ArchéoSciences

33 (2009)
Authentication and analysis of goldwork

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Référence électronique
Michael Melcher, Manfred Schreiner, Birgit Bühler, Andrea M. Pülz et Ulrike Muss, « Investigation of ancient gold objects from Artemision at Ephesus using portable µ-XRF », *ArchéoSciences* [En ligne], 33 | 2009, mis en ligne le 10 décembre 2012, consulté le 09 janvier 2013. URL : http://archeosciences.revues.org/2172

Éditeur : Presses universitaires de Rennes
http://archeosciences.revues.org
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Investigation of ancient gold objects from Artemision at Ephesus using portable µ-XRF

Enquête sur les objets anciens en or de l'Artemision à Ephèse au moyen d'un équipement de µFX portable

Michael Melcher*, Manfred Schreiner*, Birgit Bühler**, Andrea M. Pülz*** and Ulrike Muss****

Abstract: During two measurement campaigns in the Archaeological Museum in Istanbul and the Ephesus Museum in Selçuk, Turkey, more than 80 ancient gold objects (e.g. appliqués, statuettes and coins) from the 8th-6th centuries BC were analyzed using portable XRF instruments in order to obtain information on the chemical composition and homogeneity of the artefacts discovered during excavations in the sanctuary of Artemis at Ephesus. These results and complementary studies on the manufacturing techniques employed for making these objects will contribute to our knowledge of metalworking, trade, as well as the transfer of ideas and technologies at Ephesus and in Western Asia in the Archaic period.
The objects can be characterized as homogeneous alloys, mainly consisting of gold (Au), silver (Ag) and copper (Cu). A high compositional variation of Au and Ag between different objects could be determined (Au between 48.7 and 99.9%, Ag between <detection limit (dl) and 50.9%, Cu between <dl and 4.4%).
These results demonstrated the range of gold alloys represented within the collection and allowed a discrimination between natural and artificial gold alloys (including the identification of 'refined' gold). In some cases, objects which were closely related from a typological, stylistic and/or technological point of view were also similar in composition, differing only in the sub-percent range.

Résumé : *Plus de 80 objets anciens en or (p.ex. appliques, statuettes et monnaies) datés du VIIIe-VIe siècle av. J.-C. et trouvés lors des fouilles du sanctuaire d'Artémise à Ephèse, ont été analysés au moyen d'un équipement de FX portable pendant les deux campagnes de mesure réalisées au musée archéologique d'Istanbul et au musée d'Ephèse à Selçuk, Turquie, de façon à obtenir des informations sur leur composition chimique et sur leur homogénéité. Ces résultats, complémentés par des études sur leurs techniques de fabrication, contribuent à la connaissance du travail du métal, de son commerce, ainsi que du transfert d'idées et technologies à Ephèse et dans l'Asie de l'Ouest pendant la période Archaïque.*
Les objets ont été fabriqués avec des alliages homogènes, se composant en majorité d'or (Au), argent (Ag) et cuivre (Cu). Une forte variation de teneurs a pu être mise en évidence pour l'Au et l'Ag dans le cas de différents objets (Au entre 48,7 and 99,9 %, Ag entre < limite de détection (dl) et 509 %, Cu entre < dl et 4,4 %).
Ces résultats montrent la gamme d'alliages d'or de la collection et permettent de discriminer entre alliages d'or naturels et artificiels (en incluant l'identification d'or « affiné »). Dans certains cas d'objets de typologie, style et/or techniques de fabrication proches, leurs compositions sont identiques, la différence n'apparaissant qu'au niveau du sous-pourcent.

Keywords: Gold, Ephesus, Artemision, XRF.

Mots-clés : *Or, Éphèse, Artemision, FX.*

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rec. Aug. 2009 ; acc. Nov. 2009

1. Introduction and historical background

About 1.500 gold objects were found in the sanctuary of the goddess Artemis at Ephesus, Turkey (Pülz, 2009). Most of these occurred in strata located under the Archaic *dipteros* – the so-called "Temple of Croesus" – and may thus be dated to the second half of the 7th or the first half of the 6th century BC (Hogarth, 1908; Bammer and Muss, 1996). Within the Archaic period, the Artemision is unique in terms of the large number and variety of gold jewellery. No other sanctuary from this period has yielded a similar wealth of gold objects. During the British and Austrian excavation campaigns at this site, a small number of figural objects, such as statuettes in human or animal form and miniature objects, were found. They were deposited in the sanctuary as votive gifts. The vast majority of gold objects, however, are dress ornaments and jewellery.

