# From Damascus to Denia: scientific analysis of three groups of Fatimid period metalwork

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*ABSTRACT: A selection of 153 Fatimid period (11th–early 12th century AD) copper-alloy objects from three of the four major archaeological assemblages were analysed by ICP-AES. Five alloy types were identified and these are found to correspond well with the alloys mentioned in the contemporary literature. One group, made of high-tin bronze, was subjected to metallographic examination. Objects from all three sites have identical chemistry, although four compositional groups were identified on the basis of trace elements. However, these do not correspond to the geographical find spots, but to stylistic criteria. Lead isotope studies were used in conjunction with trace elements to clarify the likely origins of some of the objects. The results allow discussion of the production and distribution of copper-alloy metalwork within the medieval Islamic world.*

## Introduction

Studies of Islamic metalwork that include a significant scientific component are few and far between; most notable is *Persian Metal Technology: 700-1300 AD*, which has not been superseded (Allan 1979). This is a comprehensive work, based primarily on the interpretation of contemporary texts, but also drawing on over 60 chemical analyses and numerous observations. However, this study is geographically limited to early medieval Persia and the findings may not be applicable elsewhere in the Islamic world. The same year, Craddock (1979) published 'The copper-alloys of the Medieval Islamic World', based on an undisclosed number of analyses of British Museum pieces, which have more recently been incorporated into a larger work of synthesis (149 objects: Craddock *et al* 1998). Both these works are limited by the scope of the British Museum holdings, which are mainly 'art' pieces from the 12th century and later. Nevertheless, the latter work remains the most comprehensive analytical overview of Islamic copper-alloys yet published. Other analyses include those of 18 pieces in the Freer Gallery, Washington, spanning 800 years (Atil *et al* 1985) and others in papers dealing primarily with art historical topics (*eg* Melikian-Chirvani 1974). Access to suitable material has also presented problems; western museum holdings (such as the Ashmolean Museum, British Museum and Freer Gallery) are limited and often biased towards 'art' pieces. In addition, the excavation of well-dated and provenanced material in the countries of origin can be problematic; the archaeology of many of the countries which recently were, or are, part of the Islamic world remain strongly politically charged, to the detriment of academic enquiry.

## Archaeological context

In 1998 at Tiberias in the modern state of Israel a remarkable cache of Fatimid metalwork was uncovered during rescue excavations just outside the modern town (Khamis and Amir, 1999). The find consisted of approximately 1000 copper-alloy objects including all types of decorative and utilitarian metalwork from large, grand lampstands to small harness fittings. The objects were found in three ceramic storage jars that had been buried beneath the floor of a workshop. The author was asked to undertake the scientific analysis of a representative selection of the assemblage which will appear in the forthcoming catalogue. However, the discovery

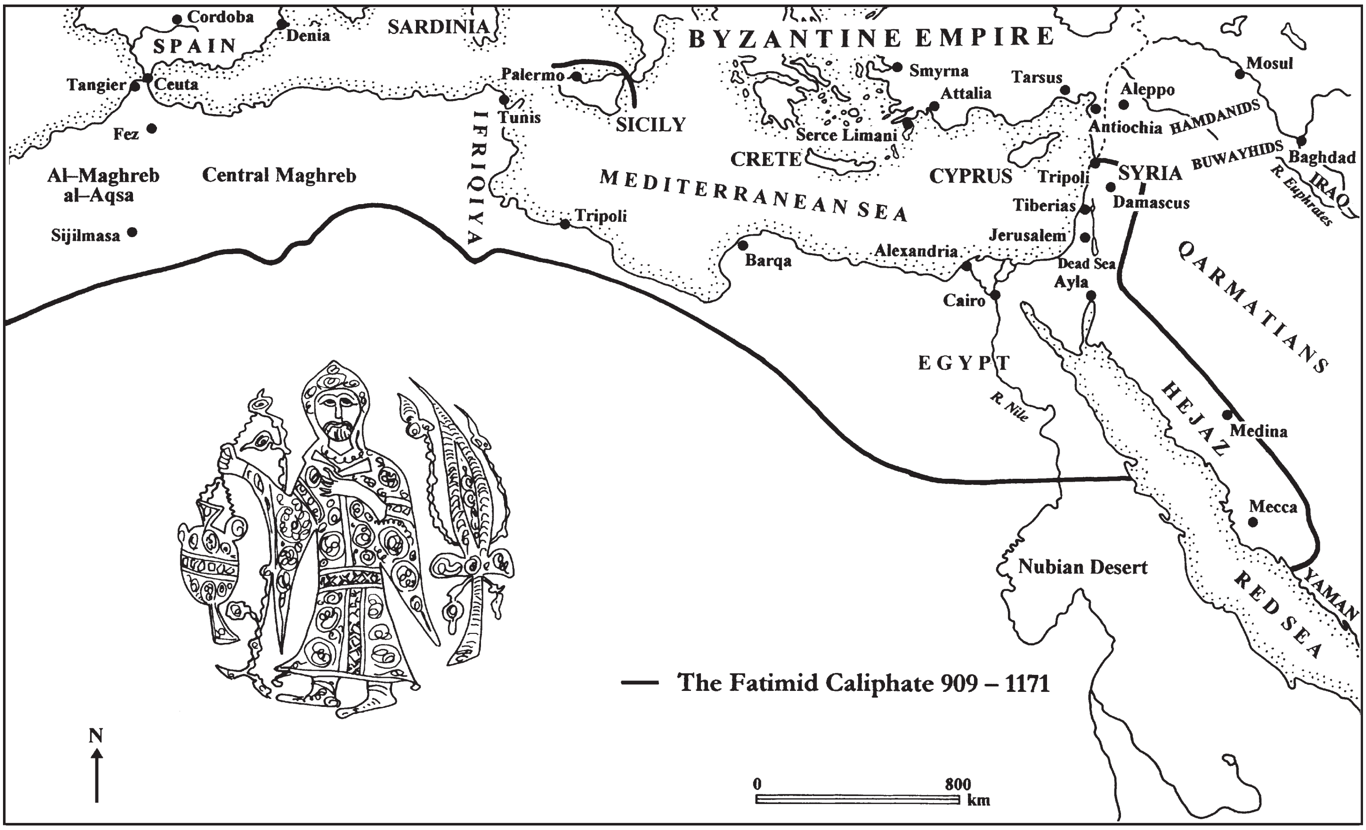


*Figure 1: Map showing the extent of the Fatimid Caliphate and the location of the sites mentioned in the text.*

of the Tiberias assemblage presented an opportunity to undertake a more far-reaching analytical survey of Fatimid copper-alloy metalwork and to address some questions regarding its production.

There are three other assemblages of Fatimid metalwork from what can be regarded as good archaeological contexts (Fig 1); a group of 118 recently-excavated objects from Caesarea on the coast of Israel, 100km south of Tiberias, a group of 150 objects found in Denia in Spain, and the Fatimid metalwork from the Serçe Liman shipwreck discovered off the coast of south-west Turkey. The Caesarea hoard has been studied by Sariel Shalev of Haifa University in Israel (as yet unpublished), but the other two assemblages have only been subjected to a limited scientific study (Azuar 1989; Barnes *et al* 1986; Brill 2003). Permission was therefore sought to take samples from these copper-alloy objects.

Denia is a coastal town located on the Cap de la Nau, the nearest point on the Iberian Peninsula to the Balearic Islands; it is approximately 90km from Valencia and Alicante. Historically Denia was a Roman municipium abandoned by the end of the 7th century but re-occupied three hundred years later by Spain's Arab rulers who recognised the site's advantages as a natural harbour. The Caliph 'Abd ar-Rahman III (912-961) installed a shipyard there and the town grew in importance as a naval and mercantile centre, being well defended by a spectacular castle constructed on the hill in the centre of the town. After the collapse of the Cordovan Caliphate at the beginning of the 11th century, Denia became the administrative head of the Islamic *Taiyfa* states, a series of successor kingdoms founded by the *Fata amiri* Muyahid. Denia controlled much of the eastern part of Al-Andalus, including the Balearic Islands and, for a while, laid claim to Sardinia, although without realization. The royal court in Denia was renowned throughout the Islamic world for its sophistication and refinement and its merchants traded widely.

The hoard of Fatimid metalwork was found by labourers installing pipework for drinking water during the 1920s. It was found inside a large earthenware jar in a similar fashion to the hoard from Tiberias and many of the pieces are stylistically identical to those in the Israeli group. The dating of the hoard to the Fatimid period is purely on stylistic grounds and the majority of the pieces have been attributed to Egyptian workshops on the basis of parallels in museum collections.

The group of metalwork from the Serçe Liman wreck has a rather different context. The ship from which the metalwork came was a Byzantine merchantman that sank on its return voyage from Fatimid Syria to Constantinople (van Doorninck 2003). The ship and its crew were almost certainly from a port to the north of Constantinople, possibly Raidestos, on the northern shores of the Sea of Marmara, and there are also strong indications of a Bulgarian link amongst the artefacts from the ship and its cargo (*ibid*). However, the Fatimid connection is also very strong with not only the cargo of 3 metric tons of Syrian glass cullet, but also many of the artefacts including glass weights, jewellery, glazed bowls, glassware and, of course, the copper-alloy metalwork (*ibid*). Of the 15 objects analysed, Allan (2003) classifies nine as stylistically Fatimid [out of a total of 14 listed]. Six other copper-alloy objects that are not regarded as Fatimid were also analysed; three small heart-shaped objects, a steelyard weight, a scale-pan and a highly decorated sword hilt. Of these, the heart shaped objects are of unknown function and have been given a Bulgarian provenance by lead isotope analysis (*ibid*), the steelyard weight and scale pan are regarded as stylistically Byzantine, although accompanied by Fatimid glass weights, and the sword hilt is also thought to be Byzantine. Lead isotope analysis carried out on metal from the sword hilt and the steelyard give very similar results, which are consistent with a Turkish or Iranian origin for both objects (Barnes *et al* 1986). The significance of these earlier lead isotope analyses and their relationship to these analyses is discussed below.

## The objects analysed and techniques used

This paper presents the results of 153 detailed chemical analysis of 145 artefacts from the three assemblages; these are listed in Table 2 (Appendix 2). The majority of analyses (121) are of objects from the Tiberias assemblage because it is by far the largest group, providing slightly more than a 10% sample and expanding on the group analysed for the catalogue. Fifteen of the approximately 20 copper-alloy objects from the Serçe Liman assemblage were analysed and 12 objects from the Denia hoard (providing slightly less than a 10% sample). The objects were selected to represent as broad as possible a spectrum of artefact types, whilst including items of particular art historical or archaeological interest (such as the sword hilt from Serçe Liman and the 'Coptic' incense burner from Tiberias). The bulk chemical analysis was by inductively coupled plasma atomic emission spectrometry (ICP-AES) and additional imaging and micro-analyses were by scanning electron microscopy in conjunction with energy dispersive analysis (SEM-EDS). Lead isotope analysis of two of the Tiberias objects was undertaken by laser-ablation multi-collector inductively-coupled plasma mass spectrometry (LA-MC-ICPMS). Full details of the analytical methods are given in Appendix 1, below.

## The results

### *Alloy types*

Across the objects from all three sites there are five principal alloy types represented; brass (the alloy of copper and zinc), bronze (copper and tin), un-alloyed copper, gunmetals (ternary alloys containing both zinc and tin) and high-tin bronzes (bronzes containing over 15% tin). The actual percentages that define, for example, an alloy as being a brass or a gunmetal, vary slightly from researcher to researcher. For the purposes of this study the approximate limits are: brass contains over 5% zinc and less than 5% tin, a bronze contains more than 5% tin, a gunmetal more than 2% tin and 2-5% zinc, and un-alloyed coppers have less than 2% either tin or zinc. Any of these alloys is a leaded bronze, leaded brass etc if it contains over 5% lead.

The choice of alloy type is interesting and reflects both the aesthetic and technological considerations of the people making and using the objects. The high-tin bronzes form a group deserving special attention. The compositions can be represented graphically and Figure 2 shows the distribution of alloy types as defined by tin and zinc contents. The vessels (ewers, buckets, cauldrons, bottles etc) can be divided into two groups; those made of brass and those made of high-tin bronze.

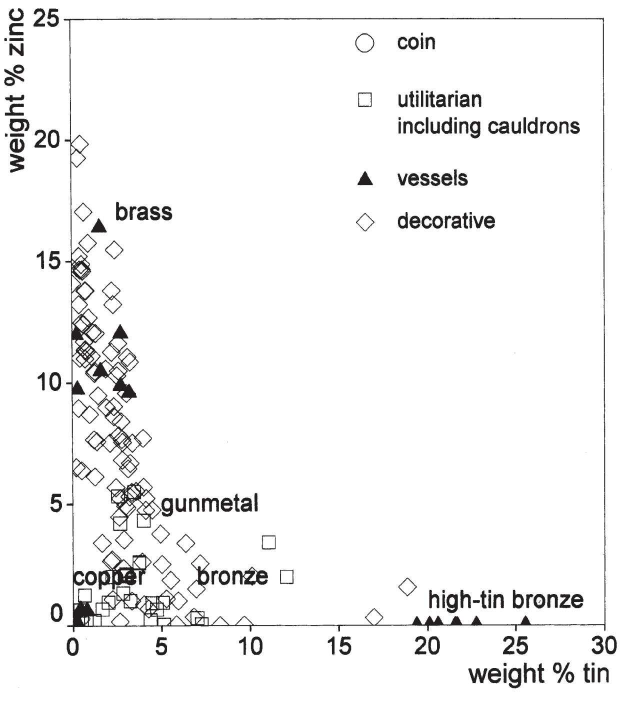


*Figure 2: Zinc and tin contents of analysed objects showing the alloy types represented.*

The 'decorative' objects in general are made of brass (*eg* lampstands made up of tripod, stem and tray), whilst the more 'utilitarian' objects are made of gunmetal or copper. The Byzantine coins found with the Tiberias metalwork are all made of un-alloyed copper, as are the 'utilitarian' vessels, both the cooking pots (525:27, MV4, MV3, MV2, MV1) and the larger buckets (525:18, 525:25/2, MV7, MV8). Inevitably a number of exceptions exist reflecting the inadequacies of the groupings; the arguably 'decorative' 'lamp fillers' are predominantly (three out of five) made of gunmetal, five lamp tripods are made of gunmetal as are three decorative handles. The high-tin bronze lamp-stand tray from Denia and jug from Serçe Liman are also notable exceptions and will be discussed below. The sword ferrules from Tiberias are all of very similar types and are equally divided between brass, gunmetal and bronze, but the highly decorated Byzantine style sword hilt is made of a low-zinc brass. The single gilded fitting (567: 40) is made of un-alloyed copper, the material that has traditionally been used as the substrate for gilding (Oddy 1982), because the presence of lead will cause the gilding to discolour (Craddock 1977, 108).

