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pXRF Analysis of Cypriot Gold Coins of the Classical Period

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E. Markou, A. Charalambous and V. Kassianidou*

The paper presents the results of pXRF analysis of 48 gold coins, issued by the kings of Cyprus during the Classical period. The coins are preserved in Cyprus, in the collections of the Department of Antiquities of Cyprus (27 coins) and the Bank of Cyprus Cultural Foundation (21 coins). The objective of this project is to trace the amount of gold, as well as, that of other elements in the alloy used by the kings of Cyprus to issue gold coinage and to reconsider the economic policies of the Cypriot kings during the fourth century BC.

Introduction

In Evangeline Markou's monograph on the gold coinage produced by the kings of Cyprus during the Classical period, a chapter was dedicated to the chemical analysis of a significant number of coins in the numismatic catalogue, namely 53, preserved in the collection of the Cabinet des Médailles in the Bibliothèque Nationale de France in Paris (Markou 2011: 210–219). The coins were analyzed in the Laboratory IRAMAT of the Centre Ernest Babelon in Orleans in two phases and via two different analytical techniques. Proton Activation Analysis (PAA) was

* Evangeline Markou, Institute of Historical Research, National Hellenic Research Foundation (NHRF) (emarkou@eie.gr).

Andreas Charalambous, Archaeological Research Unit, University of Cyprus (anchar@ucy.ac.cy).

Vasiliki Kassianidou, Archaeological Research Unit, University of Cyprus (v.kassianidou@ucy.ac.cy).

used to analyze 21 coins issued by the kings of Kition and the results were published in 2002 (Gondonneau and Amandry 2002: 339–349). The remaining 31 coins were analyzed through Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) (Gratuze *et al.* 2004: 163–169) and the results were published, together with those of the coins of the kings of Kition, in 2011 (Markou 2011: 210–219). Six additional coins from the Fitzwilliam Museum's collection were also analyzed, using the specific gravity method (Oddy and Hughes 1970: 75–87), which is not as reliable as the ones mentioned above, but still gave a general impression on the percentage of the gold (Markou 2011: 220).

When the Archaeological Research Unit of the University of Cyprus acquired a handheld portable X-ray Fluorescence (pXRF) instrument, and shortly after it launched the Marie Curie Initial Training Network entitled New Archaeological Research Network for Integrating Approaches to ancient material studies (NARNIA) the opportunity arose to perform chemical analysis on the gold coins preserved in the coin collections of the Department of Antiquities of Cyprus (27 coins) and of the Bank of Cyprus Cultural Foundation (21 coins). The aim of this new interdisciplinary and collaborative project is to almost double the number of analyzed gold coins from Cyprus (a total of 48 coins have been included in this study) and to investigate the historical aspects of the economic policy of the kings of Cyprus during the Archaic and Classical periods.

2. Method of Analysis

A portable, handheld Innov-X Delta Energy-Dispersive XRF analyzer (pXRF) was used for the non destructive chemical analysis and the determination of the elemental composition of the gold coins. Energy-Dispersive X-ray Fluorescence (EDXRF) spectrometry is a well-known, non-destructive, fast and multi-element analytical method. The portable XRF (pXRF henceforth), with low detection limits for major, minor and some trace elements, can determine the chemical composition of the surface of an object without sampling or coming into contact with it (Lutz and Pernicka 1996: 313; Guerra 1998: 74; Karydas 2007: 419–420; Frahm and Doonan 2013: 1425–1426). The use of the pXRF instrument was requisite due to the fact that sampling or removing the coins from the museums was not permitted. Therefore conventional laboratory analysis, which would have made possible the application of other more reliable analytical techniques, such as PAA or LA-ICP-MS which have lower detection limits than the XRF technique, especially for trace elements (Guerra 2008: 318–320), was out of the question (Kogan *et al.* 1994: 342; Gondonneau and Guerra 2002: 577–578). This is why the portable handheld XRF, which allows the non-destructive analysis of coins and other metal artefacts, is becoming more and more popular, even though it only provides a chemical profile for the surface, which may not be representative of the whole. Objects which are covered with corrosion products are particularly problematic, but this is not a problem with gold artefacts which are usually in excellent condition, due to the resistance of gold to corrosion. One should, however, bear in mind that in the case of gold coins, it is possible that there is some overestimation of the gold contents because of surface enrichment effects and depletion of the less noble metals, which depend mainly on alloy composition, method of manufacture, burial conditions and the extend of cleaning and polishing of the artefact post excavation (Tate 1986: 22; Araújo *et al.* 1993: 451–452; Craddock *et al.* 1998: 112; Guerra 1998: 74; Cowell and Hyne 2000: 172; Karydas *et al.* 2004: 19).

The specific instrument applied for the analysis is equipped with a 4 W, 50 kV tantalum anode X-Ray tube and a high performance Silicon Drift Detector (SDD) with a resolution of 155 eV (Mo-Kα), covered by a 20 mm detector window. The X-rays are emitted by a miniaturized X-ray tube, located in the internal structure of the instrument, behind a prolene film window. The diameter of the X-Ray beam, adjusted by the use of a collimation coin, is smaller than 3 mm (~2.5 mm). The final measurement value for each analyzed coin presented here is actually the mean value of eight measurements performed on both sides of the coin, four on the obverse and four on the reverse. In some coins where more areas with surface details like inscriptions were observed, more than eight measurements were taken. The measurement time for each spot analysis was 70 seconds.

The analytical mode of the instrument employed for the analyzes of the coins is Alloy Plus. For this mode Beam 1 (40 kV) analyzes the elements Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Hf, Ta, W, Re, Au, Pb, Bi, Zr, Nb, Mo, Pd, Ag, Sn and Sb, while Beam 2 (10 kV) is used for the determination of Mg, Al, Si, P and S. The limits of detection (LODs) of the specific instrument for the main elements which can be found in a gold alloy namely Ag, Cu and Fe are 250 ppm. For Sn, Zn, Bi, Pb and Pd they are 350 ppm.

For quantitative analysis, the Alloy Plus mode utilizes a Fundamental Parameters algorithm to determine elemental concentration. This method calculates chemistry from the spectral data, without the requirement of stored fingerprints. More specifically, the Fundamental Parameters algorithm involves iterative corrections to raw X-ray counts based on the measured chemical composition, accounting for expected differences in various X-ray phenomena, such as X-ray emission, diffraction and secondary fluorescence (Frahm 2013, 1082).

Furthermore, in order to check the accuracy of the applied mode, a gold certified reference material (CRM) 0744-16 (FLUXANA Reference Materials, Germany) was also analyzed. The results of the analysis of the gold certified reference material along with the uncertainty and the detection limits of the instrument for the specific elements are provided in Table 1 (below).