Among the gold finds, approximately 530 appliqués were found in the sanctuary of Artemis, representing at the same time the major group of artefacts (Pülz and Bühler, 2006). Most of them show holes on the edges and can therefore be addressed as garment decorations (e.g. Selçuk, inv. no. 1/71/89, Fig. 1). Because of the lack of parallels which would point to individual appliqués votive offerings in the Artemision, an interpretation of these objects as representing decorations of the cult image (Romano, 1988) or ritual garment offerings seems likely.

It is interesting, however, that none of the gold statuettes found in the Artemision from the 7th or 6th centuries BC which represent the adored goddess show garments or dresses with appliqué decorations, like later copies. A solemn figurine wears a dress whose border is decorated with meander patterns (Selçuk, inv. no. 2/59/80).

The second most important group of gold jewellery items consists of spherical and drop-shaped pendants and beads (some of which look like fruit), pins with floral heads, fibulae (predominantly of the Phrygian 'Asia Minor' type), brooches in the shape of birds of prey, and boat-shaped earrings with, in some cases, elaborate decoration (Bühler and Pülz, 2009). The vast majority of gold earrings found in the Archaic temple of Artemis at Ephesus belong to the so-called 'boat-shaped' type (sometimes also referred to as 'leech-shaped'), with a swollen body, which may be plain or decorated. Earrings of this type are very common in Western Anatolia. The best parallels for the examples from Ephesus were found in the Güre region (Özgen and Öztürk, 1996), Sardes, Lydia (Waldbaum, 1983), the Bayındır grave mound in northern Lycia (Özgen and Öztürk, 1996) and among the objects from the Norbert Schimmel Collection (Muscarella, 1974).

Most of the motifs or figurines refer to Artemis as the goddess of fertility, or her representation as the mistress of animals. For example, the bird of prey (Istanbul, inv. no. 3093, Fig. 2) is considered to be sacred to the goddess, and

Figure 1: (See colour plate) Appliqué from the sanctuary of Artemis (Selçuk, inv. no. 1/71/89).
Figure 1: (Voir planche couleur) Appliqué du sanctuaire d'Artemise (Selçuk, inv. no. 1/71/89).

Figure 2: (See colour plate) Bird of prey (Istanbul, inv. no. 3093).
Figure 2: (Voir planche couleur) Rapace (Istanbul, inv. no. 3093).

it is found in the form of brooches, pendants or statuettes in the sanctuary (Bühler and Pülz, 2008). The bee, a symbol of reincarnation and fertility which is closely connected with the cult of Artemis, also appears in many variations, from naturalistic to very abstract forms (Pülz, 2001). Various pendants, beads and pin heads resemble fruits or seed and can therefore be interpreted as symbols of fertility. However, there are also individual finds, like a gold object in the form of a barley seed, with a real seed inside, which links it directly to the cult of Artemis.

There is no other sanctuary in the Archaic period which is, both in terms of quantity and quality, comparable to the Artemision in terms of the assemblage of gold objects. Only collections of artefacts originating from graves, especially gold jewellery from Rhodes (650-600 BC) (Laffineur, 1978), and from the Lydian Tumuli (Özgen and Öztürk, 1996) are similar in numbers. The latter, of course, are dated to a much later period (the end of the 6th and the beginning of the 5th century BC), but, in terms of their forms, motifs, and techniques, they strongly resemble the Ephesian finds.

When considering the artefacts found in the Artemision, it can be shown that the majority of them are related to forms indigenous to Ionia, and that they were created in local workshops. The unique fibulae decorated with a combination of lion heads and falcon heads embedded in a flower (Selçuk, inv. no. 1/43/94, Fig. 3) have no parallels in the Archaic world, and can therefore be addressed as a specific Ephesian product (Freiberger and Gschwantler, 2008). On the other hand, there are a few objects, such as, for example, a richly decorated head of a griffon (Selçuk, inv. no. 117/61/90) or a piece of jewellery in the form of a blossom, whose style and technology is strikingly similar to Rhodes jewellery of the Orientalizing period, so that the hypothesis of an import can be considered.

Figure 3: Fibulae decorated with a combination of lion heads and falcon heads embedded in a flower (Selçuk, inv. no. 1/43/94).
Figure 3 : Fibule décorée d'une combinaison de têtes de lions et de faucons entourée de motifs floraux (Selçuk, inv. no. 1/43/94).