## *High-tin bronzes*

One of the bells (525:226) is made of a relatively high tin-bronze (17% tin), although this tin content is not as high as is found in the classic high-tin bronze vessels. This sort of alloy is often called bell metal; the higher tin content producing a harder metal which gives a clearer ring (Jennings 1999, 12). Modern bell metal, used for the casting of church bells, contains 23% of tin, however medieval bell compositions can contain as little as 13% tin (Hanson and Pell-Walpole 1951, 17).

The high-tin bronzes account for only six of the Tiberias samples taken and, assuming a broadly representative selection was made, must therefore be regarded as a rare alloy type, accounting for less than 5% of objects analysed. The other two groups each revealed a single example of high-tin bronze; a small jug from Serçe Liman (MV10) and a fragment of a lamp tray or plate (D81). All six of the Tiberias pieces are from bowls of broadly similar form; 575:30/6, 575:47 and 575:71/1 are simple, open formed bowls which have a number of distinctively sharp and clean breaks. The remaining samples were from similar distinctively-shaped fragments. A characteristic feature of high-tin bronzes is their brittleness resulting in glass-like breakage and often a glossy black patina or green and brownish-red wart-like eruptions. Both features were observed in the Tiberias bowls, and the Serçe Liman jug has an even glossy black patina, a feature commented on during Brill's surface analyses that lead him to assume that the vessel was made of tinned copper (Brill 2003). The forms of the Tiberias bowls and the Denia tray are also a feature distinctive of high-tin bronzes; the use of open, simple shapes, often hemispherical bowls or flattish trays reflects the difficulties of the manufacturing process. Depending on the exact nature of the production process, the alloy when fresh is silvery or golden in colour and very brittle; the latter characteristic being responsible for the distinctive 'shattered' appearance of both the complete bowls and the fragments. The important thing about the working properties of this alloy is that it is only plastic between 500°C and its melting point at around 750–800°C (Goodway 1987, 17). If the alloy is allowed to cool slowly from its working temperature, it will shatter easily; if it is quenched it will remain reasonably malleable, although not as malleable as ordinary bronze. Consequently, if a thin-walled vessel is required, it is best to shape this alloy by forging at red heat and then quenching it at a temperature above 520°C (Goodway 1987, 1). The precise temperature at which the alloy was quenched is crucial to the degree of ductility achieved and is also an indication of the skill and understanding of the metalworker. The working history of an alloy can be ascertained through study of its microstructure; the result of the metallographic analysis of the Tiberias bowls is discussed below.

The Serçe Liman jug (MV10), on the other hand, is a complex closed shape quite unsuited to the production process described above. However, Allan (2003) describes the jug as having a 'heavy cast body', which indeed it does and this explains the apparent unsuitability of material to form. In fact cast high-tin bronze vessels of similar form but earlier date (7th–8th century) are found in Lakpour's (1997) publication of the high-tin bronze metalwork in the National Museum of Iran.

Compositionally the high-tin bronze pieces fit well with the analyses of high-tin bronzes reported by Allan (1979); they all have similar tin contents of between 18.9% and 25.6% (mean 21.3 ± 2.1%) compared to between 31.2% and 19% for Allan's analyses (mean of four 22.6%). Similarly, the tin contents of the nine pieces published by Melikian-Chirvani (1974) for which analyses are available vary between 21.6% and 23.6%. There is one exceptional value of 31.2% which, it is stated, is likely to be an enhanced value due to the surface enrichment of tin caused by corrosion processes (Melikian-Chirvani 1974, 148); this is the same analysis as the 31.2% reported by Allan. Removing this analysis reduces the mean of Allan's data to 19.7% tin. Melikian-Chirvani's reported analyses give a mean of 22.7% tin (for eight analyses).

The lead content of the high-tin bronzes is generally low; less than 1% in all cases except for the tray from Denia that contains 1.84%, resulting in a mean lead content of 0.29% for all eight objects. This is similar to the comparative data. The only exception is a cymbal in the Louvre, reported by Allan, which contains about 15% lead. The presence of even small amounts of lead will severely hinder both cold- and hot-working. This is because lead is effectively insoluble in copper-alloys, remaining unevenly distributed as small globules, thereby causing discontinuities within the metal structure and resulting in weakness and breakage. The few literary references that mention the manufacture of high-tin bronze (see discussion below) indicate that hot-working was the usual method of production with casting less common, and, indeed, the Fatimid high-tin bronze vessels here are mainly produced by hot-working with the exception of the jug (MV10) (see below). The slightly higher lead content of the tray (D81) may indicate that this object was also cast.

## *The lead content of alloys*

Whilst even a low lead content is detrimental to the cold- or hot-working properties of all copper-alloys, the addition of 2% or so of lead will benefit castings. Lead reduces both the melting point and the viscosity of the alloy, making it easier to produce sound castings (pressure-tightness) and additions of lead will also aid a lathe-based finishing process by assisting lubrication and causing complete shearing of the chips produced during turning (Hudson and Hudson 1967, 275). Several of the artefacts analysed showed clear signs of having been finished on some type of lathe – usually concentric rings around a central indentation – and large amounts of waste turnings were found inside two of the vessels in the Tiberias hoard that are consistent with this sort of finishing process (Ponting forthcoming a). Thus it is of interest to investigate the lead content of the alloys used in Fatimid copper-alloys and to see whether the negative and positive properties of lead were appreciated.

Figure 3 shows the lead and tin contents with the artefacts categorized according to the method of manufacture assumed from visual inspection. The wrought artefacts, other than the high-tin bronzes mentioned above, form a discrete group having low lead (<5%) as well as low tin (<2%), reflecting the fact that they are usually made of a relatively high-zinc brass, or of unalloyed copper (Fig 4).

Whilst, on one level, it appears that the improved ductility of copper and brass over bronze was appreciated by the smiths, why one type of artefact should be made of brass whilst another is made of copper poses an interesting question. The answer apparent from the data presented here appears to be status; the wrought objects made of copper are, apart from the gilded fitting and the coins, utilitarian vessels – cooking pots and buckets. Copper artefacts account for less than 12% of the objects sampled from Tiberias and Denia but half of the objects sampled from the Serçe Liman shipwreck are made of copper. This reflects the fact that the two hoards were composed of items selected for deposition at, in the case of Tiberias, a workshop, whilst the Serçe Liman

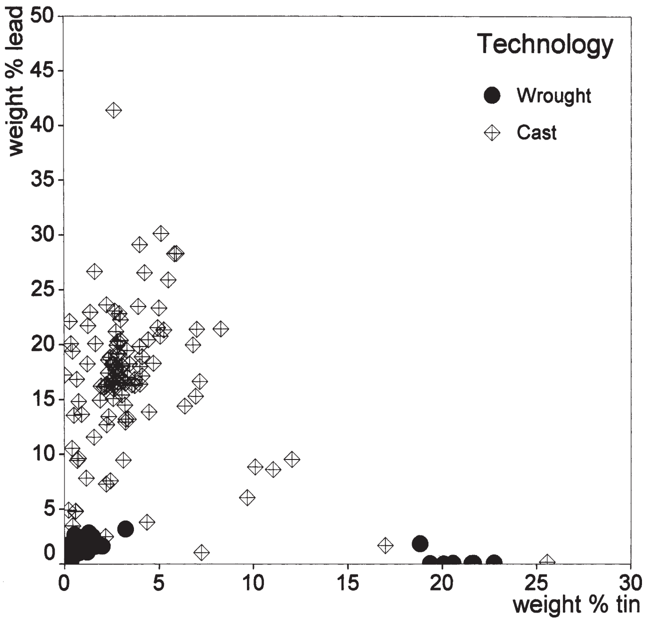


*Figure 3: Correlation of lead and tin contents with manufacturing technology.*

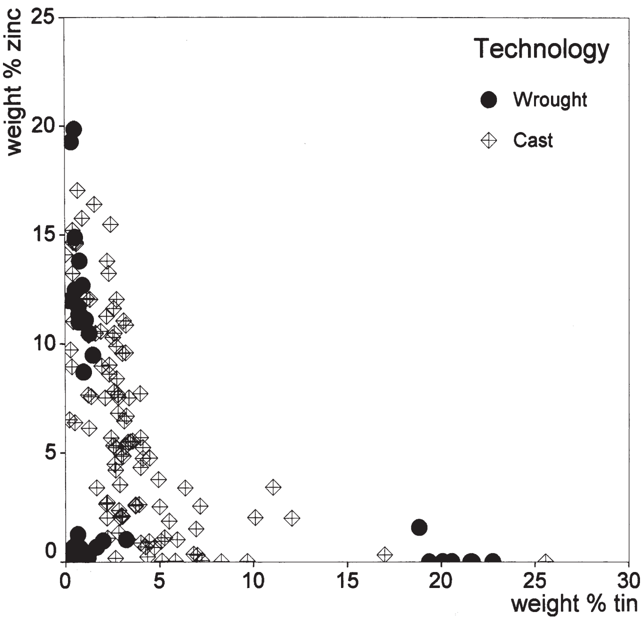


*Figure 4: Correlation of zinc and tin contents with manufacturing technology.*

assemblage comprises of the everyday (utilitarian) objects owned by the crew of a merchant ship.

The cast items have a much more variable composition, but can be divided into two groups, both generally containing over 5% lead (mostly over 10%). The first often have over 2% tin together with zinc in concentrations generally under 10%. The other comprises of items containing over 10% zinc, generally with less than 3% tin; these are usually less highly leaded and are similar in composition to the wrought high-zinc brasses (Fig 4). The overall impression, therefore, is of generally a good choice of alloy for certain, often quite specific, purposes. There is fairly careful control of the lead content, especially with regard to the wrought pieces and the one gilded object.

## *Minor and trace elements*

All metal ores contain small amounts of other metallic elements that are geochemically related to the main metal present in that ore. Some of these will be carried through smelting and refining processes and into the finished metal artefact. This allows certain characteristics of the parent ore to be present in the smelted and refined metal. Furthermore, there will also be small amounts of similar metals associated with the flux (almost certainly added at this period to assist smelting) and, of course, with the alloying metals themselves. During the processes of smelting, refining and alloying, the amounts of these contaminants change depending on the technology of the processes and the chemical properties of the individual elements (Tylecote *et al* 1977; Merkel 1990, 113–8). Thus, by understanding the processes and their chemistry, it is sometimes possible to gain an insight into the ore types used, the technology employed in their processing, and therefore to characterise the artefacts on a basis largely independent of intentional human intervention. However, it is unlikely that artefacts can be attributed to their ore sources because of the changes brought about by the smelting and refining, along with possibly centuries of re-melting. The minor and trace elements measured in the artefacts from the three assemblages present a picture of a largely homogeneous group, something of a surprise given the geographical spread of the three find spots. However, there are small groups of outliers that repay closer scrutiny. Cobalt and antimony are elements that are usually closely related to the ores from which the copper was extracted, and their concentrations are therefore scaled to copper in Figure 5. This illustrates the general homogeneity and lack of obvious structure in the dataset but also shows a group of seven samples with high cobalt and low antimony contents. These are all the high-tin bronze objects including the lamp tray from Denia (D81). However, the Serce Liman jug (MV10) is not included here, as its cobalt content places it in the main group. However, it should not be excluded from the high-tin bronze group purely on this basis, as the size of the sample taken for analysis was particularly small. This means that the levels of accuracy and precision for an element present at such a low concentration will be poor, so the actual value quoted is unreliable for this particular element in this particular sample.

The cobalt values relative to copper for the high-tin bronze pieces (0.08–0.12%) are much higher than is usual for the majority of the Fatimid metalwork (mean 0.02%). Furthermore, the tight cluster suggests that these vessels were made from similar metal, possibly in closely allied workshops. There are also four other objects with high levels of cobalt; MV7, 525:226, 575:85 and 575:32. The bucket from Serçe Liman (MV7) has also been analysed for lead isotope ratios and these indicate that the copper probably originated in Iran (Allan 2003). The Ewer (575:85) is of a classic type with a pomegranate motif that is generally regarded as being of Persian manufacture (Khamis and Amir 1999). This circumstantial evidence, together with the general association of high-tin bronze production with Iran (Lakpour 1997) makes it tempting to suggest that this high cobalt group may be Iranian.