Table 1. The results of the chemical analysis of the gold certified reference material 0744-16 and the detection limits of the pXRF instrument for the specific elements.

Element	**Gold Certified Reference Material 0744-16**		**Uncertainty (%)**		**Detection Limits (ppm)**
	Certified Value (%)	Measured Value (%) ± std	Absolute	Relative	
Au	55.54	56.9 ± 0.08	1.36	2.45	250
Ag	26.27	25.7 ± 0.05	-0.57	2.16	250
Cu	10.25	9.7 ± 0.02	-0.55	5.36	250
Zn	1.38	1.3 ± 0.01	-0.08	5.8	350
Pd	6.56	6.3 ± 0.02	-0.26	3.96	350

A high resolution digital handheld microscope (ProScope HR, Bodelin Technologies) was used to study in detail the surface of the coins, especially in the areas where symbols or inscriptions were observed.

3. Results of pXRF analysis

The 48 gold coins analyzed in the present study are represented in plates 8–9. The number of each coin corresponds to the list of coins in Table 3 (below). At least four kingdoms and eight kings were represented in the studied assemblage but the greatest majority of the coins was issued by the kings of Salamis (24 coins, corresponding to 50% of the total assemblage) and of Kition (18 coins, corresponding to 37.5% of the total assemblage). The remaining 13% of the analyzed coins were produced by the king of Soloi, Eunostos (3 coins, corresponding to 6.25% of the total assemblage) and of the king Sa(-) or Sta(-) (also 3 coins, corresponding to 6.25% of the total assemblage) who ruled in a still unidentified Cypriot kingdom (Markou 2006, 43–54). The two most represented Cypriot kings were Evagoras I of Salamis and Pumayaton of Kition, with 13 coins each (c. 27%).

Table 2. The distribution of the coins analyzed in the present study using pXRF.

Kingdom / King	Kition	Salamis	Soloi	Uncertain	TOTAL	Percentage of coins of each king in the study
Milkyaton	1	-	-	-		2.1%
Milkyaton or Pumayaton	4	-	-	-		8.3%
Pumayaton	13	-	-	-		27.1%
Evagoras I	-	13	-	-		27.1%
Nikokles	-	5	-			10.4%
Nikokles or Evagoras II	-	1	-	-		2.1%
Evagoras II	-	4	-	-		8.3%
Pnytagoras	-	1	-	-		2.1%
Eunostos	-	-	3	-		6.25%
Sa(-) or Sta(-)	-	-	-	3		6.25%
Total coins from each kingdom	18	24	3	3	48	100%
Percentage of coins from each kingdom in the study	37.5%	50%	6.25%	6.25%	100%	

With the pXRF instrument, the following elements were detected: gold (Au), silver (Ag), copper (Cu), lead (Pb), tin (Sn), iron (Fe), and palladium (Pd); the results are presented in detail in Table 3, below, together with information on the issuing authority, the kingdom, the regnal year (available only for the coinage of Pumayaton), the denomination, the accession number and the bibliographical reference.[1]

1 In Table 3, the following abbreviations have been used: a) for the metal analysis: n.d. = not detected b) for the museums and the collections that kindly gave their permission to study the numismatic material: DAC Nicosia = Department of Antiquities of Cyprus, Cyprus Museum; DAC Larnaca = Department of Antiquities of Cyprus, Larnaca District Museum; DAC Idalion = Department of Antiquities of Cyprus, Local Museum of Ancient Idalion; BOCCF Coll. = Bank of Cyprus Cultural Foundation collection; BOCCF Tsiapra-Pierides = Bank of Cyprus Cultural Foundation, Tsiapra-Pierides Collection. The coins from the Bank of Cyprus Cultural Foundation collection have been published in Iacovou 1994, Zapiti and Michaelidou 2008; the Tsiapra-Pierides collection has been published by Michaelidou and Zapiti (2002: 316–327). The reference column directs the reader to the references in Markou (2011: 99–131), where further information on the provenance on each coin can be found.

Table 3. The results of pXRF analysis of gold coins from Cyprus.

No	Kingdom	King	Date	Denomination	Museum/ Collection	Au	Ag	Cu	Pb	Sn	Fe	Pd	Reference
1	Kition	Milkyaton		1/2 stater (4.15 g)	BOCCF coll., 1998-03-03	99.2 ± 0.1	0.5 ± 0.05	n.d	0.09 ± 0.01	n.d	0.07 ± 0.01	0.08 ± 0.01	Markou 2011, 12
2	Kition	Milkyaton or Pumayaton		1/10 stater (0.83 g)	DAC, Larnaca, HC 68	99.6 ± 0.1	n.d	n.d	0.1 ± 0.01	n.d	0.2 ± 0.03	0.06 ± 0.01	Markou 2011, 40
3	Kition	Milkyaton or Pumayaton		1/10 stater (0.83 g)	DAC, Nicosia, 1933/III-18/2	99.7 ± 0.1	n.d	n.d	0.1 ± 0.01	n.d	0.08 ± 0.01	0.07 ± 0.01	Markou 2011, 26
4	Kition	Milkyaton or Pumayaton		1/10 stater (0.80 g)	BOCCF coll., 1984-01-25	98.9 ± 0.1	0.8 ± 0.05	n.d	0.1 ± 0.01	n.d	0.06 ± 0.01	0.06 ± 0.01	Markou 2011, 31
5	Kition	Milkyaton or Pumayaton		1/10 stater (0.81 g)	BOCCF, Tsiapra, 433	99.5 ± 0.1	0.3 ± 0.03	n.d	0.09 ± 0.01	n.d	n.d	0.07 ± 0.01	Markou 2011, 23
6	Kition	Pumayaton	?	1/2 stater (4.16 g)	DAC, Nicosia, 1953/viii-12/1	99.1 ± 0.1	0.4 ± 0.05	n.d	0.1 ± 0.01	n.d	0.1 ± 0.01	0.07 ± 0.01	Markou 2011, 186
7	Kition	Pumayaton	23	1/2 stater (4.15 g)	DAC, Larnaca, HC 65	96.9 ± 0.2	2.1 ± 0.1	n.d	0.09 ± 0.01	0.06 ± 0.01	n.d	0.09 ± 0.01	Markou 2011, 81
8	Kition	Pumayaton	23	1/2 stater (4.10 g)	BOCCF coll., 1993-02-01	96.7 ± 0.2	2.7 ± 0.1	n.d	0.2 ± 0.02	0.09 ± 0.01	0.2 ± 0.02	0.08 ± 0.01	Markou 2011, 87
9	Kition	Pumayaton	23	1/2 stater (4.16 g)	BOCCF, Tsiapra, 434	97.4 ± 0.2	2.3 ± 0.1	n.d	0.09 ± 0.01	0.07 ± 0.01	n.d	0.1 ± 0.01	Markou 2011, 90
10	Kition	Pumayaton	25	1/2 stater (4.09 g)	BOCCF, Tsiapra, 435	97 ± 0.1	2.8 ± 0.1	n.d	0.1 ± 0.01	n.d	n.d	0.08 ± 0.01	Markou 2011, 96