Statuettes and miniature objects (such as human extremities and small vessels) in particular were not objects intended for daily use, but designed for the purpose of giving. Through precious votive offerings, such as gold objects, one could show not only one's religious faith but also demonstrate one's status as compared to other individuals. However, votive offerings were obviously even more than that: they were also prestige objects for the recipient, that is the deity or its mortal representative (i.e. the priest), because, through precious gifts, status and power over other sanctuaries were strengthened (Godelier, 1999).

2. Methods

83 of these objects, among them 11 coins, were selected for material analysis using two different self-built portable X-ray fluorescence (XRF) instruments (henceforth referred to as XRF I and XRF II), according to the different requirements of the areas on the objects' surfaces to be analyzed. Instrument XRF I (COPRA, Compact Portable Roentgen Analyzer, Fig. 4), constructed within the EU-Project No. SMT4-CT98-2237 and used for the measurement campaign in the Istanbul Archaeological Museum, is characterized by a very small diameter (half-value width of 126 µm at 40 kV, 0.4 mA, Fe-Kα) of the primary X-ray beam (anode material: molybdenum), which is achieved by a polycapillary. As a result, this instrument is particularly suited for investigations of micro-domains on the surfaces of (gold) objects. A proper focusing on the desired domain is achieved by an external object positioning system (allowing for a positioning of the object with an accuracy of 0.01 mm in all 3 spatial directions), a microscope and a CCD-camera. For the detection of the fluorescence radiation, a drift chamber detector (Röntec X-flash L) with an energy resolution of <170 eV is used.

Instrument XRF II (Fig. 5), used for investigations in the Ephesus Museum in Selçuk, is equipped with a Rhodium (Rh) X-ray tube (Oxford XTF5011), a silicon drift detector (Röntec XFlash 1000), and a positioning system consisting of two laser beams (Desnica, 2005; Desnica and Schreiner, 2006). The diameter of the primary beam is approximately

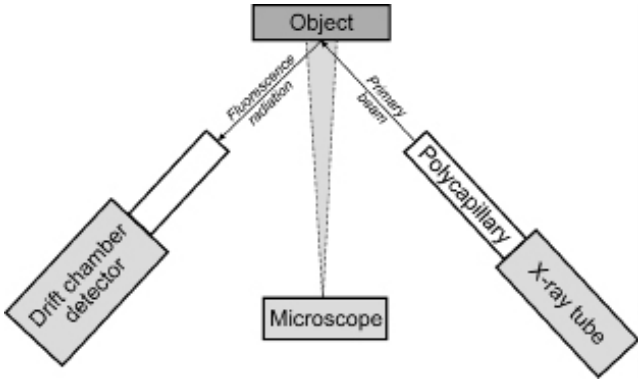

Figure 4: Scheme of the instrument XRF I used for the investigation of objects in the Archaeological Museum, Istanbul.
Figure 4: Schéma de l'équipement de FX-I utilisé dans l'étude des objets du musée archéologique d'Istanbul.

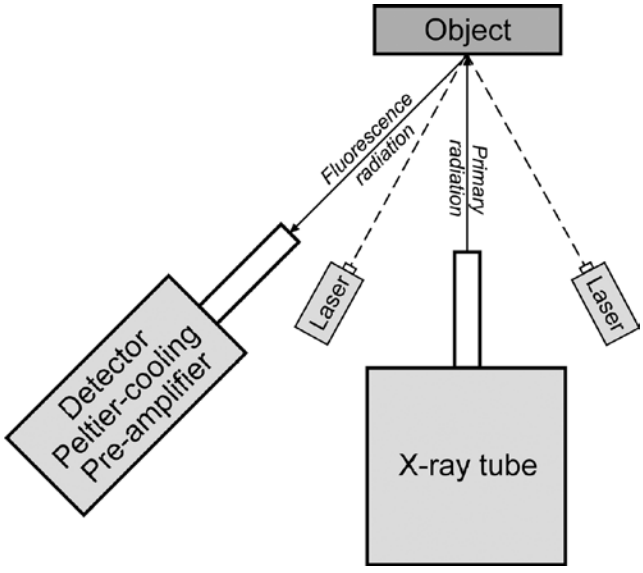

Figure 5: Scheme of the instrument XRF II used for the investigation of objects in the Ephesus Museum, Selçuk.
Figure 5 : Schéma de l'équipement de FX-II utilisé dans l'étude des objets du musée d'Ephèse à Selçuk.