A correlation exists between the antimony, arsenic and silver (all significant at the 0.01 level) indicating that these three elements are geochemically related and are therefore most likely to be characteristic of the copper

*Table 1: Mean and standard deviation (wt%) of trace elements in cluster groups 1-4.*

| Group | Element (wt%) | | | | | |
|---|---|---|---|---|---|---|
| | As | Sb | Co | Ni | Fe | Ag |
| 1 | 0.275±0.080 | 0.041±0.017 | 0.028±0.011 | 0.217±0.129 | 0.178±0.064 | 0.036±0.012 |
| 2 | 0.394±0.144 | 0.206±0.098 | 0.016±0.010 | 0.070±0.027 | 0.429±0.864 | 0.085±0.029 |
| 3 | 0.137±0.056 | 0.038±0.030 | 0.061±0.030 | 0.038±0.011 | 0.439±0.410 | 0.021±0.011 |
| 4 | 0.171±0.177 | 0.161±0.120 | 0.003±0.005 | 0.030±0.015 | 0.016±0.025 | 0.085±0.034 |

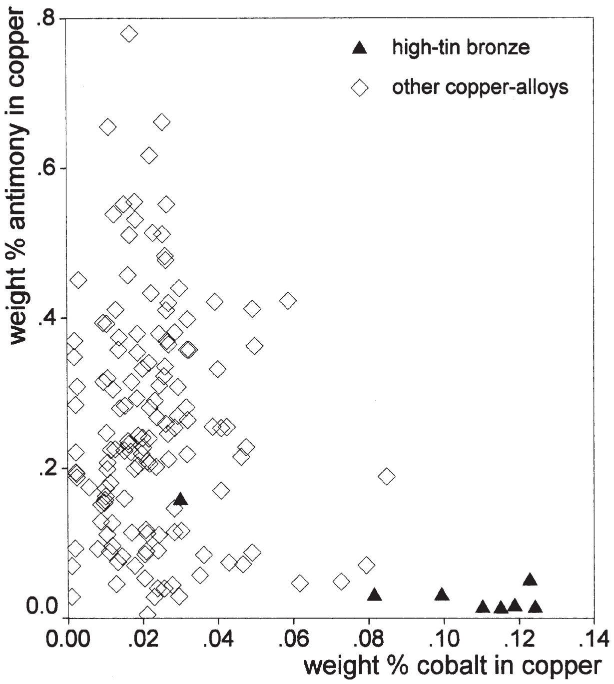


*Figure 5: Antimony versus cobalt contents scaled to copper.*

rather than of the alloying components. A scatter-plot of arsenic against antimony which excludes the high-tin bronzes (Fig 6), suggests three possible compositional groups. The majority of the metalwork forms a tight group containing relatively high levels of both arsenic and antimony. The scatter of points with low arsenic and variable antimony contains four of the five Byzantine copper coins and the soap-box or *ushnan* (MV9) and the scale pan (GW972) from the Serçe Liman wreck. The objects containing moderate levels of both arsenic

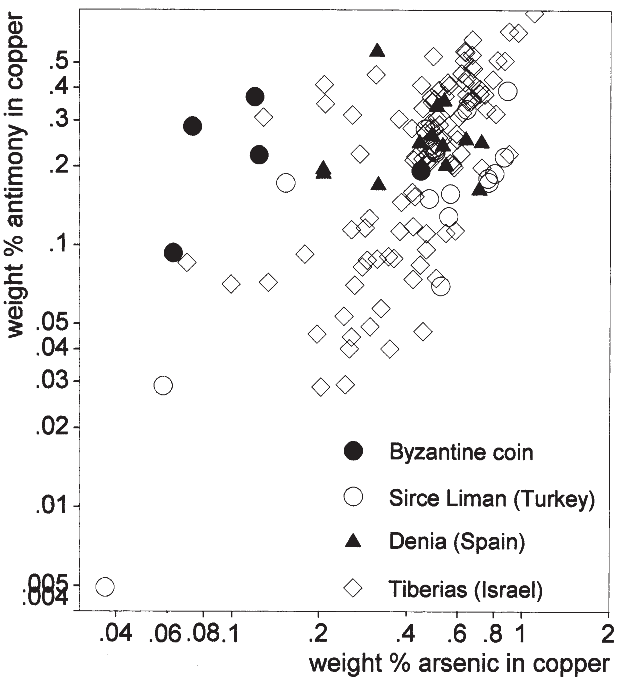


*Figure 6: Antimony versus arsenic contents scaled to copper for each site.*

and antimony includes the pomegranate ewer (575:85) and the mosque lamp grilles (525:160/7, 525:113/98, 525:113/99).

## *Multi-variate analysis of trace element data*

The bivariate scatter plots provide tantalizing suggestions of structure, so a multivariate method was needed that used all the trace element data simultaneously. A cluster analysis was run on all the samples using the trace elements consistently present above detection limits; silver, cobalt, iron, nickel, arsenic and antimony. The data were first log transformed to satisfy assumptions of normality (Baxter 1994, 40) and clustered by the group average method. Four clusters were generated that are reasonable in terms

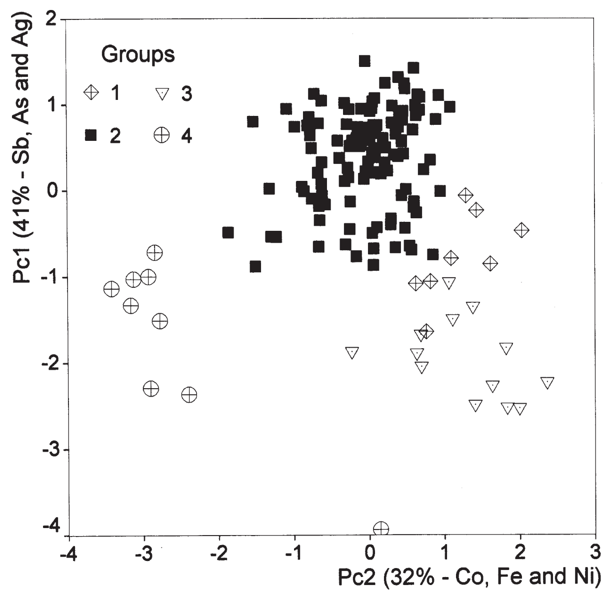


*Figure 7: Scatter plot showing the first two principal components for each cluster group.*

of agglomeration distance and group membership. The log-transformed data were then subjected to a principal components analysis (PCA) and plotted according to the cluster analysis groupings. PCA combines all the variables into two or three linear combinations of data without making any prior assumptions about groupings. These combinations ('components') can then be plotted and investigated for structure (Baxter 1994, 48-62). The plotting of the first two components (Fig 7) confirms the validity of the four groups suggested by the cluster analysis. The component loadings also correspond well with the expected geochemical affinities; cobalt, iron and nickel against antimony, arsenic and silver. The groups identified are therefore defined by combinations of trace elements that are geo-chemically determined and must, in some way, relate to the technology and/or the source(s) of the metal in the artefacts themselves.

Group 4 is characterized by moderate levels of arsenic and antimony and low levels of cobalt. In terms of artefacts, it contains all the Byzantine coins, the scale pan (GW972) classified as Byzantine by the excavator (van Doorninck 2003), and the soap-box (MV9) given a Sardinian provenance by lead isotope analysis (Allan 2003). This group also includes a bronze candle-stick (525:110/3) and a cauldron (MV4).

Group 3 has low levels of all the trace elements with the exception of iron and cobalt, which are particularly high and also geochemically related. It contains all the high-tin bronze objects, including the Serçe Liman jug (MV10), reinforcing the doubts noted above about its cobalt content. The group also contains the pomegranate ewer (575:85), a lampstand tripod (525:69) and the bells (575:107/1, 525:226 and 525:926).

Groups 1 and 2 both have relatively high levels of arsenic, but can be separated by the differences in their respective antimony, nickel and silver concentrations. Group 1 contains the three mosque lamp grilles (525:160/7, 525:113/98 and 525:113/99), the canteens (525:? and 525:101), the ladle (525:132/0), the bucket (525:25/2) and a vessel (575:32). The rest of the material comprises Group 2 and includes pieces of workshop waste.

The incense-burner of apparently incontrovertible Coptic Egyptian style (575: 61/2) appears in Group 2 as does the pre-Fatimid Byzantine-style pricket lamp tripod (575:74), both of which have been given an Egyptian provenance on the basis of style (Khamis and Amir 1999). A number of the other pieces in Group 2 are also traditionally regarded as Egyptian, in particular the successor to the 'pricket' lampstand, the classic Fatimid tray lampstand (Ward 1993, 64), made up of tripod, stem and tray. The analysed pieces from both Tiberias and Denia represent a minimum of 16 lampstands, with tripods the most frequent element. It is therefore surprising that these items are in the same compositional group as all the pieces from Tiberias that relate to manufacture and which must therefore have been made there; the unfinished casting (525:160/6), the casting debris (525:113a and b) and the turnings (575:32 and 575:85). Additionally, Group 2 also includes such domestic items as cauldrons (525:27, MV1a, MV2, MV3), buckets (MV7 and MV8) and mortars and pestles (525:132/5, 525:179, 525:15, MV11), items so mundane that they are unlikely to have been traded widely. Thus the Tiberias cauldrons, mortars and pestles were probably made in Syria-Palestine, although the lead isotope analyses of the Serçe Liman cauldrons suggest an Iranian origin for the copper in them (Allan 2003). Furthermore, a piece of a lamp tripod (525:38/2) from Tiberias bears the name of its maker, Abbas, and his place of work, Damascus (Allan, pers comm), adding further weight to the case for Group 2 artefacts being manufactured from Iranian metal within an area of Syria-Palestine that included Damascus (only about 100km from Tiberias). Non-Fatimid objects in this Group include the steelyard weight and heart-shaped objects, mentioned above, as well as the Byzantine sword hilt (GW56), which has been given an Iranian origin by lead isotope analysis (Barnes *et al* 1986). An alternative explanation is that the presence of stylistically Egyptian and isotopically Iranian metalwork may suggest that it is impossible to separate copper-based metalwork from these sources by their trace element signatures. This issue is discussed further below.

Groups 1, 3 and 4 are more clear-cut in their artifactual composition and consist of objects from further afield. Group 3, as already suggested, has strong Persian links, although the chemistry is clearly different to that of the Group 2 Serçe Liman cauldrons which are also of possible Iranian origin. Group 4, being mainly the Byzantine coins, appears to have a distinctly western flavour. Group 1 is interesting as it contains the three mosque lamp grilles, suggesting that these have a distinct and different origin to the other objects.

The compositional groupings based on trace element chemistry reflect certain stylistic and typological groupings, rather than find spots (Fig 8). Other stylistic distinctions, however, are not reflected in the compositional groupings. For instance, the tall, thin lampstand without tray or pricket from Denia that has been classified as a specifically Andalusian type (D48) is no different in its chemistry from the other lampstands. The 10th century brass objects from Granada (Craddock *et al* 1998) are notable in having significant traces of manganese that mark them out as different from other Islamic metalwork. This composition relates to a particularly western method of brass production where traces of manganese in the zinc ore used are passed directly into the brass metal (Ponting 1999). None of the brass objects from Denia that were analysed contains measurable levels of manganese and are therefore unlikely to be local Andalusian products. The decorated hemispherical bowl from Denia (D79) that matches the form of the high-tin bronze bowls from Tiberias is made of heavily leaded bronze with only moderate levels of cobalt. It was possibly made in imitation of the high-tin bronze examples, and highly leaded alloys have been identified in other copies of high-tin bronze objects

(Craddock *et al* 1998, 109). On the basis of trace element chemistry it appears that most of the objects from Denia and the Serçe Liman merchant ship came from the same metal supply pool as the objects from the Tiberias workshop. The exceptions to this are the high-tin bronzes pieces that are all from a similar source, and a small number of other objects including several that are of quite distinct styles or types, such as the Persian pomegranate ewer and the mosque lamp grilles.

## *Lead isotope analysis*

The fact that the chemical analysis does not seem able to distinguish between Syrio-Palestinian objects, stylistically Egyptian objects and isotopically Iranian objects is of some concern. Either re-cycling of copper-alloys over hundreds of years has thoroughly homogenised the chemical signatures of the different workshops or the stylistically Egyptian objects were actually made in Syria-Palestine or in Egypt of metal from the same source(s) as that used in Syria-Palestine. Egypt was certainly the centre of Fatimid power and culture, and the majority of publications dealing with Fatimid metalwork state with conviction that all artefacts such as lampstands and bottles were manufactured there (Ward 1993). Indeed, the study of the Denia assemblage (Azuar 1989) states that the majority, if not all, of the pieces in the Denia hoard were imported from Egypt. But was it really the case that workshops in Egypt were the only producers of this distinctive form of metalwork? To further address this question lead-isotope analysis was conducted on samples from two of the Tiberias objects: the Coptic Egyptian incense burner (575:61/2) and the lampstand tripod with the name of Abbas of Damascus cast into it (525:38/2). The isotope

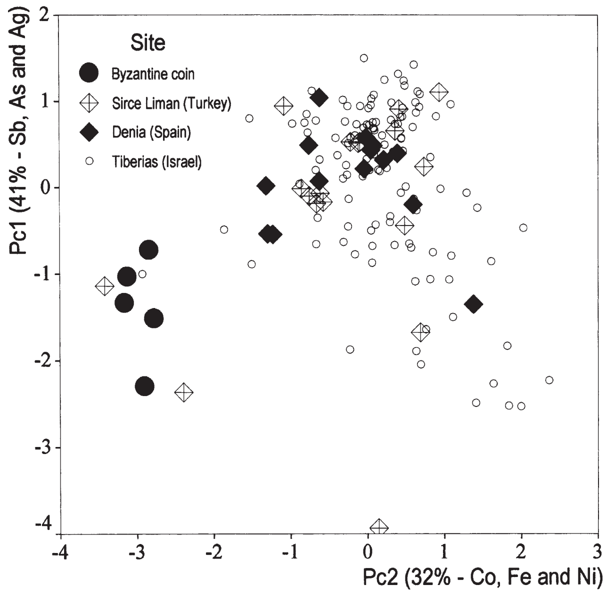


*Figure 8: Scatter plot showing the first two principal components by site.*

ratios were then compared to those derived from lead and copper ores of known origin and to some recently published artefacts (Barnes *et al* 1986, Dayton and Dayton 1986, Gale 1980, Gale and Stos-Gale 1981, Gale *et al* 1981, Stos-Gale and Gale 1981, Gale *et al* 1990, al-Saa'd 2000, Sayre *et al* 1992, Seeliger *et al* 1985, Wagner *et al* 1985, Wagner *et al* 1986, Wolf *et al* 2003, Yener *et al* 1991). The isotope ratios for the two samples are both relatively low; 2.0815 and 2.0794 for $^{208}Pb/^{206}Pb$ and 0.8435 and 0.8391 for $^{207}Pb/^{206}Pb$ respectively. They plot (Fig 9) close to the Serçe Liman metalwork that was attributed to either Arpalik in Turkey or Khama Surma in Iran (Barnes *et al* 1986) and within the field of isotope data for Turkish lead ores, especially those from the Taurus mountains (Yener *et al* 1991). Lead isotopes of