No	Kingdom	King	Date	Denomination	Museum / Collection	Au	Ag	Cu	Pb	Sn	Fe	Pd	Reference
11	Kition	Pumayaton	30	1/2 stater (4.16 g)	DAC, Larnaca, HC 64	97.2 ± 0.2	2.5 ± 0.1	n.d	0.09 ± 0.01	n.d	0.07 ± 0.01	0.08 ± 0.01	Markou 2011, 151
12	Kition	Pumayaton	32	1/2 stater (4.13 g)	DAC, Nicosia, 1957/II-14/1	97.1 ± 0.2	2.6 ± 0.1	n.d	0.1 ± 0.01	0.07 ± 0.01	n.d	0.07 ± 0.01	Markou 2011, 156
13	Kition	Pumayaton	40	1/2 stater (4.14 g)	DAC, Larnaca, HC 67	97.1 ± 0.2	2.5 ± 0.1	n.d	0.1 ± 0.01	0.06 ± 0.01	0.1 ± 0.01	0.08 ± 0.01	Markou 2011, 168
14	Kition	Pumayaton	40	1/2 stater (4.15 g)	DAC, Nicosia, 1949/XII-22/1	98.3 ± 0.2	1.4 ± 0.05	n.d	0.09 ± 0.01	n.d	0.1 ± 0.01	0.09 ± 0.01	Markou 2011, 160
15	Kition	Pumayaton	40	1/2 stater (4.11 g)	DAC, Nicosia, A571	97.7 ± 0.1	2 ± 0.05	n.d	0.1 ± 0.01	0.07 ± 0.01	n.d	0.08 ± 0.01	Markou 2011, 161
16	Kition	Pumayaton	40	1/2 stater (4.14 g)	BOCCF, Tsiapra, 436	97.8 ± 0.1	2 ± 0.1	n.d	0.09 ± 0.01	n.d	n.d	0.09 ± 0.01	Markou 2011, 159
17	Kition	Pumayaton	46	1/2 stater (4.10 g)	DAC, Nicosia, LH 9	97.1 ± 0.2	2.6 ± 0.1	n.d	0.1 ± 0.01	n.d	0.07 ± 0.01	0.07 ± 0.01	Markou 2011, 183
18	Kition	Pumayaton	46	1/2 stater (4.11 g)	DAC, Larnaca, HC 66	97.6 ± 0.1	2.1 ± 0.1	n.d	0.09 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	Markou 2011, 177
19	Salamis	Evagoras I		1/4 stater (2.05 g)	BOCCF coll., 1985-02-01	92.2 ± 0.3	6.1 ± 0.2	1.1 ± 0.1	0.1 ± 0.01	0.1 ± 0.01	0.3 ± 0.03	0.08 ± 0.01	Markou 2011, 194
20	Salamis	Evagoras I		1/10 stater (0.64 g)	DAC, Nicosia, A19	94.3 ± 0.2	5.2 ± 0.1	n.d	0.1 ± 0.01	0.1 ± 0.01	0.2 ± 0.02	0.06 ± 0.01	Markou 2011, 234

No	Kingdom	King	Date	Denomination	Museum/ Collection	Au	Ag	Cu	Pb	Sn	Fe	Pd	Reference
21	Salamis	Evagoras I		1/10 stater (0.71 g)	DAC, Nicosia, A95	91.6 ± 0.3	6.8 ± 0.1	1.2 ± 0.1	0.1 ± 0.01	0.1 ± 0.01	0.09 ± 0.01	0.06 ± 0.01	Markou 2011, 248
22	Salamis	Evagoras I		1/10 stater (0.60 g)	DAC, Nicosia, HC 22	89.7 ± 0.3	6.9 ± 0.1	2.6 ± 0.2	0.1 ± 0.01	0.1 ± 0.01	0.5 ± 0.05	0.06 ± 0.01	Markou 2011, 250
23	Salamis	Evagoras I		1/10 stater (0.73 g)	DAC, Nicosia, HC 20	88.4 ± 0.4	9 ± 0.2	1.9 ± 0.1	0.09 ± 0.01	0.1 ± 0.01	0.4 ± 0.03	0.06 ± 0.01	Markou 2011, 252
24	Salamis	Evagoras I		1/10 stater (0.54 g)	DAC, Nicosia, A85	90.7 ± 0.4	4.9 ± 0.2	3.9 ± 0.2	0.09 ± 0.01	0.1 ± 0.01	0.2 ± 0.02	0.06 ± 0.01	Markou 2011, 258
25	Salamis	Evagoras I		1/10 stater (0.61 g)	DAC, Nicosia, 1935/II-13/1	89.4 ± 0.4	7.7 ± 0.2	2.2 ± 0.1	0.1 ± 0.01	0.2 ± 0.02	0.3 ± 0.02	0.06 ± 0.01	Markou 2011, 266
26	Salamis	Evagoras I		1/10 stater (0.72 g)	BOCCF coll., 1984-01-13	91.7 ± 0.3	7 ± 0.2	0.9 ± 0.1	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.07 ± 0.01	Markou 2011, 204
27	Salamis	Evagoras I		1/10 stater (0.72 g)	BOCCF, Tsiapra, 421	93.7 ± 0.3	5.1 ± 0.2	0.9 ± 0.1	0.09 ± 0.01	0.1 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	Markou 2011, 236
28	Salamis	Evagoras I		1/10 stater (0.54 g)	BOCCF, Tsiapra, 424	92.5 ± 0.3	6.7 ± 0.2	0.4 ± 0.03	0.09 ± 0.01	0.2 ± 0.02	n.d	0.06 ± 0.01	Markou 2011, 262
29	Salamis	Evagoras I		1/10 stater (0.62 g)	BOCCF, Tsiapra, 423	89.8 ± 0.3	7.3 ± 0.2	2.5 ± 0.1	0.09 ± 0.01	0.2 ± 0.02	n.d	0.06 ± 0.01	Markou 2011, 275
30	Salamis	Evagoras I		1/10 stater (0.66 g)	BOCCF, Tsiapra, 422	88.8 ± 0.3	8.6 ± 0.2	2.2 ± 0.1	0.09 ± 0.01	0.2 ± 0.02	n.d	0.06 ± 0.01	Markou 2011, 279
31	Salamis	Evagoras I		1/20 stater (0.24 g)	DAC, Nicosia, A84	89.3 ± 0.4	7.4 ± 0.2	2.8 ± 0.1	0.1 ± 0.01	0.2 ± 0.02	0.1 ± 0.01	0.06 ± 0.01	Markou 2011, 285

