreath were made by the author using modern materials, to get a feel for the materials and an idea of how long it might have taken to make a wreath.

- Copper sheet 0.5mm thick supplied by Sheet Metal Products
- Montmorillonite for the fabric of the berries supplied by Bath Potters (1137 Smooth Terracotta)
- Calcite, kaolinite, titanium dioxide, talc and goethite for the coatings supplied by Naissance (www.naitr.com), and Minerals-Water
- Rabbit skin glue supplied in pellets by Liberon Limited
- Glair was made by beating egg whites, left to stand for 24 hours
- Gold leaf was purchased in Myanmar and from UK bookbinding suppliers.
- Pigments were purchased from a supplier in the US.

The leaves were cut from copper sheet using tin snips and scissors, although chisels and a sharp knife were also tested. The berries were formed by hand from montmorillonite (**Figs. 12 and 13**).

The dry pigments such as calcite and kaolinite were mixed into a slurry with water and painted on the leaves and berries without an adhesive, and the exercise was then repeated using glair and finally animal glue mixed with the dry pigments as it was found that the calcite slurry did not adhere to the copper unless an adhesive was applied. A layer of glair or animal glue was painted on the coating once it was dry. The gold leaf was cut into squares approximately 0.5cmx0.5cm and laid on the berries and leaves after the glair had been in position for about 20 minutes and was still tacky.

Lead white was mixed with gum arabic and a few drops of distilled water, then painted on the clay berries. It was found that the lead white did not coat the berries unless mixed with calcite or kaolin. As it had been used on flowers and some of the berries, cinnabar was mixed with gum arabic and painted on a white background (kaolin).

The author does not have any experience of making jewellery, but has used gold leaf on leather in bookbinding with glair and a hot tool. She estimated that it would take one person with moderate skills about a week to make a wreath, assuming the copper sheet and gold leaf had been obtained ready-made, as well as the wires for the stems, and that the bone ribs had been shaped and cut to size. This was the same as estimated by a jeweller to whom the procedures for making a wreath in antiquity were explained. Features such as colour or gilded stems would of course add to the time needed.

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Table 1: Results of metals analysis on selected wreaths

For the reasons explained in the Appendix, no attempt at quantification is done for the HHXRF. Quantifications where possible are given in weight percent and have been normalised to 100%. ✓ indicates that an element was present, x indicates that an element was checked specifically and not present.

Mus. no.	Part	Method	Al	Si	Ca	Fe	Cu	Sn	Au	Pb	Ag	Hg
BM 1861, 0425.2 (Kamiros)	Gilding on leaf	HHXRF			x	tr	✓		✓		x	x
BM 1861, 0425.2 (Kamiros)	Leaf sub-strate	HHXRF	tr	✓	tr	✓	✓	x	✓	x		
Aineia 7572	Gilding on circlet	µXRF◊			2	1	1		96		x	x
Aineia 7572	Gilding on berry	SEM/ EDS	1.8	1	4.9	tr	0.7		92.3		0.6	x
Aineia 7572	Gilding on leaf	SEM/ EDS			tr	tr	3.5		96.5		x	x
Aineia 7572	Leaf sub-strate	SEM/ EDS			0.7		97.4	x	tr			
Nikisiani Δ	Gilding on berry	HHXRF		✓	✓	✓	✓		✓	x	x	x
Nikisiani Γ	Gilding on berry	HHXRF			✓		✓		✓	x	x	x
Metaponto	Gilding on berry	HHXRF			tr	✓	✓		✓	tr	x	x
Metaponto	Leaf sub-strate	HHXRF			tr	tr	✓	x	✓	x	x	x
MArTA 56586	Gilding on rosette	HHXRF			✓	✓	✓		✓	tr	x	X
MArTA 107617	Circlet	HHXRF				tr	x	x	x	✓	x	X
Rhodes M1379	Circlet	HHXRF				tr	tr	x	x	✓	x	x
Pergamon (**item 7**)/P1	Gold on circlet	µXRF*					0.5		99.4			
Pergamon (**item 7**)/P1	leaf	µXRF*				0.1	95.8	3.8		0.1		

◊ Analysis by chemists at Archaeological Museum of Thessaloniki
* Analysed by the Rathgen Laboratory

Table 2: Analysis of coating and pigments from selected wreaths

Following convention, the results obtained with SEM/EDS for minerals (silicates, carbonates etc) have been combined with oxygen (stoichiometric), allowing comparison with published data; all are given in weight percent (to one decimal point) and have been normalised to 100%. For the reasons explained in the Appendix, no attempt at quantification is done for the HHXRF. ✓ indicates that an element was present, x indicates that an element was checked specifically and not present.

Mus.no	**Part**	**Method**	**Al/ Al_2O_3**	**Si/ SiO_2**	**K**	Ca/ **CaO**	Fe/ **FeO**	**Cu**	**Au**	**Pb**	**Hg**	**other**
BM 1861, 0425.2 (Camirus)	Coating on bone circlet	HHXRF		✓	x	✓	✓	✓	✓	✓		
BM 1861, 0425.2 (Camirus)	Coating on berries	HHXRF		✓		✓	✓			x		Ti, Cl, S
Ainiea 7572	White coating on berry	SEM/ EDS	27.4	38.0		7.6	4.0	✓	✓			Ti (0.7). S
Akanthos	White and red flower	HHXRF				✓	✓				✓	
Derveni D	Coating Circlet	µXRF◊	38.5	50.5		1.7	4.2	✓	✓			P,S, Ti
Pilaf Tepe	Berry	HHXRF				✓	✓	✓				
Phoinikas 3	Coating on berry	SEM/ EDS	26.1	59.3	Tr	0.9	1.6	✓	✓	x		Mg, Ti (1.0), S
Phoinikas 5,3	Coating on berry	SEM/EDS	41.0	52.1	Tr	0.4	0.4	tr				S
Phoinikas Macedon-ian Tomb	White flower with red	HHXRF	✓	✓		✓	✓		tr	x	✓	S
Rhodes M1149	Off white coating on berry	HHXRF				✓	✓	✓	✓			
Rhodes M1378	Coating on rosette	HHXRF	✓	✓		tr	✓	✓		tr		
Metaponto	Berry off white coating	HHXRF	✓	✓		✓	✓	✓	✓	x		
Metaponto	Grapes off white coating	HHXRF	✓	✓		✓	✓	✓	✓	x		
MArTA 50710 (**item 3**)	Red flower	HHXRF				✓	✓	✓	x	✓	✓	
MArTA 50710 **item 3**	White rosette	HHXRF		✓		✓	tr		x	✓		S, Ti

MArTA 107663-5	White on rosette	HHXRF	✓	✓		✓	✓		x	✓		
Nikisiani A	White coating on flower	HHXRF				✓	✓	✓		✓		
Nikisiani B	White coating on berry	HHXRF		✓		✓	✓	✓	✓			S
Nikisiani Δ	White and blue on berry	HHXRF				✓		✓	✓	x		
Nikisiani A §	White coating on flower	Raman§										
Nikisiani Δ §	White and blue coating on berry	Raman§										
Nikisiani Δ §	Red flower	Raman										
Nikisiani A§	Red berry	Raman										
Phoinikas Macedon-ian Tomb§	Yellow flower	Raman										

§ Analysis by Dr Dimitrios Lambakis, Higher Ecclesiastical Academy, Thessaloniki
◊ Analysis by chemists at Archaeology Museum of Thessaloniki