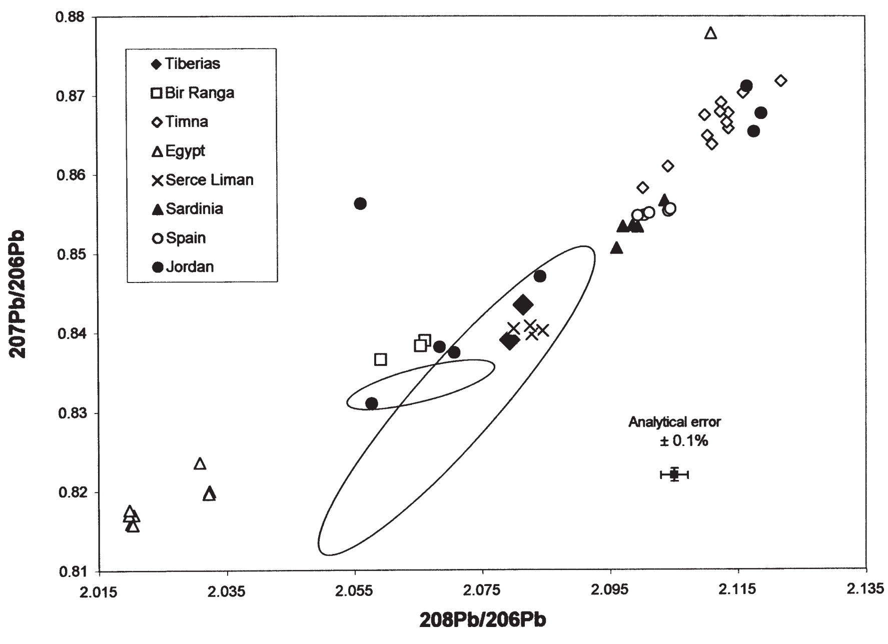


*Figure 9: Lead isotope ratios ($^{207}Pb/^{206}Pb$ v. $^{208}Pb/^{206}Pb$) for Tiberias and comparative data. The large ellipse represents data for ores from Turkey and the Nakhlak region of Iran; the small ellipse that for ores from the Anarak and Anguran regions of Iran (see text for data sources).*

contemporary lead glazes on Egyptian pottery made at Fustat (Old Cairo) are also within the field, but these have been shown to be made of lead from the Jibal region of Iran (the modern mining area of Nakhlak) (Wolf *et al* 2003). Significantly, the majority of Egyptian leads have considerably lower $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios, with the exception of the Bir Ranga ores which are reasonably close to the Tiberias samples, but which clearly do not overlap. The Timna copper ores are similarly distant, having $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios considerably higher than either sample. It therefore seems likely that neither the incense burner nor the lampstand was made in Egypt; they were probably made from chemically and isotopically similar metal containing lead with matches in Turkey and Iran. This is discussed below.

### *Metallographic study of the high-tin bronze bowls from Tiberias*

Three of the high-tin bronze bowls sampled for ICP-AES were also sampled for SEM-EDS (sample nos. #4 – fragment, #36 – fragment and #74 – 575:71/1). As discussed above, all the compositions are very similar (Tables 1 and 2) and include a consistently high level of cobalt. All the samples investigated showed two distinct phases ($\alpha$ and $\beta$) together with elongated inclusions of copper sulphide. Sample #4 was somewhat more heavily corroded (Fig 10), the effect of the corrosion processes was to etch the acicular (needle-like) martensitic structures, making them visible under the SEM without the necessity of further chemical etching. Microscopy of the polished sections after etching with alcoholic ferric chloride confirmed the structures, showing a clear matrix of martensitic $\beta$-phase with islands of lightly etched $\alpha$-phase – quite similar to the structures observed in the corroded areas of sample #4.

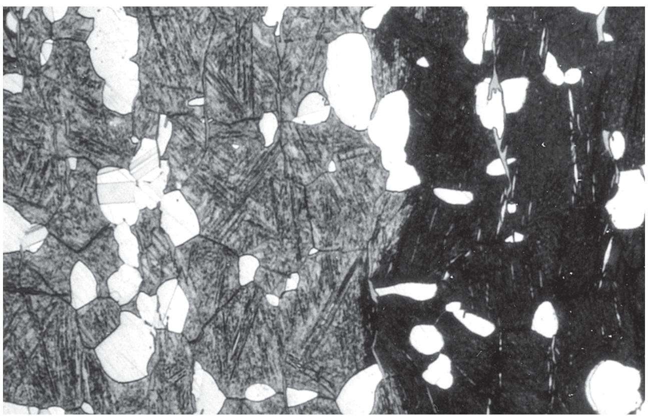

*Figure 10: Section of corroded high-tin bronze bowl (#4) showing the pale $\alpha$-phase, the darker grey acicular $\beta$-phase and, to the right of the picture, the corroded $\beta$-phase. Magnification x 105.*

Microanalysis showed an $\alpha$-phase of around 16% tin and a $\beta$-phase of 23% tin. No $\gamma$-phase appears to be present. The copper-tin phase diagram (Fig 11) indicates that, for the compositions measured for these samples, the $\alpha$ and $\beta$ phases will only exist together between 586°C and around 800°C (where pure $\beta$ would form), so the quenching temperature must have been judged to within about 200°C. The ratios of $\alpha$- to $\beta$-phases can be used to further refine the estimated quenching temperature, with more $\beta$-phase indicating quenching closer to the pure $\beta$-phase boundary and a correspondingly higher quenching temperature. On this basis quenching temperatures of around 650°C to 660°C are indicated. In all three of the samples investigated, hot-working and annealing, prior to quenching, above the recrystallization temperature for the $\alpha$-phase, is indicated by the presence of annealing twins (Fig 12).

## Discussion

The results of this study can be discussed on two levels; firstly, the choice and composition of the alloys, and secondly, the trace element and lead isotope data, and what they tell us about the origins and mode of production of the different pieces. The alloy types identified conform well with those discussed by Allan (1979). The use of copper, high-tin bronze, brass, gunmetal and bronze are all recorded for early Islamic metalwork.

### *Copper*

The terms s*ufr, qitr, mis* and *nahas* in the texts are perhaps best translated as 'un-alloyed' copper; this is copper with very low levels of the usual alloying components, zinc, tin and lead. Only 15 copper artefacts (excluding the coins) were analysed, 11 out of the 15 were wrought vessels and all of these had zinc, tin and lead contents of 2% or less. This small proportion (10%) suggests that copper was a relatively uncommon metal in the early Islamic repertoire and is, indeed, in agreement with Allan's statement (1979, 39) that few early Islamic copper objects are known, and that the majority of these are wrought. Copper was used for ordinary metalwork: for example, cooking pots and large buckets used for holding water (Goitein 1983, 140). On a site by site basis, however, wrought copper vessels make up half of the Serçe Liman assemblage compared with only 5% of the Tiberias samples and none of the Denia samples. As noted above, these figures suggest copper was used for cauldrons and other utilitarian objects, as suggested by the information gleaned from Goitein's study of the Cairo Geniza documents (*ibid*).

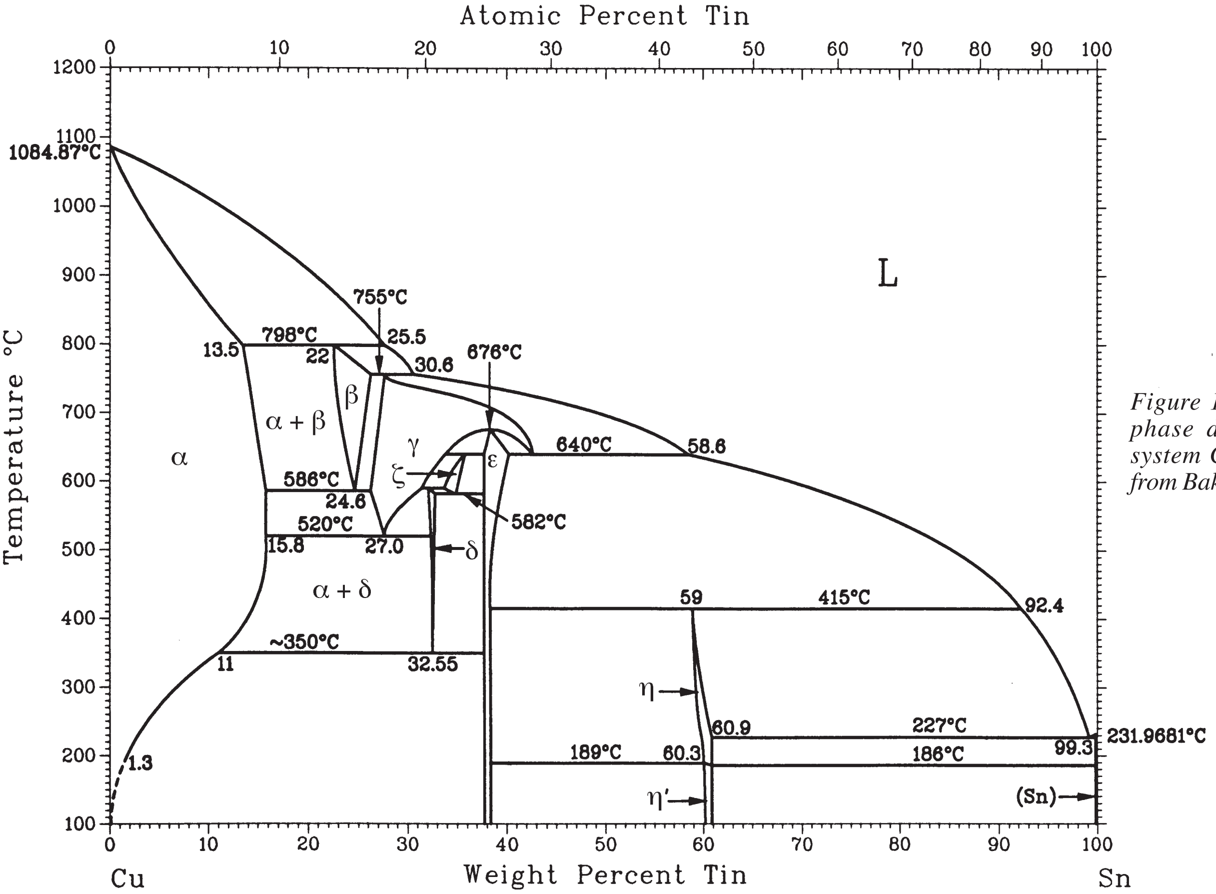


*Figure 11: Equilibrium phase diagram of the system Cu-Sn (adapted from Baker 1992, 2•178)*

## Brass

Called *Birinj* or *Shabah* in the texts, brass is an alloy of zinc and copper, and is noted for its golden colour and its ductility. Although metallic zinc was not readily available in the Mediterranean world until the 15th century (Craddock *et al* 1998, 76) it is well known that brass had been made there by the cementation process since the 1st century BC (Craddock 1995, 297). In particular, in the early Roman Principate, brass was the preferred copper alloy for both coinage and for decorative fittings for the panoply of its soldiers (Ponting and Segal 1998; Ponting 2003). Later, brass became increasingly common in the Roman world and its use gradually replaced bronze in many applications. Often brass and bronze were re-cycled together, resulting in alloys containing several percent of both tin and zinc; an alloy now known as gunmetal. Following the break-up of the Roman Empire and the collapse of its complex long-distance trade routes, access to the tin-producing provinces of Spain and Britain must have become extremely limited (Craddock *et al* 1998, 73) so, as a consequence, the use of brass and gunmetal increased considerably. In Palestine, brass and gunmetal had become the ubiquitous copper alloys by the 6th century AD (Ponting forthcoming b). With the arrival of the Ummayad Arabs in the mid-7th century there was a short-lived return to bronze, possibly related to the re-use of architectural bronzes from ancient cities (Ponting 1999). However, by the end of the 8th century, zinc-containing alloys were again very much the norm. Why the fashion for this golden coloured metal was so strong in the Near East is a complex subject, however, it seems likely that history and tradition had as much to do with it as the availability of tin. Craddock (1979) saw early Islam as the inheritors of the classical traditions of metalwork, and indeed Islam in its early years borrowed

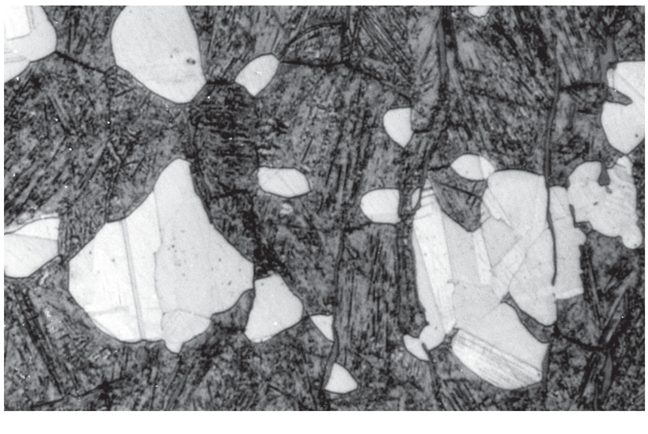

*Figure 12: Section of high-tin bronze bowl (#36) showing annealing twins in the pale α-phase. Magnification x 210.*

heavily from Roman, Byzantine and Sassanian culture. Certainly by the Fatimid period zinc-containing alloys were the norm, with brass being a common alloy used for a variety of decorative, everyday artefacts.

The cementation method of brass production is a solid state diffusion process where zinc oxide is mixed with finely divided copper metal in a crucible where a reducing atmosphere is maintained through the addition of crushed charcoal and the temperature is kept at just below the melting point of copper. This was the method employed during antiquity, as has been described by Bayley (1998). The Islamic literature, however, describes a somewhat different process where zinc oxide (*tutiya*) is added directly to molten copper. This probably explains why the average zinc content of Islamic brass is less than 20% (17% in Craddock *et al* 1998, 75; 11% for all the brass objects in Table 2).