No	Kingdom	King	Date	Denomination	Museum/ Collection	Au	Ag	Cu	Pb	Sn	Fe	Pd	Reference
32	Salamis	Nikokles		1/3 stater (2.41 g)	BOCCF coll., 1998-05-01	98.6 ± 0.1	1 ± 0.1	n.d	0.1 ± 0.01	n.d	0.2 ± 0.02	0.08 ± 0.01	Markou 2011, 296
33	Salamis	Nikokles		1/12 stater (0.69 g)	DAC, Nicosia, 1958/II-13/1	98.2 ± 0.2	1.1 ± 0.1	n.d	0.1 ± 0.01	n.d	0.5 ± 0.05	0.08 ± 0.01	Markou 2011, 332
34	Salamis	Nikokles		1/12 stater (0.67 g)	DAC, Nicosia, 1952/X-43/2	98.8 ± 0.1	0.6 ± 0.05	n.d	0.1 ± 0.01	0.09 ± 0.01	0.3 ± 0.03	0.08 ± 0.01	Markou 2011, 338
35	Salamis	Nikokles		1/12 stater (0.67 g)	BOCCF coll., 1989-01-01	98.4 ± 0.1	1.1 ± 0.1	n.d	0.09 ± 0.01	n.d	0.3 ± 0.02	0.08 ± 0.01	Markou 2011, 334
36	Salamis	Nikokles		1/12 stater (0.69 g)	BOCCF, Tsiapra, 425	99.3 ± 0.2	0.5 ± 0.04	n.d	0.08 ± 0.01	n.d	0.06 ± 0.01	0.07 ± 0.01	Markou 2011, 352
37	Salamis	Nikokles or Evagoras II		1/12 stater (0.65 g)	DAC, Nicosia, A541	97.5 ± 0.2	2.2 ± 0.1	n.d	0.09 ± 0.01	n.d	0.07 ± 0.01	0.09 ± 0.01	Markou 2011, 363
38	Salamis	Evagoras II		1/8 stater (0.95 g)	DAC, Nicosia, A 542	89.7 ± 0.3	5.2 ± 0.1	4.8 ± 0.1	0.09 ± 0.01	0.1 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	Markou 2011, 372
39	Salamis	Evagoras II		1/12 stater (0.72 g)	DAC, Nicosia, A 540	96.5 ± 0.2	2.9 ± 0.1	n.d	0.1 ± 0.01	0.2 ± 0.02	0.2 ± 0.02	0.06 ± 0.01	Markou 2011, 379
40	Salamis	Evagoras II		1/12 stater (0.65 g)	BOCCF coll., 1984-01-16	98.4 ± 0.2	1.3 ± 0.1	n.d	0.09 ± 0.01	n.d	0.07 ± 0.01	0.08 ± 0.01	Markou 2011, 393
41	Salamis	Evagoras II		1/12 stater (0.64 g)	BOCCF, Tsiapra, 426	98.2 ± 0.2	1.4 ± 0.1	n.d	0.09 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	Markou 2011, 404

No	Kingdom	King	Date	Denomination	Museum/ Collection	Au	Ag	Cu	Pb	Sn	Fe	Pd	Reference
42	Salamis	Pnytagoras		Stater (8.35 g)	BOCCF coll., 1988-05-01	98.7 ± 0.2	1.1 ± 0.1	n.d	0.09 ± 0.01	n.d	0.06 ± 0.01	0.1 ± 0.01	Markou 2011, 416
43	Soloi	Eunostos		1/12 stater (0.66 g)	DAC, Nicosia, HC 93	97.5 ± 0.2	2.1 ± 0.1	n.d	0.1 ± 0.01	n.d	0.2 ± 0.02	0.07 ± 0.01	Markou 2011, 452
44	Soloi	Eunostos		1/12 stater (0.66 g)	DAC, Nicosia, no acc. no.	96.3 ± 0.2	3.3 ± 0.1	n.d	0.1 ± 0.01	0.09 ± 0.01	0.1 ± 0.01	0.06 ± 0.01	Markou 2011, 453
45	Soloi	Eunostos		1/12 stater (0.68 g)	BOCCF coll., 1984-01-27	97.1 ± 0.2	2.5 ± 0.1	n.d	0.09 ± 0.01	0.09 ± 0.01	0.1 ± 0.01	0.07 ± 0.01	Markou 2011, 454
46	Uncertain	Sa(-) or Sta(-)		1/2 stater (4.17 g)	DAC, Nicosia, 1945/VII-19/1	98.2 ± 0.2	1.5 ± 0.1	n.d	0.1 ± 0.01	n.d	0.1 ± 0.01	0.1 ± 0.01	Markou 2011, 1
47	Uncertain	Sa(-) or Sta(-)		1/2 stater (4.16 g)	BOCCF, Tsiapra, 441	99 ± 0.1	0.8 ± 0.05	n.d	0.08 ± 0.01	n.d	n.d	0.1 ± 0.01	Markou 2011, 4
48	Uncertain	Sa(-) or Sta(-)		1/5 stater (1.53 g)	DAC, Nicosia, A 562	92.4 ± 0.3	7.1 ± 0.2	0.08 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.06 ± 0.01	Markou 2011, 8

The 48 gold coins analyzed in the present study show a percentage in gold that varies between 88.4 % (no. 23) and 99.7% (no. 3), while 33 out of 48 coins (c. 69%) show a percentage of gold that exceeds 96% (Fig. 1, below). The coins of the kings of Kition have a gold content that varies from c. 96.1% to 99.7%. The gold content in the coins of the kings of Salamis varies from 88.4% to 99.3%, as the assemblage of coins from Salamis includes a group which has a noticeable lower percentage in gold (nos. 19–31). The coins issued by the king of Soloi, Eunostos, have a rather high gold content, above 96%, while those issued by the king Sa(-) or Sta(-), who ruled in an unidentified kingdom, show a percentage that varies from 92.3% to 99%.