1 mm. Due to their relatively low weight, both instruments are especially suited for investigations of objects on site (i.e. in museums, collections, or near excavations) and enable a qualitative and quantitative determination of major, minor and trace elements in a non-destructive manner.

For all measurements, a tube voltage of 35 kV, a tube current of 0.8 mA, and a measurement time of 200 s were used. Additionally, the tube was equipped with a 12.5 µm palladium (Pd)-filter for suppression of diffraction peaks in the resulting spectrum. Typically, 3-4 measurement points were set on an object's surface. The spectra were quantified using 18 appropriate standard materials in the systems Au-Ag-Cu and Ag-Cu, as well as the software WinAxil (Win Axil X-ray Analysis Software, Canberra Benelux, Belgium). The cross-checking of the quality of the quantification in order to estimate analytical errors was carried out by the quantification of these standard materials. Relative errors of less than 3% for the main components Au and Ag (compositional range ≥30 wt%), and less than 20% for the minor component Cu (compositional range ≤5 wt%) were verified.

3. Results and Discussion

Table 1 presents the results of the analyses in tabular form. In addition to the major and minor elements Au, Ag and Cu, in some cases Fe was also detected in small amounts. As the Fe intensities also showed significant variations between different measurement points, the presence of Fe might be due to superficial contaminations of the objects. The most important result of these XRF analyses is the identification of 8 objects that were made of a gold alloy with very high Au content, of more than 97%, that is of almost pure – and therefore refined – gold. Four of these objects have an Au content of more than 99%, containing only traces of Cu and/or Ag: one is a cast miniature pendant in the shape of a human being (Istanbul, inv. no. 3071), while the other three objects (Istanbul, inv. nos. 3175 a, 3175 b and Selçuk, inv. no. 42/41/86) are appliqués of identical type (type b.5-variant 10, according to A.M. Pülz; see e.g. Pülz and Bühler 2006). The other four objects in this group are high-quality jewellery items which consist of a large number of individual sheet-gold components and fine decorative elements (mainly granulation, in some cases also beaded wires): a brooch (Istanbul, inv. no.3157) and an earring (Istanbul, inv. no. 3033), which may have been products of the same workshop, as well as an insect-shaped miniature pendant (Istanbul, inv. no. 3087) and brooch (Istanbul, inv. no. 3088). The Au content of these four objects varies between 97.2% and 98.9%, the Cu content between 1.1% and 2.8%, and they all contain no Ag. As these four objects consist of a large number of components, it is possible that at least some of the copper detected on the surface of these objects is due to the process of reaction soldering with copper salts, which may have been used to join these components. If this assumption is correct, the actual gold content of the sheet-gold components used to produce these objects may have been even higher. Significantly, all eight jewellery items with an Au content of more than 97% are products of outstanding quality.