Allan (1979) provides details of contemporary accounts dealing with brass production in the medieval Islamic world. However, it is useful to give specific examples here. The account nearest in date to the material discussed here is that of al-Biruni, writing in the 11th century:

> '*Shabah* is copper made yellow by mixing into it *tutiya* with sweetened things (*halawat*) etc as additives until it becomes like gold.' (*ibid*, 39)

Here we have the concept of mixing zinc oxide into copper, which suggests a molten copper rather than a solid-state process. A later, 13th century document, written in Persia by al-Kashani, gives a fuller description of an apparently identical process:

> 'If they *bray* [mash – as in a mortar] half-pounded *tutiya* with raisins without seeds until it becomes soft, and it is roasted without burning over a low fire, and if copper is melted and they throw into it a certain amount of the prepared *tutiya* and cover the top of the crucible for a moment until the *tutiya* has had its effect, and it then cools down, copper results the colour of red gold.' (*ibid*, 42)

Both al-Biruni and al-Kashani firmly link *tutiya* with brass (*ibid*, 40). But what of *tutiya* itself, the mystery ingredient? Again there are texts that provide the clues; al-Kashani relates that:

> 'They make a furnace and fix earthenware pegs in its walls, pour the *tutiya* ore onto a shelf there and make a strong fire. Fumes from the burning of this ore rise and attach themselves to the earthenware pegs. When they remove the fire and it is cooled they separate the sublimed *tutiya* from those pegs.' (*ibid*, 40)

Such pegs have been found in large quantities in Iran (Barnes 1973). The analyses of the pegs confirm their use as surfaces on to which the zinc oxide vapour condensed as it billowed up from the roasting furnace. Unfortunately there is no similar evidence for zinc oxide production from any location further west, thus both the literature (which is Persian) and the archaeological evidence may indicate a local production method. However, it does seem that technologies within the Arab world were fairly consistent. Indeed, al-Kashani, immediately following the description quoted above, tells us that Syrian brass is produced from *tutiya* in this way, and is, he believes, the best brass and the most like gold (Allan 1979, 42). Thus the literature seems to indicate the same methods and the same raw materials were used in Syria as in Persia. Furthermore, the slightly lower average zinc content of medieval Islamic brass would also support a process where zinc oxide was sprinkled over a crucible of molten copper, rather than the true solid-state cementation process described by Bayley (1998).

The Fatimid brasses reported here conform well with the composition expected of brass produced in the way described in the texts; they have a relatively low zinc content compared with Roman brass or with later European brass where the zinc contents are in excess of 25%. Certainly, in the European brass industry, the aim was to extend the valuable copper with cheaper zinc (Percy 1861). In the Islamic world it seems that copper was a relatively inexpensive commodity and the *tutiya* the valuable additive, capable of turning copper into a golden metal. Consequently, the lower zinc content was not considered a disadvantage, provided the golden colour was obtained, and so merely sprinkling the zinc oxide over the molten copper was sufficient, despite the much smaller contact area which limited the amount of zinc absorbed.

## *Gunmetal and other ternary alloys*

The most interesting of the analyses are those of ternary alloys. The same general spread of ternary alloys is found here as was identified by Allan (1979, 52) amongst Persian metalwork. These include alloys with equal zinc and tin, with more tin than zinc, with more zinc than tin and with varying additions of lead; an apparently bewildering range with little clear evidence of selection. However, the texts may again provide a clue. Allan identified three ternary alloy types of differing composition (Allan 1979, 53). The question, of course, is whether the descriptions in al-Biruni, al-Kashani and others, dealing with metalwork in Persia, are more generally applicable. Goitein (1967) provides ample evidence for the extent of contacts throughout the Islamic world and the continual exchange of ideas and attitudes that this engendered. Certainly, the texts were written by people who travelled widely in the Islamic world, and as we have seen the method of brass production was clearly the same in Syria as in Persia.

According to Allan (1979), the ternary copper-alloys mentioned in the texts are:

- *Batruy, tal, tabtuyah* – leaded copper. It is used for mortars, cauldrons and casseroles.
- *Shabah mufragh* – a gunmetal made of *batruy* and brass and used for candlesticks, lampstands, furnace equipment and water basins.
- *Dararuy* – leaded gunmetal. An alloy of the poorest quality made by mixing high-tin bronze (*safidruy*), leaded copper (*tal*), copper (*mis*) and brass (*birinj*) – in other words, an alloy of just about anything that was available.

From the spread of the analyses we can, in the most general of terms, interpret the leaded copper as an impure copper (containing up to 3% of zinc and/or tin) mixed with around 20% of lead. *Shabah mufragh* must therefore be a leaded brass, with a reduced zinc content and probably a little tin. *Dararuy* would, according to its description, have the most variable of compositions containing zinc, tin and lead, but probably more tin than zinc because of the addition of high-tin bronze, whereas the zinc in the *birinj* would have been diluted further. On this basis it is possible to suggest very approximate compositions for these alloys. *Batruy, tal, tabtuyah* contain up to 3% of tin and/or zinc plus about 20% lead. *Shabah mufragh* has 2–5% tin, up to 10% zinc and up to 30% lead. *Dararuy* has 5–15% tin, up to 4% zinc and at least 5% lead.

Lead is the most inconsistent component, with considerable unpredictability. This must reflect its role both as a cheap bulking agent and as a practical addition for casting alloys. Thus cast *shabah mufragh* would contain significant lead, whilst wrought *shabah mufragh* would not. The crucial distinction between *shabah mufragh* and *dararuy* seems to be the interplay of the tin and zinc contents; the former having more zinc than tin, whilst the later has more tin than zinc. If we then ascribe to each of the Fatimid artefacts an alloy definition according to this discussion and plot the zinc and tin contents again, we get an interesting result (Fig 13). The alloy descriptions as interpreted above form three quite discrete groups. This seems to suggest that this interpretation is meaningful and there is also a correlation between some of the artefacts types – the mortars for example – and the alloy descriptions in the texts.

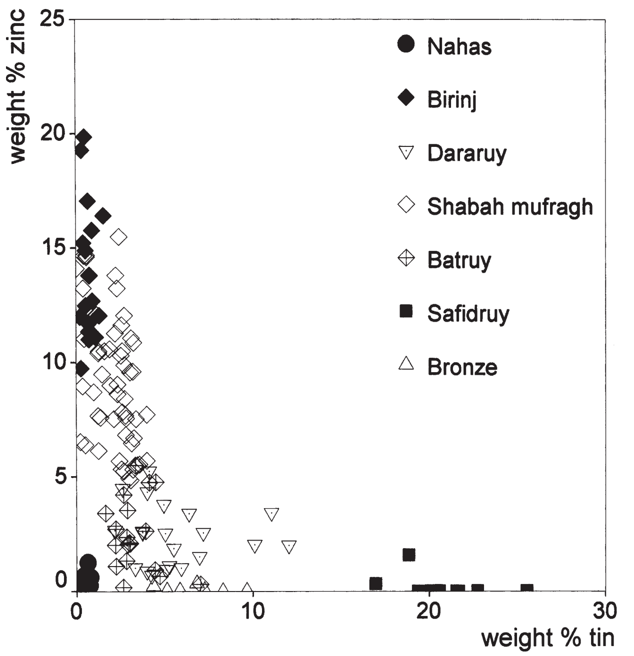


*Fig 13: Correlation of tin and zinc contents with Arabic alloy names.*

## *Bronze and high-tin bronze*

Bronze is not well represented in Fatimid metalwork. It is also difficult to identify in the texts discussed by Allan; the word *sufr* appears to mean any copper-alloy as well as copper, and likewise *nahas* may mean un-alloyed copper or bronze. Thus the identification of bronze here and its separation from either un-alloyed copper or *dararuy* may well be false. If we look at Figure 13, there does seem to be a significant separation between un-alloyed copper and alloyed copper, but very little distinction between bronze and *dararuy*. The latter suggests that the bronzes may be merely a variant of *dararuy* where the zinc content is negligible, while the former suggests that there must be a word for un-alloyed copper rather than generic copper-alloy terms.

Medieval Persian texts call high-tin bronzes *sefid-ruy* or *talqoon* (see Lakpour 1997, 130–6; Allan 1979, 46–9 and Melikian-Chirvani 1974, 123–6 for the origins and meaning of the names) but are not very clear about how it was formed into vessels. One reference in the *Dehkhoda Lexicon*, quoting Ali ibn-e Mohammad, says:

> '*talqoon* is a yellow copper whose difference with other yellow copper lies in its yellowness and in the fact that when it is brought out of the forge and beaten it displays an elongation, turns yellow, and does not break until it is cold.' (Lakpour 1997, 135)

This suggests that the alloy was hot-worked and the mentioning of it breaking when cold suggests this is a specific tendency of the alloy. Other medieval Persian texts refer to this brittleness; Abo'l Qasem Kashani (early 14th century) refers to *sefid-ruy* as being both white, like silver and hard and brittle (dry). Al-Biruni (writing in the 11th century) describes another characteristic of high-tin bronzes, the sound it makes when struck. He tells a story about a governor of Khurasan who, after drinking from a bowl of *sefid-ruy*, threw the vessel to the ground where it is described as giving out a ringing sound. As mentioned above, high-tin bronzes are noted for their sound when struck, even bronzes containing lower levels of tin, between 15-20%, are usually referred to as bell metal in Europe and noted for the clarity of sound when cast into an open (bell)-shape and struck.

The contemporary texts indicate that high-tin bronze vessels were clearly a frequently-encountered luxury item in early medieval Persia. One story of its origins in the Islamic repertoire is told by Abo'l Qasem Kashani (early 14th century):

> 'Its production was initiated by al-Hajjaj (late 7th century), who gave orders that all gold and silver wares be broken, banned any further manufacture, and forbade drinking out of gold and silver vessels in the provinces of Araq and Fars. The doctors (*hokama*) of the time mixed tin and copper for the grandees and rich people and made the required vessels.' (Melikian-Chirvani 1974, 124)

Thus in Persia at least, high-tin bronze artefacts seem to have been produced as substitutes for objects of precious metal, and became fashionable, especially amongst the affluent classes who had embraced Islam (*ibid*, 126). Indeed, there are other examples of tin being used as a substitute for silver; there are tin inlays in brass weights from the Ummayad period in Palestine and in a Persian 'stem-bowl' now in the Ashmolean museum (Allan 1979, 28) as well as the general use of tinned copper throughout the Near East down to the present. It should, however, be pointed out that high-tin bronzes had been known in Persia since at least the 7th century BC and possibly as early as the end of the second millennium BC (Lakpour 1997), so they are not an Islamic 'invention' but rather a re-discovery. The use of the alloy certainly seems to have spread throughout the Islamic world; the tray from Denia (D81) is the most westerly example of the alloy that has been confirmed by analysis and the jug from the Serçe Liman wreck (MV10) shows how the material was spread outside the Islamic world. Melikian-Chirvani also reports of seeing a possible *sefid-ruy* bucket in Madrid Museum (1974, 124).

The association of high-tin bronze with silver, together with its oriental origins, marks this alloy out as special. This is reflected in its scarcity within all the assemblages, and also in its exotic trace element profile which forms a quite distinct trace element group (Group 3). In particular the consistent and relatively high levels of cobalt suggest that this alloy was produced in different and quite specific workshops not related to those which produced the bulk of the Fatimid metalwork analysed. High-tin bronze is traditionally associated with Persia (Lakpour 1997), especially Khurasan (Melikian-Chirvani 1974), a province that borders Northern India, where examples of the alloy are known from Taxilla as early as the first millennium BC (Srinivasan 1998).

## *Trace element and lead isotope data*

Leaving aside the high-tin bronzes and other objects with significantly higher cobalt levels, the analysis of trace elements has allowed the metalwork to be divided into three compositional groups. One (Group 4) is predominantly composed of the Byzantine coins whose origin is in no doubt. The other artefacts that are grouped with the coins may therefore also have a western origin – or were made of specifically 'western' metal. These include the scale pan from the Serçe Liman wreck (GW972) which has also been classified as Byzantine by the excavator, and the *ushnan* (soap-box) from the same assemblage (MV9) which has been given a Sardinian origin by lead isotope analysis and has stylistic traits suggesting a Sicilian origin (Allan 2003). The bronze bowl from Tiberias (525:110/3), may represent the likely fate of the Byzantine coins had they not been buried. The second, small group of objects (Group 1) is dominated by the mosque lamp grilles. The third, large group contains the majority of all three assemblages, including the Tiberias pieces relating to metalworking, the signed Damascus lampstand as well as the 'Egyptian Coptic' incense burner and the Egyptian-style lampstands from both Denia and Tiberias. This last group can probably be regarded as the products of Syrio-Palestinian workshops, including both Damascus and Tiberias.

Damascus, as the texts tell us, was a centre for the production of copper-alloy artefacts during this period and later. The trousseau lists amongst the Cairo Geniza documents contain several mentions of Damascene copper-alloy artefacts from the 11th to 13th centuries, including lamps (Goitein 1983, 134), basin and ewer (*ibid*, 139), buckets (*ibid*, 140) and cups (*ibid*, 147). Of course, we have no way of knowing whether a 'Damascus basin with its ewer' meant that the artefacts themselves were actually made in Damascus, or were of a particular style that owed its origin to Damascus artisans but was widely copied. The same must also be true for those objects regarded by art-historians as 'Egyptian' or 'Persian', simply because examples of a particular form or style have been found in these places (Ward 1993, 65). Objects made of chemically indistinguishable alloys were clearly produced in Syria-Palestine too, as the finds from Tiberias show.

Lead isotope analyses shed considerable light on the 'out of Egypt' question and also support the trace element groupings. A recent paper dealing with the lead-glazed pottery of Fatimid Egypt (Wolf *et al* 2003) shows that viable Egyptian lead sources were not used in the manufacture of lead glazes. It appears that prior to 1025 the main source supplying lead to Fustat (Old Cairo) was Iran and there are documentary sources that refer to the export of lead from there during the same period. In the medieval Islamic world, as in the ancient world, the predominant source of silver was argentiferous lead, so it is likely that most lead at this time was a by-product of silver extraction. Iran was no exception, having large deposits of argentiferous lead ores throughout the country (Allan 1979). The main deposits are in the central region of Jibal and Fars (Anarak-Yazd-Nakhlak), the south-eastern region of Kerman and the north-western region of Jibal-Anguran. There is documentary evidence for the production of silver from all these regions from at least the 10th century (Allan 1979) and it is significant that the sources also report lead production from exactly the same locations (*ibid*, 17). The Egyptian lead resources, however, are not argentiferous and were therefore not exploited during the early medieval period. After 1025 the sources of the lead for Fustat's glazes seem to have changed to Turkey (especially the Taurus Mountain region) and the western Mediterranean, probably Spain and Sardinia, where again there is good evidence for silver production during this period (Wolf *et al* 2003, 415).