The percentage of silver and mainly copper is low in most coins studied. Such low levels of silver and copper may indicate the use of refined gold. Native gold is always naturally alloyed with silver (Moorey 1994: 217). The relative concentrations may vary greatly. For example native gold from the Pactolus river contains about 17–30% silver (Cowell and Hyne 2000: 172), while in Egyptian ore deposits concentrations of silver in the range of 10–25% have been reported (Rehren *et al.* 1996: 6). Gold from placer deposits is usually of higher purity. Copper occurs only as an impurity in native gold and it is almost totally absent from alluvial placer deposits (Rehren *et al.* 1996: 6). If silver was added to the gold then there should be a positive correlation between the amount of silver and that of lead: refined silver is produced through cupellation and traces of lead always accompany the precious metal (Barrandon 1988: 7). Unfortunately, the concentration of lead in this set of analysis does not allow the investigation of such a correlation. Lead (Pb) is a common natural impurity of native gold (Ogden 1982: 21) and in the studied coins is present in levels ranging between 0.08 and 0.2% but the vast majority contains between 0.09 and 0.1%.

As clearly shown in figure 2, the percentage of copper increases significantly in the coins which have a silver content that is above 5%. As noted above, although copper may be present in the natural alloy of gold and silver, called electrum (Moorey 1994: 217), it is usually found as an impurity. It is clear that in the case of this group of analyzed coins the copper was deliberately added. This may have been done in an effort to counteract the whitening effect resulting by the increased amount of silver, which may have also been deliberately added to the gold. (see below). In other words it may indicate that the copper was added to "fix" the colour of the alloy used to produce the coins, so that their lower gold content would not be visually detectable. Such a practice was known already in the Early Bronze Age (Tylecote 1987: 80–82, fig. 81).

Iron was detected in the vast majority of the studied coins in levels ranging between 0.03 and 0.5%. Iron in such small concentrations is common in most native gold (Ogden 1982: 19). In the case of the present study, however, in which the chemical composition is determined by pXRF, a non-destructive analytical

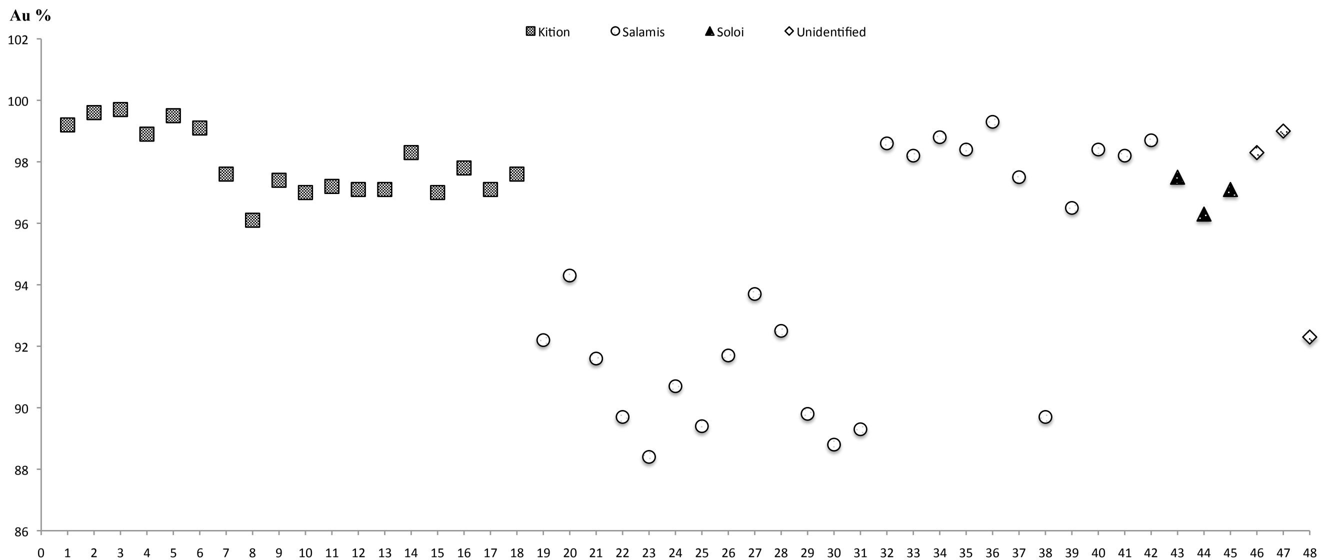

Figure 1. Percentage (%) of gold (Au) in the gold coins from Cyprus.
The numbers on the horizontal axis correspond to the catalogue number of the coin in Table 3.

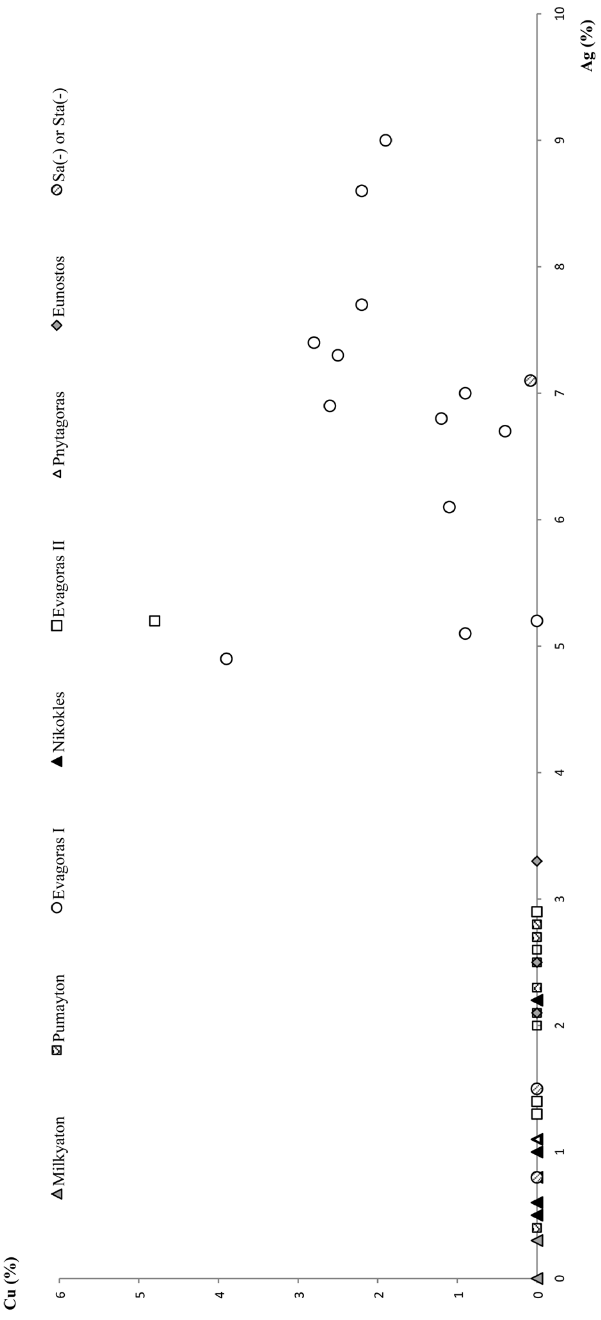

Figure 2. The concentration of silver (Ag) in weight percent versus the concentration of copper (Cu) in weight % in the gold coins from Cyprus.

technique which provides a surface analysis, the iron may be attributed to minute surface deposits rich in iron not related to the alloy (Cowell and Hyne 2000: 173).