Object inv. no.	Au	Ag	Cu	Object inv. no.	Au	Ag	Cu	Object inv. no.	Au	Ag	Cu
3175	99.9 (0.0)	0.0 (0.0)	0.1 (0.0)	**105/30/77**	70.0 (2.5)	28.2 (2.5)	1.9 (0.0)	**184/54/88**	58.0 (1.5)	40.5 (1.6)	1.6 (0.2)
3176	99.9 (0.0)	0.0 (0.0)	0.1 (0.0)	**50/41/86**	68.6 (0.3)	28.7 (0.1)	2.9 (0.3)	**18/41/86**	57.7 (0.7)	41.0 (0.9)	1.3 (0.3)
3071	99.5 (1.4)	0.0 (0.0)	0.6 (1.4)	**53/32/85**	68.6 (3.4)	29.4 (3.5)	2.1 (0.4)	**3079**	57.6 (5.0)	40.4 (5.4)	2.0 (0.4)
42/41/86	99.5 (0.1)	0.4 (0.1)	0.1 (0.0)	**115/61/90**	68.1 (0.4)	31.1 (0.5)	0.8 (0.0)	**17/41/86**	57.0 (1.0)	41.5 (1.0)	1.6 (0.1)
3157	98.9 (0.7)	0.0 (0.0)	1.1 (0.7)	**1/42/93**	67.5 (2.3)	31.9 (2.1)	0.6 (0.2)	**58/38/81**	56.6 (2.6)	41.4 (2.4)	2.0 (0.2)
3087	98.4 (1.1)	0.0 (0.0)	1.6 (1.1)	**47**	67.3 (0.2)	32.0 (0.3)	0.8 (0.1)	**29/68/89**	56.2 (1.3)	42.2 (1.7)	1.7 (0.4)
3033	98.3 (1.7)	0.0 (0.0)	1.7 (1.7)	**37/41/86**	67.0 (3.4)	31.7 (3.3)	1.4 (0.1)	**3078**	55.7 (5.9)	42.4 (6.4)	1.9 (0.5)
3088	97.2 (0.5)	0.0 (0.0)	2.8 (0.5)	**12/42/93**	66.2 (1.3)	31.3 (1.2)	2.6 (0.1)	**3106**	55.3 (4.4)	42.3 (4.4)	2.4 (1.5)
133/61/87	95.3 (0.0)	4.0 (0.2)	0.8 (0.1)	**1/59/80a**	66.0 (0.7)	33.0 (1.0)	1.0 (0.7)	**2/59/80**	55.1 (2.0)	43.8 (2.3)	1.7 (0.3)
2/42/93	92.4 (1.7)	3.8 (0.8)	3.9 (1.0)	**45/41/86**	65.9 (5.7)	32.9 (5.8)	1.3 (0.1)	**3061**	52.6 (1.8)	45.4 (2.7)	2.1 (0.9)
12/41/86	92.2 (1.3)	6.0 (0.9)	1.9 (0.4)	**1/59/80b**	65.8 (0.7)	33.2 (0.7)	1.1 (0.1)	**3062**	52.2 (1.3)	45.6 (1.9)	2.2 (0.6)
3/42/93	91.3 (2.5)	4.3 (0.9)	4.0 (1.3)	**13/42/93**	64.2 (2.2)	33.5 (2.3)	2.4 (0.1)	**3077**	51.5 (1.2)	45.7 (1.4)	2.9 (0.4)
4/42/93	91.1 (3.4)	4.6 (0.7)	4.4 (3.2)	**3/51/91**	62.9 (0.0)	35.1 (0.1)	2.0 (0.2)	**3118**	50.2 (2.1)	47.8 (2.0)	2.0 (0.4)
1/43/94	91.0 (1.0)	4.8 (0.5)	4.3 (1.1)	**3159**	62.8 (3.6)	34.9 (3.1)	2.3 (1.4)	**32/68/89**	50.0 (0.7)	46.8 (0.8)	3.2 (0.2)
3084	84.2 (2.9)	14.6 (3.1)	1.1 (0.2)	**38/68/89**	62.6 (0.5)	36.2 (0.4)	1.2 (0.0)	**183/54/88**	49.0 (4.7)	49.6 (4.1)	1.4 (0.8)
3083	84.1 (2.2)	14.9 (2.9)	0.8 (0.7)	**50/32/85**	62.4 (2.8)	34.3 (3.0)	3.3 (0.1)	**40/41/86**	48.7 (9.8)	50.9 (9.7)	0.4 (0.0)
117/61/90	83.4 (1.4)	15.4 (0.5)	1.2 (0.9)	**7/43/94**	62.3 (2.1)	35.6 (2.0)	2.0 (0.6)	**Coins**			
3090	80.6 (8.7)	16.0 (7.4)	3.4 (3.2)	**15/43/94**	61.9 (2.8)	36.3 (2.8)	1.8 (0.1)	**101/41/86**	83.2 (4.2)	15.7 (4.2)	1.2 (0.1)
1/41/86	78.7 (0.6)	18.5 (0.3)	2.9 (0.9)	**52/32/85**	61.3 (1.3)	37.3 (1.2)	1.5 (0.1)	**99/43/94**	66.5 (7.0)	31.9 (7.3)	1.6 (0.3)
111/61/87	78.1 (0.8)	20.3 (0.7)	1.7 (0.1)	**75/32/85**	61.2 (1.5)	36.6 (1.6)	2.2 (0.4)	**99/41/86**	64.5 (1.2)	34.7 (1.2)	0.8 (0.1)
63/32/85	77.5 (0.2)	19.9 (0.4)	2.6 (0.2)	**29/51/91**	61.2 (0.7)	36.1 (0.6)	2.8 (0.1)	**100/41/86**	62.2 (2.0)	36.7 (2.1)	1.2 (0.1)
135/61/87	77.2 (-)	21.0 (-)	1.8 (-)	**91/32/85**	60.8 (3.0)	36.9 (3.3)	2.4 (0.3)	**98/43/94**	60.7 (1.3)	37.7 (1.2)	1.7 (0.1)
182/54/88	74.4 (0.9)	23.3 (1.1)	2.3 (0.2)	**3093**	60.8 (1.0)	36.3 (1.8)	2.9 (0.8)	**318/61/87**	60.7 (4.4)	37.0 (4.1)	2.4 (0.5)
3076	74.2 (7.3)	24.2 (7.2)	1.7 (0.3)	**174/38/81**	60.6 (1.6)	35.8 (1.7)	3.6 (0.2)	**96/41/86**	60.6 (1.9)	38.4 (1.7)	1.1 (0.2)
110/61/87	73.9 (0.8)	24.0 (1.0)	2.2 (0.1)	**3039**	60.1 (5.0)	35.7 (5.6)	4.3 (3.2)	**95/41/86**	60.5 (3.2)	38.3 (3.2)	1.2 (0.0)
112/61/87	72.5 (0.4)	25.1 (0.5)	2.5 (0.0)	**6/19/81**	59.7 (0.7)	37.9 (0.6)	2.5 (0.0)	**317/61/87**	57.1 (3.8)	41.1 (3.4)	1.8 (0.4)
17/51/91	71.4 (3.9)	27.0 (3.6)	1.6 (0.3)	**1/71/89**	58.8 (2.3)	37.9 (2.9)	3.3 (0.7)	**98/41/86**	56.4 (0.3)	42.1 (0.3)	1.6 (0.0)
8/59/80	70.1 (1.4)	27.6 (1.1)	2.3 (0.4)	**10/43/94**	58.5 (1.5)	39.2 (1.4)	2.4 (0.1)	**23/51/91**	43.4 (6.8)	51.1 (6.9)	5.6 (0.1)