Allan's survey of Persian metalwork (1979) also lists the locations of copper sources gleaned from early Islamic texts and these overlap extensively with the locations listed as silver and lead sources. Thus there is documentary support for the view that copper and lead may have the same origin, as suggested by the lead isotope data. This further supports an Iranian origin for the metal for the Group 2 metalwork, whilst accepting that much of it was made in Syria-Palestine if not actually in Tiberias. Documentary evidence exists recording the export of Iranian copper in the medieval period (Allan 1979, 36), whilst there are few copper or lead sources recorded for Syria, Jordan, Lebanon and Iraq other than the well known deposits of Feinan (Jordan) and Timna (Israel). Both of these can be discounted as sources for the Fatimid metalwork on the basis of the quite distinctive isotope signature for this ore body (see Fig 9), although, interestingly, three of the 14th century Jordanian pieces analysed by al-Saa'd (2000) have isotope signatures that strongly suggest Feinan or Timna as the origin for their metal.

Given their lead contents (9.5% and 14.9% respectively), the isotope signatures of the two Tiberias pieces will inevitably be dominated by the added lead. It can therefore be argued that it is the lead that is being sourced to Iran or Turkey rather than the copper (Rohl and Needham 1998, 5). On this basis a case could be made that the incense burner (or the lampstand for that matter) was indeed made in Egypt, and it was the lead in the alloy that had been imported from Iran or Turkey, as was the case with the lead in the glazes. However, these two isotope ratios are very similar to those of the Serçe Liman objects and the trace-element chemistry had originally placed the incense burner in Group 2, together with the inscribed lampstand, the Serçe Liman pieces and other items that strongly suggested a non-Egyptian (Syrio-Palestinian) origin. Furthermore, not only do the leaded items from the Serçe Liman wreck have Iranian or Turkish isotope signatures, but the copper cauldrons and buckets also have Iranian lead isotope signatures and the small amount of lead in these items is unlikely to have been added and therefore must have been present in the copper ores. Thus both the leaded and non-leaded copper-alloy objects from the Serçe Liman wreck have Iranian or Turkish isotope signatures and trace element signatures which place them in Group 2. Both the Tiberias pieces have Iranian or Turkish lead isotope signatures and trace element signatures which also place them in Group 2. There is therefore a strong case for both of the Tiberias pieces not being made in Egypt.

The trace-element chemistry is used to suggest a Syrio-Palestinian origin for Group 2 purely because several of the Group 2 items from Tiberias clearly indicate that copper-alloy objects were being manufactured there, and one item (525:38/2) carries an inscription indicating that it was made in Damascus. This may seem inconsistent with lead isotope ratios that consistently point to Iran or Turkey – not only those reported here but those for the majority of the Serçe Liman objects that also fall in Group 2. However, Iranian lead was exported widely, as we have seen, and therefore the isotope signature will only point to the source of the lead, not the location of the workshop producing the artefact. The copper could just as easily have been traded into Syria-Palestine, as the lead and the isotope signature again points to the ore source rather than the workshop. It seems likely that the Serçe Liman merchant ship would have obtained its copper cauldrons from somewhere along the coast of Syria-Palestine; indeed, Allan (2003) also points to the style of one of the cauldrons (MV8) with an Iranian isotope signature and Group 2 trace elements as being notably Syrian.

## Conclusions

On balance a good case can be made for the metalwork forming trace element Group 2 being Syrio-Palestinian in terms of its manufacture, but the metal originating in Iran and/or Turkey. Such a conclusion should not surprise us because it is quite clear that there were close contacts between the peoples across the Islamic world. Goitein's detailed study of the documents deposited in the Geniza of a Palestinian synagogue in Fustat and covering the period from 969 to 1250 reveal the extent of these contacts and the attitudes of people to making journeys that would make many of us think twice today. The Mediterranean was the highway of the Islamic world and one was very much on 'home turf' within it. An example given by Goitein concerns a merchant from Bône in Algeria who wanted to collect debts in Fustat a few days before they were due by pretending that he was going to Yemen in south Arabia. When his Egyptian debtor realised that he was only travelling as far as Algeria he was furious, stating in a letter that '…had I known he was only going to the West, I would not have paid him a thing' (Goitein 1967, 42). It is clear from these studies that a journey from Spain to Syria-Palestine or from Turkey to Egypt was a humdrum experience (*ibid*). Thus to find metalwork in Spain that has a chemistry linking it to material found in a workshop in Israel, but which was mined in Iran, should come as no surprise. Indeed there are many letters in the Geniza collections that have references to Andalusis, Andalusi goods and travel to Andalusian ports such as Denia. Commodities from the eastern Islamic world were continually available in al-Andalus, often trans-shipped through Sicily or Tunisia (Constable 1994, 35). There are references to Andalusi merchants in the Hijaz, Iraq and as far away as Aden in the 9th and 10th centuries and an anonymous 10th century geography, the Hudu¯d al-Salam, tells us that Spanish produce was brought to Syria (*ibid*). In the 12th century, the geographer Zuhri noted that luxury goods from India, China and Iraq were exported to Africa and Spain, and, conversely, that Sevillan olive oil was exported to Egypt (*ibid*, 38). The important thing here thought is the overall impression that such contacts were extremely ordinary and everyday. Whilst the exceptional did occur, such as the large scale shipment of food from Denia to Egypt by Denia's ruler, Ibn Muja¯hid, during a period of famine, the Geniza documents present a picture of continual traffic throughout the Islamic world, one that is born-out by the analysis of the metalwork presented here.

## Appendix 1: analytical methods

Samples for ICP-AES were taken by drilling into an inconspicuous area of the artefact with a high-speed steel drill and collecting the turnings. The first millimetre or two of material was always discarded so as to avoid contamination by corrosion products and metal not representative of the bulk. The thin-walled vessels from Tiberias were sometimes too thin to sample in this way, so a section was cut using a jeweller's saw, or, for the high-tin bowls, snapped-off with pliers. Part of this was cleaned of corrosion and dissolved for ICP-AES. In the case of the high-tin bronze bowls, the remainder was then mounted in resin and polished to allow optical microscopy and SEM-EDS analyses.

The sample preparation method used for the ICP-AES analysis was essentially that discussed by Hughes *et al* (1976). The ICP-AES used was a Perkin Elmer Plasma 400 instrument, calibrated using mixed multi-element standards that were matrix-matched. Quality control solutions (in conjunction with the quality control software QC expert) and Standard Reference Materials (SRM) were run every ten samples to monitor accuracy and precision. Accuracy, based on multiple analyses of the two SRMs used spread across all analyses, is better than 8% for all major and minor elements with the poorer figures generally corresponding to the lower levels of concentration (*ie* copper <1%, nickel < 5%). The accuracy of the trace elements is better than 20%, again with the poorer values occurring when the concentrations approach the limits of detection (*ie* manganese with 18% error on a certified value of 0.0019%). The instrumental precision (coefficient of variation across three replicate analyses of the same sample) is generally better than 3%, whilst analytical precision (coefficient of variation of multiple analyses of the same SRM across all analyses) is generally better than 5% for major, minor and trace elements over all analyses.

The SEM-EDS system used was a JEOL IC845 SEM with an Oxford Instruments ISIS 200 energy dispersive analysis system. The EDS system has a SiLi detector with a standard beryllium window operated at 25kV for 200s (approx 2000 counts on cobalt metal). Analytical precision is better

*(continued on p104)*

## Appendix 2: analytical data

*Table 2: ICP-AES analyses of Fatimid metalwork.*

| Sample | Description | Element (wt%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sn | As | Zn | Sb | Pb | Co | Ni | Mn | Fe | Cu | Ag |
| *Tiberias hoard* | | | | | | | | | | | | |
| 525:160/7 | mosque lamp | 0.95 | 0.207 | 12.67 | 0.025 | 1.60 | 0.025 | 0.111 | 0.0001 | 0.159 | 83.8 | 0.050 |
| 525:160/5 | spoon | 0.51 | 0.321 | 19.84 | 0.123 | 2.02 | 0.012 | 0.093 | 0.0013 | 0.298 | 76.8 | 0.075 |
| 575: 18 | lamp tripod | 2.53 | 0.442 | 10.29 | 0.238 | 18.20 | 0.021 | 0.112 | 0.0012 | 0.324 | 66.4 | 0.074 |
| SEM #4 | bowl | 20.59 | 0.137 | 0.01 | 0.010 | 0.06 | 0.080 | 0.043 | 0.0001 | 0.345 | 67.6 | 0.023 |
| 575: 74 | lamp tripod: pricket type | 2.42 | 0.239 | 15.47 | 0.042 | 7.61 | 0.026 | 0.114 | 0.0003 | 0.472 | 73.3 | 0.095 |
| 525: 120 | lamp tripod | 2.61 | 0.417 | 10.49 | 0.217 | 18.21 | 0.017 | 0.072 | 0.0010 | 0.348 | 67.3 | 0.079 |
| 525: ? | canteen hinge | 1.29 | 0.301 | 10.48 | 0.074 | 2.84 | 0.017 | 0.129 | 0.0012 | 0.255 | 83.2 | 0.055 |
| 525: ? | rivet from hinge | 1.48 | 0.230 | 9.47 | 0.040 | 2.50 | 0.025 | 0.164 | 0.0007 | 0.286 | 89.0 | 0.045 |
| 525: 139/1 | canteen | 0.79 | 0.376 | 13.79 | 0.090 | 2.07 | 0.020 | 0.110 | 0.0006 | 0.210 | 80.6 | 0.050 |
| 575: 105/1 | tray leg | 5.93 | 0.477 | 1.03 | 0.244 | 28.30 | 0.012 | 0.073 | 0.0001 | 0.049 | 64.3 | 0.155 |
| 525: 132/5 | pestle | 2.21 | 0.486 | 2.02 | 0.429 | 16.22 | 0.014 | 0.109 | 0.0001 | 0.075 | 77.3 | 0.073 |
| 525: 101 | canteen | 0.55 | 0.272 | 14.89 | 0.031 | 2.64 | 0.020 | 0.411 | 0.0005 | 0.088 | 77.6 | 0.017 |
| 575: 101 | candle stick | 1.16 | 0.264 | 12.08 | 0.069 | 7.85 | 0.018 | 0.048 | 0.0003 | 0.265 | 76.3 | 0.043 |
| 525: 139/4 | candle bowl | 1.39 | 0.586 | 7.58 | 0.432 | 22.94 | 0.017 | 0.061 | 0.0002 | 0.857 | 65.3 | 0.065 |
| 525: 109/2 | lamp tripod | 0.75 | 0.188 | 13.80 | 0.228 | 9.62 | 0.007 | 0.036 | 0.0112 | 1.410 | 72.2 | 0.085 |
| 525: 80/15 | lamp stem | 0.41 | 0.149 | 13.23 | 0.295 | 10.55 | 0.035 | 0.034 | 0.0120 | 1.104 | 71.6 | 0.070 |
| 525: 69 | lamp tripod (mean of 3 samples) | 0.44 | 0.089 | 14.66 | 0.048 | 19.40 | 0.031 | 0.055 | 0.0002 | 0.296 | 66.6 | 0.020 |
| 525: 107/2 | lamp tripod | 2.32 | 0.298 | 13.22 | 0.133 | 17.41 | 0.007 | 0.018 | 0.0001 | 0.265 | 64.1 | 0.090 |
| 575: 95 | lamp tripod (mean of 3 samples) | 4.94 | 0.430 | 3.78 | 0.373 | 21.55 | 0.018 | 0.067 | 0.0002 | 0.210 | 67.7 | 0.081 |
| 525: 80/4 | lamp stem | 0.02 | 0.492 | 14.10 | 0.135 | 17.23 | 0.007 | 0.027 | 0.0001 | 0.283 | 68.0 | 0.084 |
| 525: 54 | lamp stem | 2.78 | 0.399 | 7.68 | 0.171 | 19.93 | 0.029 | 0.058 | 0.0002 | 0.281 | 67.1 | 0.078 |
| 525: 80/8 | lamp stem | 2.33 | 0.426 | 9.02 | 0.193 | 18.58 | 0.017 | 0.055 | 0.0004 | 0.425 | 72.1 | 0.073 |
| 575: 29/2 | lamp stem | 3.98 | 0.371 | 7.72 | 0.132 | 19.83 | 0.012 | 0.067 | 0.0011 | 0.225 | 64.7 | 0.108 |
| 525: 113/2 | lamp filler | 2.83 | 0.349 | 2.36 | 0.164 | 20.30 | 0.012 | 0.080 | 0.0001 | 0.322 | 73.9 | 0.208 |
| 525: 71/1 | lamp filler | 5.50 | 0.268 | 1.88 | 0.135 | 25.90 | 0.017 | 0.077 | 0.0006 | 0.231 | 63.5 | 0.105 |
| 525: 113/1 | lamp filler | 2.21 | 0.584 | 2.72 | 0.320 | 16.35 | 0.017 | 0.112 | 0.0002 | 0.082 | 73.9 | 0.084 |
| 525: 130 | lamp filler | 2.60 | 0.351 | 7.81 | 0.172 | 16.93 | 0.013 | 0.048 | 0.0005 | 0.362 | 70.4 | 0.075 |
| 525: 181 | lamp filler | 2.65 | 0.267 | 0.19 | 0.204 | 41.40 | 0.005 | 0.038 | 0.0001 | 0.025 | 51.9 | 0.148 |
| 525: 80/13 | lamp stem (mean of 3 samples) | 0.67 | 0.312 | 12.41 | 0.287 | 16.83 | 0.009 | 0.053 | 0.0014 | 0.387 | 69.7 | 0.075 |
| 525: 78/21 | large screw from lamp stand | 7.00 | 0.760 | 0.31 | 0.542 | 21.40 | 0.012 | 0.047 | 0.0001 | 0.202 | 69.6 | 0.059 |
| 575: 114/19 | large screw from lamp stand | 7.24 | 0.721 | 0.06 | 0.286 | 1.05 | 0.010 | 0.069 | 0.0001 | 0.060 | 89.3 | 0.056 |
| 575: 30/6 | bowl | 21.68 | 0.116 | 0.01 | 0.010 | 0.05 | 0.085 | 0.040 | 0.0001 | 0.444 | 77.3 | 0.012 |
| 525: 18 | large bucket | 0.45 | 0.442 | 0.66 | 0.092 | 0.97 | 0.011 | 0.077 | 0.0002 | 0.113 | 94.9 | 0.062 |
| - | ingot? | 2.82 | 0.382 | 1.34 | 0.225 | 17.19 | 0.012 | 0.055 | 0.0001 | 0.487 | 79.5 | 0.118 |
| 575: 22 | lamp tripod | 3.33 | 0.374 | 5.50 | 0.189 | 17.00 | 0.019 | 0.098 | 0.0002 | 0.501 | 73.0 | 0.106 |
| SEM #36 | bowl | 22.76 | 0.166 | 0.02 | 0.010 | 0.08 | 0.097 | 0.045 | 0.0001 | 1.331 | 84.5 | 0.015 |
| 525: 107/4 | lamp tripod | 0.52 | 0.250 | 6.39 | 0.362 | 13.56 | 0.002 | 0.104 | 0.0042 | 0.426 | 80.1 | 0.132 |
| 525: 218/3 | lamp tripod | 2.74 | 0.442 | 8.41 | 0.280 | 17.89 | 0.039 | 0.096 | 0.0010 | 0.250 | 66.3 | 0.089 |
| 525: 109/1 | lamp tripod | 0.35 | 0.262 | 8.96 | 0.213 | 20.09 | 0.008 | 0.051 | 0.0012 | 0.246 | 69.8 | 0.060 |
| 576: 40 | gilded decoration | 0.47 | 0.841 | 0.31 | 0.210 | 0.90 | 0.011 | 0.065 | 0.0006 | 0.180 | 93.6 | 0.078 |
| 525: 113 | finger ring waster | 2.98 | 0.476 | 2.13 | 0.344 | 20.38 | 0.019 | 0.075 | 0.0002 | 0.136 | 71.2 | 0.066 |
| 525: 113 | riser | 2.90 | 0.482 | 2.06 | 0.340 | 22.83 | 0.019 | 0.074 | 0.0003 | 0.132 | 71.2 | 0.068 |
| 525: 168 | bucket body | 5.07 | 0.617 | 0.95 | 0.364 | 20.76 | 0.018 | 0.099 | 0.0001 | 0.259 | 71.2 | 0.092 |
| 525: 168 | bucket handle | 0.55 | 0.238 | 12.47 | 0.070 | 1.61 | 0.012 | 0.079 | 0.0011 | 0.172 | 84.8 | 0.055 |
| 575: 51/3 | leg (mean of 3 samples) | 2.12 | 0.339 | 7.53 | 0.247 | 16.13 | 0.013 | 0.055 | 0.0014 | 0.630 | 69.7 | 0.091 |
| 525: 146/1 | decorated handle | 6.80 | 0.463 | 0.36 | 0.372 | 19.97 | 0.009 | 0.060 | 0.0001 | 0.099 | 69.2 | 0.082 |
| 525: 160 | 'dipper' | 0.75 | 0.453 | 10.99 | 0.068 | 1.68 | 0.012 | 0.093 | 0.0003 | 0.240 | 90.0 | 0.050 |
| 525: 183/1 | 'vessel stand' | 2.88 | 0.478 | 3.54 | 0.327 | 19.13 | 0.022 | 0.110 | 0.0001 | 1.053 | 74.3 | 0.141 |
| 525: 192 | sword ferrule | 6.94 | 0.425 | 1.52 | 0.324 | 15.30 | 0.021 | 0.073 | 0.0003 | 0.151 | 77.1 | 0.103 |
| 525: 119 | fitting | 4.11 | 0.510 | 4.75 | 0.469 | 18.88 | 0.017 | 0.067 | 0.0008 | 0.472 | 76.0 | 0.091 |