Moreover, palladium was detected in all coins in levels ranging between 0.06 and 0.1%, while tin was detected in 27 coins in levels ranging between 0.06 and 0.2%. Both elements are often associated with native gold from alluvial/placer deposits (Ogden 1982: 21; Tylecote 1987: 79).

On the various issuing authorities and kings, the following observations can be made.

3.1. Kition

The coins from Kition analyzed in the current study have been issued by two kings: there is one gold hemistater issued by the king Milkyaton (no. 1), four 1/10 gold staters that are uninscribed and have been the object of a debate on whether to place them amongst the issues of Milkyaton or those of his successor Pumayaton (nos. 2–5), and 13 gold hemistaters that can be securely attributed to Pumayaton (nos. 6–18).

The hemistater of Milkyaton has a very high percentage of gold (98.5%). The four 1/10 staters are also very pure in gold, varying between 98.2% and 99%. The high percentage of gold on those coins reinforces the hypothesis that the 1/10 and the 1/20 staters with no inscription bearing the head of a young beardless Heracles on the obverse and a lion devouring a stag on the reverse, were probably issued by Milkyaton (Markou 2011: 207; 266). Finally, on the hemistaters of Pumayaton the percentage of gold varies between 96.1% and 98.4%. The regnal years that appear on the reverse of the coinage of Pumayaton help us enquire on concordances between percentage of gold and regnal year (Fig. 3).

From the 13 hemistaters of Pumayaton, only one has the regnal year date off flan, and it has not been possible to place it in a specific year via the coin die study, but it has a very high percentage of gold (99.1%) (Markou 2011: 111, no. 186). The remaining 12 coins are all dated from the regnal year 23 down to the regnal year 46; three coins are dated in the regnal year 23 and bear a percentage in gold that varies from 96.1 to 97.6%. The years 25, 30, and 32 are represented by one coin each but all of them have a similar percentage of gold of c. 97%. The four coins dated in the 40th year of Pumayaton's reign present more variations in the percentage of gold that varies from 97 to 98.3%. The two coins that bear on the reverse the regnal year 46, have a percentage of gold around 97%.

For the kings of Kition, the percentage of silver varies between below the detection limit and 2.8%. No copper was detected in the studied assemblage. The low percentage of silver in the majority of the Kition coins may indicate the use of natural unrefined gold, which always contains some silver. It is also possible that silver was added to refined gold in order to increase the hardness of the alloy. As pointed out by Barrandon, it is very difficult to differentiate between a natural and a deliberate alloy of gold and silver based on their percentages alone (Barrandon

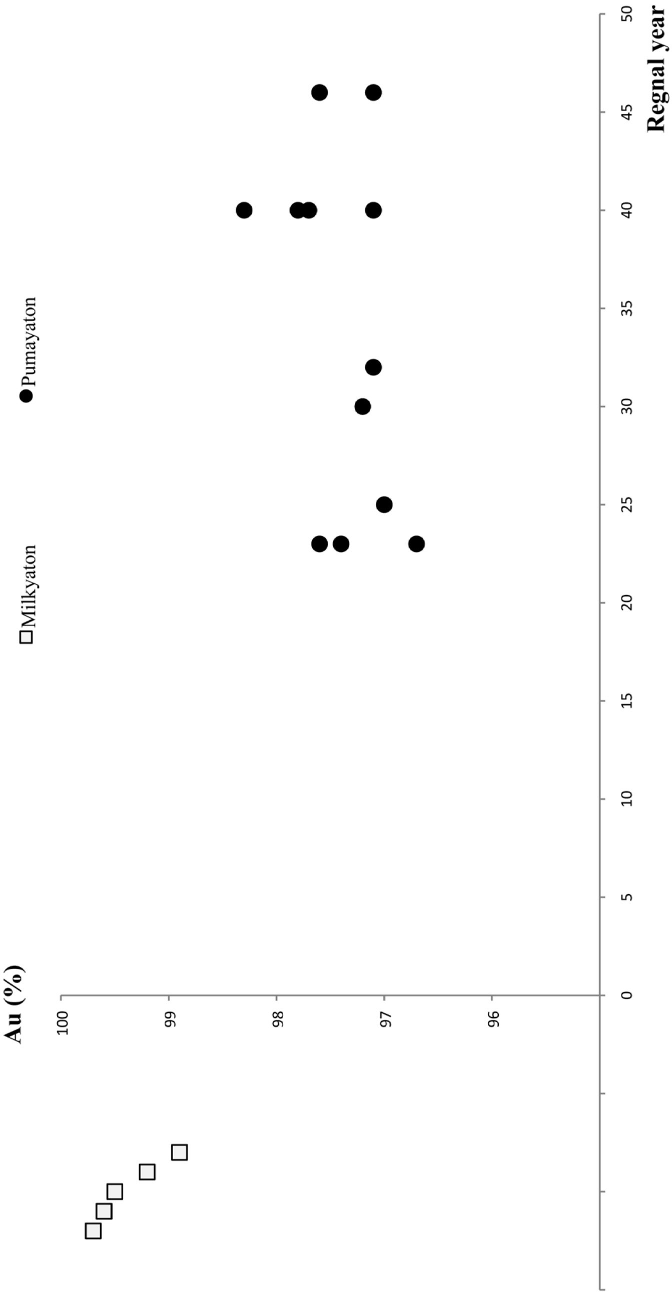

Figure 3. Percentage (%) of gold (Au) in the coins of Milkyaton and his successor Pumayaton. The horizontal axis refers to the regnal year of Pumayaton.

1988: 7). The two coins (nos 2 and 3), on the other hand, which contain no silver at all, were clearly made of refined gold (Moorey 1994: 217). The refinement of gold through the process of cementation had already been mastered by this time. Excavations at Sardis have brought to light the remains of a workshop dedicated to the refinement of electrum dating to the sixth century BC (Ramage and Craddock 2000: 10).