Table 1: Composition (average values of typically 3-4 measurements) of all 83 gold objects (72 jewellery items of different types, appliqués and statuettes, as well as 11 coins) examined in the Archaeological Museum, Istanbul and in the Ephesus Museum, Selçuk. The data are sorted by descending Au content. The numbers in brackets indicate the range (maximum value minus minimum value) observed in the single measurements.
Tableau 1: Composition (teneurs moyennes de typiquement 3-4 mesures) de tous les 83 objects en or étudiés au musée archéologique d'Istanbul et dans le musée d'Éphèse à Selçuk. Les 11 derniers objets sont des monnaies. Les données sont répertoriées par valeur décroissante de la teneur en Au. Les valeurs entre parenthèses correspondent aux gammes (valeur maximale et valeur minimale) observées pour les mesures.

The use of gold alloys with a high gold content for the production of a number of jewellery items from the sanctuary of Artemis at Ephesus is significant because this gold was obviously refined. Considering the evidence from the gold refinery at Sardis, Lydia (see Ramage and Craddock, 2000), which is dated to "no later than the middle of the sixth century BC" (Ramage and Craddock, 2000: 95), it is possible that either the raw material (the refined gold – perhaps in the form of gold bars or coins?) or the finished jewellery items were imported from Sardis. Provided this assumption is true and the date suggested for the Sardis refinery is correct, the use of refined gold could be employed as a chronological criterion, which would allow us to ascribe the objects in question to the 6th century BC. At present, most gold objects from the sanctuary of Artemis at Ephesus are ascribed to the second half of the 7th or the first half of the 6th century BC. An alternative hypothesis would be that the gold was refined in Ephesian workshops. However, to date, there is no evidence available in favour of this theory, and it is not very likely that a gold refinery was active at Ephesus before the workshops recently excavated at Sardis, which provide so far the only certain evidence for the use of the cementation process (separation of silver and gold using salt) known from the ancient world.

In this context, it is important to note that the Lydians are credited with the invention of struck coinage in the 7th century BC, and that "the first coins were of native alluvial gold, with the composition carefully adjusted by the addition of small quantities of silver to bring the gold content down to a fixed composition, just below the minimum gold content found in the metal from the Pactolus" (Ramage and Craddock, 2000: 212-213). Analyses of Lydian coins of this type from the collections of the British Museum have shown that the majority of them contain about 54% Au (with a variation of about 2%), 44% Ag (with a variation of about 2%) and 2% Cu (with a variation of 0.5%), as well as traces of Pb (up to 0.2%) and Fe (0.1-0.2%) (Ramage and Craddock, 2000: 172). Two of the 'Lydian' coins from the sanctuary of Artemis at Ephesus which were analyzed in the context of the present study have a similar composition (Selçuk, inv. nos. 317/61/87 and 98/41/86), and the same is true for a considerable number of gold objects from the same site.