*Table 2: ICP-AES analyses of Fatimid metalwork (continued 1)*

| Sample | Description | Element (wt%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sn | As | Zn | Sb | Pb | Co | Ni | Mn | Fe | Cu | Ag |
| *Tiberias hoard (continued 1)* | | | | | | | | | | | | |
| 525: 126/8 | lamp tray | 2.34 | 0.424 | 8.61 | 0.295 | 13.45 | 0.011 | 0.050 | 0.0040 | 0.645 | 78.7 | 0.090 |
| 525: 126/19 | lamp tray | 1.24 | 0.339 | 7.65 | 0.366 | 18.25 | 0.013 | 0.039 | 0.0306 | 0.762 | 68.9 | 0.065 |
| 525: 132/0 | big 'dipper' | 0.71 | 0.369 | 11.69 | 0.070 | 2.16 | 0.030 | 0.230 | 0.0005 | 0.239 | 83.0 | 0.045 |
| 525: 99/2 | animal foot | 3.57 | 0.353 | 5.54 | 0.206 | 16.32 | 0.022 | 0.124 | 0.0002 | 0.411 | 76.4 | 0.089 |
| 525: 99/3 | animal foot | 3.99 | 0.387 | 5.71 | 0.235 | 17.99 | 0.023 | 0.130 | 0.0002 | 0.487 | 76.4 | 0.094 |
| 525: 99/1 | animal foot | 3.20 | 0.312 | 5.32 | 0.178 | 14.47 | 0.020 | 0.114 | 0.0043 | 1.287 | 63.2 | 0.076 |
| 575:114/2 | single foot | 1.27 | 0.521 | 10.40 | 0.231 | 21.73 | 0.014 | 0.065 | 0.0003 | 0.267 | 69.4 | 0.073 |
| 525: 135/1 | 'long' foot | 2.96 | 0.443 | 4.92 | 0.228 | 22.26 | 0.018 | 0.073 | 0.0001 | 0.232 | 73.7 | 0.087 |
| 576: 16/2 | small bucket | 5.01 | 0.367 | 2.53 | 0.194 | 23.33 | 0.022 | 0.093 | 0.0001 | 1.255 | 76.4 | 0.202 |
| 525: 97 | small dipper | 3.90 | 0.487 | 2.64 | 0.324 | 23.48 | 0.030 | 0.088 | 0.0002 | 0.349 | 76.9 | 0.092 |
| 576: 1/4 | handle | 0.69 | 0.318 | 17.04 | 0.089 | 9.46 | 0.016 | 0.039 | 0.0002 | 0.215 | 75.6 | 0.048 |
| 576: 1/5 | handle | 0.23 | 0.117 | 6.52 | 0.282 | 4.91 | 0.002 | 0.035 | 0.0001 | 0.220 | 91.2 | 0.137 |
| 525: 198 | handle | 2.43 | 0.484 | 5.70 | 0.270 | 18.85 | 0.022 | 0.093 | 0.0001 | 0.587 | 67.9 | 0.083 |
| 576: 11/3 | handle | 3.38 | 0.349 | 7.52 | 0.173 | 13.20 | 0.014 | 0.069 | 0.0001 | 0.263 | 72.0 | 0.076 |
| 576: 1/2 | handle | 3.25 | 0.194 | 6.69 | 0.086 | 13.20 | 0.021 | 0.070 | 0.0001 | 0.212 | 75.0 | 0.072 |
| 525: 179 | mortar | 3.03 | 0.386 | 2.11 | 0.234 | 18.08 | 0.013 | 0.076 | 0.0001 | 0.103 | 74.3 | 0.102 |
| 525: 15 | mortar | 2.66 | 0.420 | 4.21 | 0.249 | 23.07 | 0.016 | 0.081 | 0.0001 | 0.181 | 65.7 | 0.095 |
| 575: 32 | turnings | 0.29 | 0.290 | 0.28 | 0.131 | 0.70 | 0.012 | 0.048 | 0.0003 | 0.060 | 95.9 | 0.072 |
| 575: 85 | pomegranate ewer | 1.57 | 0.070 | 16.41 | 0.050 | 11.55 | 0.056 | 0.032 | 0.0001 | 0.084 | 70.0 | 0.020 |
| 575: 85 | turnings | 1.21 | 0.341 | 0.23 | 0.132 | 1.11 | 0.014 | 0.050 | 0.0003 | 0.187 | 92.0 | 0.071 |
| 525: 25/2 | large bucket | 0.83 | 0.344 | 11.29 | 0.061 | 2.37 | 0.035 | 0.230 | 0.0008 | 0.207 | 82.0 | 0.038 |
| 576: 15 | vessel | 2.73 | 0.305 | 12.04 | 0.187 | 21.17 | 0.012 | 0.065 | 0.0018 | 0.478 | 63.8 | 0.096 |
| 575: 32/1 | small bowl | 4.45 | 0.451 | 0.94 | 0.368 | 20.45 | 0.012 | 0.083 | 0.0001 | 0.037 | 72.0 | 0.110 |
| 575: 71/1 | bowl SEM #74 | 21.57 | 0.175 | 0.01 | 0.010 | 0.04 | 0.093 | 0.027 | 0.0001 | 0.269 | 75.0 | 0.011 |
| 575: 66 | bottle | 2.72 | 0.550 | 9.88 | 0.345 | 17.73 | 0.015 | 0.079 | 0.0007 | 0.747 | 67.1 | 0.091 |
| 525: 203 | sword ferrule | 3.24 | 0.215 | 10.86 | 0.065 | 12.93 | 0.036 | 0.049 | 0.0008 | 0.329 | 73.5 | 0.039 |
| 525: 160/3 | sword ferrule | 4.48 | 0.381 | 4.77 | 0.175 | 13.86 | 0.036 | 0.092 | 0.0001 | 0.334 | 76.7 | 0.062 |
| 525: 153 | doming block | 12.05 | 0.459 | 2.02 | 0.168 | 9.52 | 0.009 | 0.061 | 0.0001 | 0.163 | 74.7 | 0.065 |
| 525: 160/6 | unfinished cast | 11.05 | 0.336 | 3.42 | 0.160 | 8.61 | 0.034 | 0.051 | 0.0001 | 0.193 | 74.1 | 0.052 |
| 525: 38/2 | 'Abbas' lamp tripod | 1.90 | 0.392 | 10.58 | 0.144 | 14.92 | 0.015 | 0.054 | 0.0013 | 0.241 | 69.7 | 0.059 |
| 525: 118 | handle | 4.12 | 0.377 | 5.25 | 0.182 | 17.14 | 0.027 | 0.128 | 0.0001 | 0.494 | 71.0 | 0.082 |
| 525: 129 | bird handle | 0.77 | 0.338 | 11.37 | 0.259 | 14.79 | 0.019 | 0.050 | 0.0017 | 0.479 | 70.0 | 0.099 |
| 525: 222 | bird and stag handle | 3.05 | 0.420 | 9.57 | 0.082 | 15.40 | 0.012 | 0.157 | 0.0001 | 0.122 | 71.5 | 0.075 |
| 525: 62/4 | bird handle | 6.35 | 0.376 | 3.40 | 0.212 | 14.39 | 0.017 | 0.071 | 0.0014 | 0.701 | 72.9 | 0.095 |
| 525: 103 | fine bird handle | 2.21 | 0.223 | 11.26 | 0.090 | 7.29 | 0.023 | 0.054 | 0.0001 | 0.311 | 77.4 | 0.038 |
| 575: 61/2 | Coptic incense burner | 3.11 | 0.133 | 11.05 | 0.069 | 9.47 | 0.006 | 0.071 | 0.0001 | 0.240 | 74.5 | 0.070 |
| 575: 107/1 | bell | 9.66 | 0.057 | 0.03 | 0.070 | 6.05 | 0.017 | 0.030 | 0.0005 | 0.188 | 82.0 | 0.043 |
| 525: 105 | fitting | 10.10 | 0.360 | 2.04 | 0.264 | 8.86 | 0.036 | 0.054 | 0.0023 | 0.319 | 72.8 | 0.067 |
| 525: 226 | bell | 16.97 | 0.239 | 0.33 | 0.039 | 1.69 | 0.058 | 0.048 | 0.0001 | 0.265 | 79.8 | 0.039 |
| 525: 926 | bell | 0.41 | 0.210 | 15.21 | 0.046 | 1.13 | 0.018 | 0.051 | 0.0005 | 0.162 | 86.3 | 0.013 |
| 576: 76/1 | small bucket | 2.57 | 0.438 | 11.62 | 0.242 | 15.08 | 0.022 | 0.096 | 0.0008 | 0.473 | 67.7 | 0.072 |
| 525: 4/2 | large bowl | 3.32 | 0.460 | 1.02 | 0.342 | 19.45 | 0.012 | 0.073 | 0.0001 | 0.045 | 74.9 | 0.114 |
| 525: 149/3 | large bowl | 5.83 | 0.162 | 0.05 | 0.132 | 28.29 | 0.009 | 0.014 | 0.0001 | 0.016 | 58.9 | 0.050 |
| 575: 32 | vessel | 0.24 | 0.381 | 11.98 | 0.039 | 1.43 | 0.052 | 0.399 | 0.0002 | 0.143 | 83.9 | 0.025 |
| 575: 42 | bottle | 3.20 | 0.467 | 9.60 | 0.254 | 16.47 | 0.019 | 0.073 | 0.0002 | 0.464 | 69.6 | 0.096 |
| 575: 66 | bottle | 1.62 | 0.604 | 10.49 | 0.411 | 26.68 | 0.007 | 0.070 | 0.0066 | 0.717 | 62.7 | 0.090 |
| 525: 27 | cauldron | 0.76 | 0.536 | 0.27 | 0.185 | 1.04 | 0.016 | 0.067 | 0.0008 | 0.243 | 92.5 | 0.075 |
| TC21 | Class B Follis (1035-42) | 0.01 | 0.117 | 0.01 | 0.361 | 1.07 | 0.002 | 0.035 | 0.0001 | 0.007 | 97.6 | 0.119 |
| TC40 | Class C Follis (1042-50) | 0.01 | 0.123 | 0.02 | 0.219 | 0.55 | 0.002 | 0.027 | 0.0001 | 0.005 | 99.0 | 0.120 |
| TC57 | Constantine X Follis (1059-67) | 0.01 | 0.434 | 0.02 | 0.188 | 0.44 | 0.002 | 0.025 | 0.0001 | 0.007 | 97.3 | 0.102 |
| TC31 | Class A2 Follis (976-1035) | 0.01 | 0.061 | 0.01 | 0.091 | 0.52 | 0.002 | 0.028 | 0.0001 | 0.005 | 97.6 | 0.072 |
| TC7 | Class A2 Follis (976-1035) | 0.01 | 0.069 | 0.02 | 0.267 | 0.92 | 0.002 | 0.044 | 0.0001 | 0.006 | 93.7 | 0.079 |