3.2. Salamis

From the 24 analyzed coins of Salamis (nos. 19–42), some have a high percentage of gold that goes up to 99.3%, while in other cases the percentage of gold is as low as 88.4%. The great majority of the coins studied was issued by king Evagoras I (c. 55%), while the remaining coins belong to the coin production of three of his successors, Nikokles (five coins), Evagoras II (four coins) and Pnytagoras (one coin). Finally one coin could have been issued either by Nikokles or by Evagoras II (Fig. 4).

The coins issued by king Evagoras I distinctively present a lower gold content, compared not only to the other issuing authorities of Salamis, but also to the other kings and kingdoms studied. The percentage of gold varies from 88.4 to 94.3%. The amount of silver and copper in those same coins is not negligible: silver varies between 4.9 and 9% and copper between 0.4 and 3.9% (Fig. 5, below). As argued above, the presence of the two elements in significantly higher percentages than in other coins of the same kingdom or contemporary coins of other kingdoms leads us to the conclusion that they have been deliberately added. The coins of Nikokles have a higher percentage of gold in their composition, which ranges from 98.2 up to 99.3%; the percentage of silver is very low (from 0.5 to 1.1%) while no traces of copper have been detected.

The coins of Evagoras II form a rather complicated case. The 1/12 staters (nos. 39–41) have a high percentage of gold (from 96.5% to 98.4%) and a low percentage of silver (from 1.3% to 2.9%). Copper was not detected. On the contrary, the 1/8 stater has a rather unusual composition: the percentage of gold is as low as 89.7%, while the percentages of silver (5.2%) and copper (4.8%) are especially elevated.

The only example of the so called "intermediary" group of coins (no. 37) that could be placed amongst the latest issues of Nikokles or the earliest issues of Evagoras II (Markou 2011: 170–171) has a high concentration in gold (97.5%) but does not provide any additional elements that could suggest an attribution to the one or to the other king of Salamis.

Finally, the gold stater of Pnytagoras has a high concentration in gold (98.7%) and a very low amount of silver (1.1%), while no copper was detected.

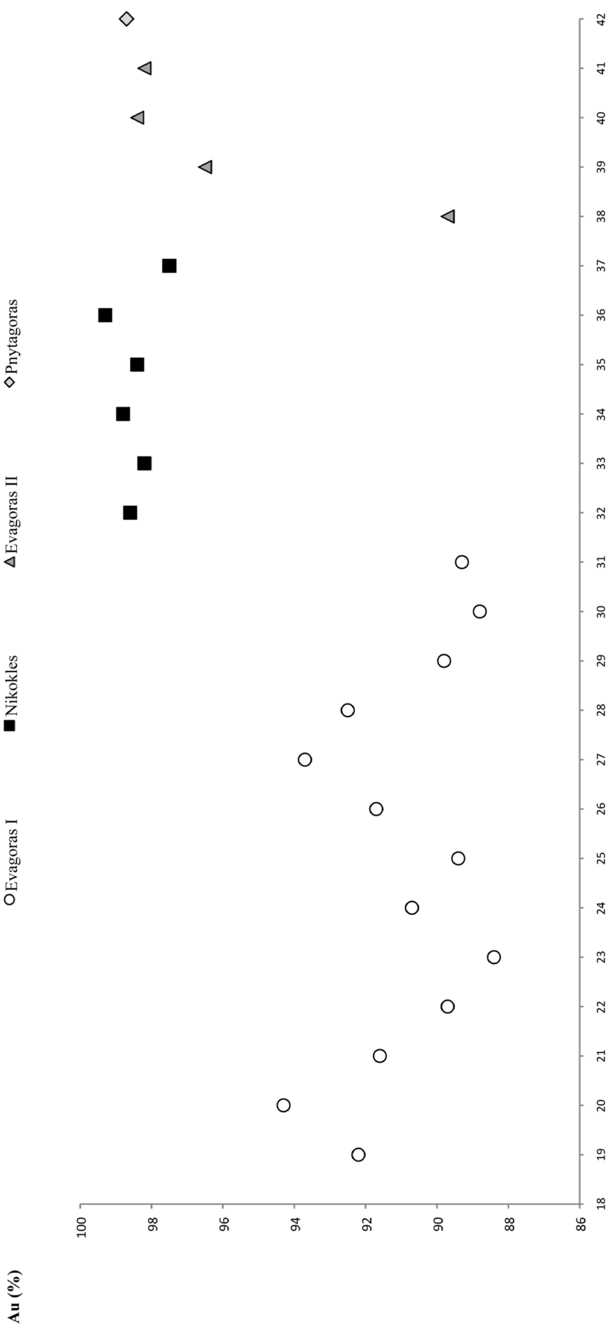

Figure 4. Percentage (%) of gold (Au) in the coins of the kings of Salamis.

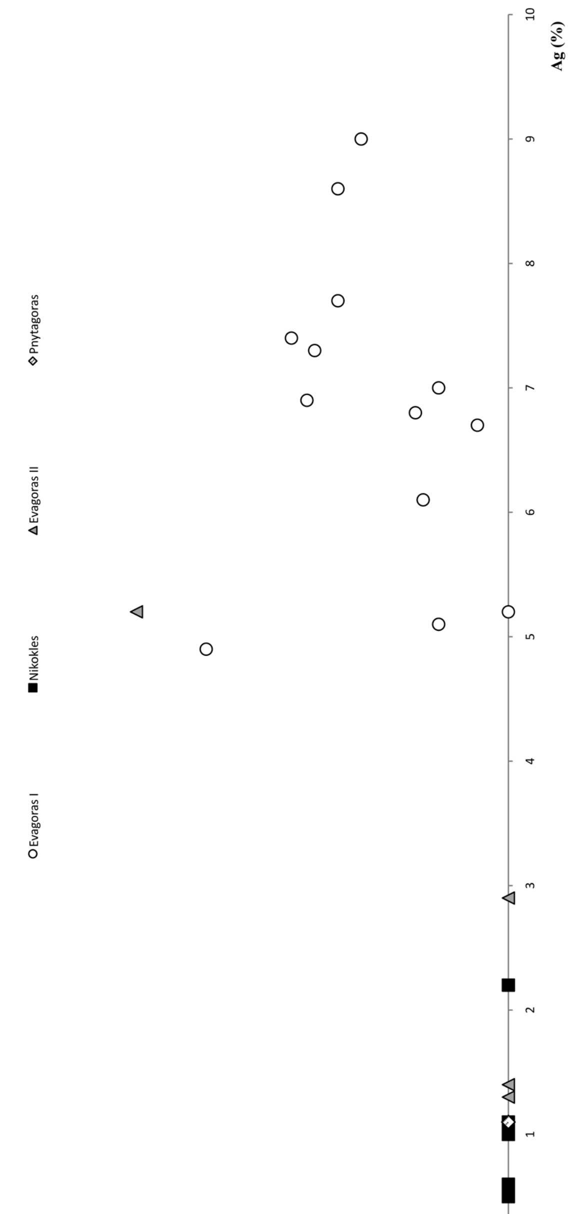

Figure 5. Percentage (%) of silver (Ag) and copper (Cu) in the coins of the kings of Salamis.