During the reign of the last king of Lydia, Croesus (561-547 BC), the first bimetallic currency system of pure gold and silver was introduced, and this required the ability to separate and refine gold and silver. All analyses of Lydian gold and silver coins have shown them to be of very high purity (98% or more), and gold of similar purity or higher was found on the sherds used to melt the refined metal in the Sardis workshops (Ramage and Craddock, 2000: 169-174).

Although native gold usually contains silver, typically between 5 and 40%, its copper content rarely exceeds 1% (Ramage and Craddock, 2000: 254). Therefore, if a gold alloy contains more than 1-2% Cu, it is likely to be an intentional alloy. Alluvial gold extracted from the river Pactolus varies in composition and is said to contain about 17-30% Ag (Ramage and Craddock, 2000: 172). The area analysis of the cross-section of a natural granule of alluvial gold found during the excavation of the Lydian gold refinery at Sardis has shown it to contain 69.6% Au, 29.8% Ag and 0.6% Cu (Ramage and Craddock, 2000: 148). This is particularly interesting in comparison with a gold globule (Selçuk, inv. no. 42/68/89) found in the sanctuary of Artemis at Ephesus, which contains 67.3% Au, 32.0% Ag and 0.8% Cu. It is thus possible that this is indeed a droplet of unrefined native gold, possibly alluvial gold from the river Pactolus or other Lydian deposits.

A number of finished gold items found in the sanctuary of Artemis at Ephesus have a similar composition, so that it is possible that they were made of unrefined native gold, possibly from Lydian deposits. Significantly, all these objects seem to be dated to the 7th century BC. Examples of such artefacts are: a high-quality, massive human statuette produced by casting, with extensive cold-working (Selçuk, inv. no. 1/42/93 – 67.5% Au, 31.9% Ag and 0.6% Cu) and three fibulae of the Phrygian 'Asia Minor' type (one pair: Selçuk, inv. no. 1/59/80a – 66.0% Au, 33.0% Ag, 1.0% Cu and inv. no. 1/59/80b – 65.8% Au, 33.2% Ag, 1.1% Cu; small single fibula: Selçuk, inv. no. 115/61/90 – 68.1% Au, 31.1% Ag, 0.8% Cu). At least one of the coins of 'Lydian' type analyzed as part of this study (Selçuk, inv. no. 99/41/86) also belongs to this category, as it contains 64.5% Au, 34.7% Ag and 0.8% Cu.

4. Conclusion

The XRF analyses presented in this study have shown that a wide range of gold alloys, both natural and intentional, were used to produce the gold objects from the temple of Artemis at Ephesus (second half of the 7th – first half of the 6th century BC). Significantly, the composition of these gold objects reflects important cultural and technological innovations of the period in question, such as the invention of the cementation process to achieve a complete separation of gold and silver, and the invention of coinage (first, a gold alloy with high silver content in the 7th century BC, then pure gold and silver coins in the 6th century BC). As these innovations took place at Sardis (Lydia), the data provide further evidence for a strong link between the sanctuary of Artemis at Ephesus and the Kingdom of Lydia. A small number of finished gold objects, as well as a piece of workshop debris, seem to consist of unrefined native gold with 32-33% Ag and approximately 1.0% Cu or below. Another small group of objects was made of virtually pure (97-98% Au or above) – and therefore refined – gold. The vast majority of objects, however, in particular most of the appliqués, have a gold content in the range of 55-70%, and a copper content of more than 1.5-2.0%, suggesting that they may have been alloys formed by adding additional silver (which presumably also contained some copper) to a natural, unrefined gold alloy.

Acknowledgement

The results presented in this paper were obtained during a research project financed by the Austrian Science Fund (FWF) and directed by PD Dr. Ulrike Muss. The authors also would like to thank the Turkish Department of Antiquities and Museums (Ankara) and the directors and staff of the Istanbul Archaeological Museum and the Ephesus-Museum Selçuk for the permission to examine the gold objects from the Artemision at Ephesus.

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