*Table 2: ICP-AES analyses of Fatimid metalwork (continued 2)*

| Sample | Description | Element (wt%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sn | As | Zn | Sb | Pb | Co | Ni | Mn | Fe | Cu | Ag |
| *Tiberias hoard (continued 2)* | | | | | | | | | | | | |
| 525:113/99 | mosque lamp | 1.11 | 0.218 | 11.11 | 0.035 | 1.38 | 0.020 | 0.092 | 0.0001 | 0.173 | 85.69 | 0.043 |
| 525: 110/3 | bowl | 5.12 | 0.134 | 0.04 | 0.223 | 30.14 | 0.001 | 0.016 | 0.0004 | 0.008 | 64.0 | 0.054 |
| 525: 143 | bowl | 2.80 | 0.505 | 6.82 | 0.270 | 19.19 | 0.020 | 0.068 | 0.0013 | 0.309 | 70.9 | 0.122 |
| 525: 26 | bucket | 0.43 | 0.512 | 0.69 | 0.105 | 1.48 | 0.010 | 0.054 | 0.0009 | 0.088 | 94.2 | 0.075 |
| 575: 114/3 | handle | 2.24 | 0.254 | 1.11 | 0.097 | 23.62 | 0.019 | 0.060 | 0.0002 | 0.846 | 66.3 | 0.136 |
| 575: #71/1 | bowl | 19.37 | 0.151 | 0.00 | 0.024 | 0.04 | 0.079 | 0.023 | 0.0000 | 0.227 | 79.1 | 0.010 |
| 525: 26 | bucket handle | 1.26 | 0.177 | 6.14 | 0.041 | 1.92 | 0.012 | 0.100 | 0.0005 | 0.188 | 89.9 | 0.079 |
| 526: 61 | casting waste | 4.35 | 0.275 | 0.24 | 0.118 | 3.81 | 0.011 | 0.061 | 0.0001 | 0.067 | 92.8 | 0.070 |
| 526: 51/3 | unfinished piece | 2.61 | 0.406 | 4.49 | 0.299 | 15.93 | 0.019 | 0.083 | 0.0022 | 0.525 | 72.9 | 0.077 |
| 526: 51/5 | unfinished piece | 2.16 | 0.234 | 2.67 | 0.062 | 2.50 | 0.016 | 0.105 | 0.0017 | 0.340 | 88.3 | 0.053 |
| 575: 102 | inscribed tray | 0.99 | 0.267 | 8.71 | 0.075 | 1.86 | 0.009 | 0.058 | 0.0023 | 0.177 | 84.3 | 0.048 |
| 576: 19/1 | lamp tripod | 3.99 | 0.280 | 0.88 | 0.208 | 29.12 | 0.016 | 0.050 | 0.0015 | 0.039 | 62.0 | 0.143 |
| 575: 30/2 | lamp tripod (small) | 2.69 | 0.362 | 5.24 | 0.158 | 16.30 | 0.016 | 0.079 | 0.0022 | 0.263 | 75.8 | 0.064 |
| 576: 113a | scrap | 0.66 | 0.365 | 1.27 | 0.109 | 0.97 | 0.020 | 0.074 | 0.0001 | 0.191 | 96.5 | 0.066 |
| 576: 113b | scrap | 0.41 | 0.414 | 0.65 | 0.150 | 1.31 | 0.010 | 0.074 | 0.0001 | 0.317 | 97.2 | 0.075 |
| 525: 132/3 | lamp | 2.55 | 0.341 | 5.33 | 0.175 | 16.38 | 0.016 | 0.062 | 0.0001 | 0.323 | 79.7 | 0.081 |
| 525: 113/98 | mosque lamp | 0.74 | 0.177 | 11.34 | 0.025 | 1.41 | 0.020 | 0.096 | 0.0001 | 0.131 | 87.4 | 0.027 |
| 575: 47 | bowl | 20.09 | 0.122 | 0.01 | 0.023 | .01 | 0.064 | 0.034 | 0.0001 | 0.496 | 78.1 | 0.012 |
| *Denia Hoard* | | | | | | | | | | | | |
| D.95 | bowl (Inverted cone) | 8.29 | 0.219 | 0.01 | 0.382 | 21.41 | 0.011 | 0.030 | 0.0001 | 0.036 | 69.3 | 0.085 |
| D.81 | lamp tray | 18.85 | 0.175 | 1.58 | 0.038 | 1.84 | 0.095 | 0.043 | 0.0001 | 0.268 | 76.9 | 0.030 |
| D.63 | handle | 1.94 | 0.390 | 8.98 | 0.145 | 16.22 | 0.017 | 0.067 | 0.0001 | 0.245 | 71.8 | 0.069 |
| D.66 bar | brazier | 0.60 | 0.162 | 14.61 | 0.153 | 4.84 | 0.002 | 0.023 | 0.0001 | 0.955 | 78.5 | 0.077 |
| D.66 hook | brazier | 0.59 | 0.162 | 14.67 | 0.147 | 4.79 | 0.002 | 0.023 | 0.0001 | 0.998 | 78.4 | 0.077 |
| D.19 | ewer | 7.16 | 0.352 | 2.56 | 0.192 | 16.62 | 0.023 | 0.070 | 0.0001 | 0.134 | 72.6 | 0.089 |
| D.93 | bowl (inverted cone) | 0.30 | 0.425 | 9.73 | 0.169 | 22.11 | 0.027 | 0.019 | 0.0001 | 0.338 | 66.6 | 0.075 |
| D.79 | bowl (hemispheric) | 5.25 | 0.513 | 1.12 | 0.176 | 21.33 | 0.007 | 0.040 | 0.0001 | 0.144 | 71.0 | 0.096 |
| D.48 | Andalusian lamp stem | 0.92 | 0.486 | 15.77 | 0.112 | 13.64 | 0.007 | 0.023 | 0.0001 | 0.277 | 68.6 | 0.071 |
| D.9 | lamp stem | 3.07 | 0.368 | 4.86 | 0.248 | 18.03 | 0.016 | 0.063 | 0.0001 | 0.282 | 72.8 | 0.087 |
| D.35 | lamp tripod | 4.25 | 0.360 | 0.70 | 0.240 | 26.56 | 0.009 | 0.061 | 0.0001 | 0.198 | 67.1 | 0.175 |
| D.33 | lamp tripod | 3.13 | 0.319 | 6.47 | 0.178 | 16.75 | 0.019 | 0.065 | 0.0001 | 0.495 | 72.3 | 0.075 |
| D.32 | lamp tripod | 0.45 | 0.268 | 11.02 | 0.143 | 3.50 | 0.034 | 0.065 | 0.0001 | 0.398 | 83.9 | 0.063 |
| D.32a | rivet on D32 | 2.82 | 0.381 | 7.56 | 0.172 | 16.57 | 0.016 | 0.059 | 0.0001 | 0.331 | 71.9 | 0.087 |
| *Serce Liman wreck* | | | | | | | | | | | | |
| MV.9 | hinge from box | 1.33 | 0.126 | 12.04 | 0.142 | 2.29 | 0.008 | 0.093 | 0.0001 | 1.616 | 82.2 | 0.050 |
| MV.9 | cylindrical box | 0.33 | 0.029 | 19.27 | 0.004 | 0.23 | 0.017 | 0.021 | 0.0001 | 0.082 | 79.9 | 0.020 |
| MV.4 | cauldron handle | 0.01 | 0.515 | 0.01 | 0.069 | 0.86 | 0.001 | 0.015 | 0.0001 | 0.007 | 98.4 | 0.122 |
| MV.3 | cauldron | 0.15 | 0.464 | 0.28 | 0.148 | 1.07 | 0.009 | 0.058 | 0.0001 | 0.159 | 97.5 | 0.085 |
| MV.2 | cauldron | 0.01 | 0.840 | 0.12 | 0.213 | 0.74 | 0.031 | 0.108 | 0.0001 | 0.409 | 97.1 | 0.135 |
| MV.1a | cauldron | 0.26 | 0.537 | 0.12 | 0.125 | 1.75 | 0.009 | 0.052 | 0.0001 | 0.222 | 96.7 | 0.098 |
| GW.1283 | steelyard weight | 3.46 | 0.331 | 5.51 | 0.200 | 18.23 | 0.010 | 0.052 | 0.0001 | 0.430 | 71.5 | 0.099 |
| GW.972 | scale pan | 0.01 | 0.057 | 0.01 | 0.029 | 0.62 | 0.001 | 0.063 | 0.0001 | 0.013 | 99.2 | 0.079 |
| MV.7 | bucket | 0.02 | 0.781 | 0.05 | 0.184 | 0.75 | 0.083 | 0.051 | 0.0001 | 0.339 | 97.5 | 0.079 |
| MV.10 | jug handle | 25.55 | 0.072 | 0.01 | 0.114 | 0.19 | 0.022 | 0.021 | 0.0001 | 1.327 | 72.8 | 0.019 |
| MV.11 | pestle | 4.72 | 0.664 | 0.67 | 0.294 | 18.28 | 0.008 | 0.049 | 0.0001 | 0.079 | 74.9 | 0.143 |
| MV.12 | heart-shaped object | 3.73 | 0.374 | 2.58 | 0.180 | 16.26 | 0.012 | 0.091 | 0.0001 | 0.182 | 76.3 | 0.097 |
| MV.13a | heart-shaped object | 4.00 | 0.370 | 4.33 | 0.168 | 16.38 | 0.015 | 0.094 | 0.0001 | 0.499 | 73.8 | 0.093 |
| GW.56 | sword hilt | 1.65 | 0.468 | 3.41 | 0.242 | 20.09 | 0.029 | 0.137 | 0.0001 | 0.606 | 72.9 | 0.090 |
| MV.13b | heart-shaped object | 3.72 | 0.378 | 2.62 | 0.176 | 16.80 | 0.012 | 0.091 | 0.0001 | 0.186 | 75.7 | 0.097 |
| MV.7 | bucket handle | 0.01 | 0.745 | 0.01 | 0.177 | 0.63 | 0.011 | 0.045 | 0.0001 | 0.090 | 98.2 | 0.073 |
| MV.8 | bucket handle | 0.01 | 0.746 | 0.00 | 0.170 | 1.15 | 0.006 | 0.062 | 0.0001 | 0.111 | 97.6 | 0.068 |
| MV.8 | bucket | 0.80 | 0.543 | 0.63 | 0.152 | 1.37 | 0.010 | 0.065 | 0.0001 | 0.106 | 96.2 | 0.070 |

than 3% for all elements above detection limits, with accuracy being about the same. Detection limits (2s) are approximately Cu 0.7%, Sn 0.7%, Zn 0.24%, Pb 0.5% and Fe 0.06%.

The LA-MC-ICPMS (laser ablation-multi collector inductively coupled plasma mass spectrometer) used for the lead isotope analyses was a New Wave Research 266nm Nd:YAG laser ablation system attached to a VG P54 Elemental MC-ICPMS. Drillings from the same samples taken for ICP-AES were mounted in resin; the surface of the mount was ablated until surplus resin was removed and the metal exposed to the laser. The shavings were then ablated using a rastered sampling approach. The instrumental configuration was adjusted to yield approximately an 8V total emission from the samples and the power was adjusted between 32% and 35% to maintain such a beam intensity. Results are based on 100 scans with an internal precision of ±0.1%1SE. A blank was determined on the resin that, under the ablation conditions above, gave an insignificant beam intensity of 0.0018V. The NBS 981 solution standard gave the following values and reproducibility for a 100ppb Pb solution doped with 10ppb of thallium run during the analysis:

$^{206}Pb/^{204}Pb = 16.932 \pm 0.015\%\ 2\sigma$,
$^{207}Pb/^{204}Pb = 15.488 \pm 0.02\%\ 2\sigma$,
$^{208}Pb/^{204}Pb = 36.685 \pm 0.027\%\ 2\sigma$,
$^{207}Pb/^{206}Pb = 0.9147 \pm 0.008\%\ 2\sigma$,
$^{208}Pb/^{206}Pb = 2.1666 \pm 0.013\%\ 2\sigma$ ($n = 56$);

details are published in Ponting *et al* (2003).

## Acknowledgements

Prof Yizhar Hirschfeld of the Hebrew University of Jerusalem introduced me to the Tiberias material and funded an initial analysis of some of it. The work presented here came out of discussions with Prof James Allan of the Ashmolean Museum, Oxford, whose enthusiasm and support lead to the project being generously funded by the British Academy (Grant No SG: 31510). Considerable gratitude is due to Dr Josep Gisbert Santonja, the Director of the Museu Arqueològic de la Ciutat de Dénia, for his interest and support for this project and especially to Prof Fred van Doorninck, Prof George Bass and Cathy Hall of the Institute of Nautical Archaeology (INA) at Bodrum, Turkey and the staff and Director of Bodrum Museum of Underwater Archaeology. Access to ICP-AES instrumentation was arranged by Chris Somerfield of the School of Environmental and Mining Engineering of Nottingham University, to whom many thanks are due for his interest, understanding and patience. Dr Jane Evans and Vanessa Pashley of the British Geological Survey introduced me to the world of lead isotope analysis and kindly undertook the isotope analyses presented here. Thanks also go to Assaf Oron for his introduction to INA and to Elias Khamis and Susan La Niece for their enthusiasm and helpful discussions. David Taylor of Nottingham University kindly drew the map in Figure 1 and Dr Justine Bayley patiently read and commented on earlier drafts of this paper.

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