3.3. Soloi

Three 1/12 staters issued by king Eunostos of Soloi have been analyzed. All the three coins have a high percentage of gold (from 96.3 to 97.5%) and a low percentage of silver (from 2.1 to 3.3%), while no copper was detected.

3.4. Unidentified kingdom, king Sa(-) or Sta(-)

The three gold coins attributed to king Sa(-) or Sta(-) of an unidentified kingdom present variations in their chemical composition that could be linked to the different denominations studied. The two hemistaters have a high percentage of gold (98.2% and 99%) and a low percentage of silver (0.8% and 1.5%) while the 1/5 stater has a low percentage of gold (92.3%) and a high percentage of silver (7.1%), with some traces of copper (0.08%).

4. The Origin of the Gold

What was the origin of the gold (and silver) used to produce these coins? Were gold and silver locally available or did they have to be imported? The mineral wealth of Cyprus is considerable. All the economically significant minerals are located in the Troodos mountain range which covers an area of about 3,200 square kilometers, that is to say more than one third of the whole island (Constantinou 1992: 332). As Troodos is one of the best preserved ophiolite complexes in the world, its geology has been thoroughly and systematically studied over the last decades (Zomeni 2006). Massive copper sulphide deposits, mainly composed of pyrite and chalcopyrite, are located in the periphery of the mountain range in the geological formation known as the pillow lavas (Constantinou 1992: 334–335). Because of these deposits Cyprus is even today considered to be one of the richest countries in copper per surface area in the world (Constantinou 1982: 15). In modern times silver and gold were also exported from Cyprus.

According to the records of the Cyprus Mines Authority, between 1935 and 1982 Cyprus exported just over 4.5 tons of gold and 26.3 tons of silver (http://www.moa.gov.cy/moa/Mines/MinesSrv.nsf/all/8586AC4EB8686A2EC22574EA0031B407/$file/Gold%20and%20 Silver%20exports.pdf?openelement). This may lead someone to the conclusion that, in Antiquity, Cyprus produced precious metals as well as copper. In fact this was not the case. By modern standards, gold and silver are present in exceptionally high values (up to 286 g/ton of gold and 466 g/ton of silver) in a geological deposit that modern miners called Devil's mud. It was given this name because of its extremely corrosive nature, a result of the high percentage of sulphuric acid it contains (Bear 1963: 184).

The precious metals, however, are in colloidal form and therefore they are not visible nor can they be collected by panning (Bear 1963: 185). They would have had to be extracted through a series of fairly complex metallurgical procedures, none of which are recorded on the island. Furthermore, it is clear that the geological stratum rich in gold and silver was of no interest to the ancients: their galleries usually cut through it, in an effort to reach the copper deposits below (Bear 1963: 186). On the contrary, in South West Spain there is ample evidence that in the Iron Age and in the Roman period silver production was based on the exploitation of similar deposits of argentiferous jarosites (Salkield 1982: 139; Rothenberg and Blanco Freijeiro 1981: 171).

That gold was most probably not produced locally is reflected in the ancient sources which often refer to the copper mines of Cyprus and to Cypriot copper but never to gold mines of Cyprus or Cypriot gold. Cypriot copper is mentioned in the ancient sources already from the nineteenth century BC (Knapp 2011: 250). By contrast, the only reference to gold mines in Cyprus is found in a passage attributed to Pseudo-Aristotle (Arist. *fr. Ph.* 266; Wallace and Orphanides 1990: 54). In other words, the geological, the archaeological and the textual evidence currently available, indicate that gold was not mined on the island.

The Cypriot kings would therefore have had to import gold from sources in the neighboring regions. The most significant gold deposits in the Eastern Mediterranean are those of Egypt and Nubia (Müller and Thiem 1999: 36–41; Klemm and Klemm 1989; Klemm *et al.* 2001). Important deposits of gold are also located in Anatolia, within Lydia, the land of King Croesus well known in antiquity for his wealth (Ramage 2000: 19), along the Black Sea coast in the Pontus area (ancient Colchis, where Jason and the Argonauts sought the Golden Fleece) and elsewhere (Bayburtoğlu and Yildirim 2008: 43–45). In the Aegean, auriferous deposits are known from the Cycladic islands of Siphnos (Wagner and Weisgerber 1985) and Thasos (Wagner and Weisgerber 1988), in Macedonia (Photos *et al.* 1989) and Thrace (Williams and Ogden 1994: 13). In the Balkans there are significant gold deposits in Apuseni Mountains and in the South Carpathians of Romania (Neacşu *et al.* 2009: 50) and in Bulgaria where the remains of a prehistoric gold mine have recently been recorded (Popov *et al.* 2011). Ancient gold mines have also been recorded at Sakdrissi in Georgia (Stöllner and Gambashidze 2011). Several gold sources are located within the boundaries of Persia and its neighbouring regions such as Afghanistan and Bactria and they would most certainly have been exploited in antiquity (Ross 2001: 68–67). The kings of Persia, according to Herodotus (3.94–102), apart from the gifts and the tribute in gold they received from Lydia, Ethiopia, Libya, and Thrace, even received tribute in gold from India (Ross 2001: 68–67). There are no gold sources in Mesopotamia, Syria or Palestine but interestingly, according to Moorey, Neo Assyrian sources indicate that "the most considerable amounts of gold were held by Tyre, Musasir and smaller quantities by Carchemish, Damascus, and Jerusalem" (Moorey 1994: 220). This gold must have been accumulated through warfare or trade. Some may even have been brought by the Phoenicians from lands far away such as the Iberian Peninsula which is rich in gold, with the most significant deposits concentrated in the regions of Porto in Portugal, and Galicia, Extremadura and Almeria in Spain (Lehrberger 1995: 119).

The Cypriot kings could either have directly imported gold from one of the regions which possessed gold deposits (most likely Egypt or Lydia) or through intermediaries such as the Phoenicians, who brought gold to the Eastern Mediterranean both from the West and from the East. The gold would have been exchanged for Cypriot copper (Kassianidou 2012: 245), as well as other locally available commodities such as wood (especially in the case of Egypt).

5. Historical Commentary

The history of the Cypriot kingdoms of the fourth century is relatively better documented, compared to that of the previous century (Markou 2013: 117–129). At the beginning of the fourth century, the sources mention the so-called "Cypriot War". This lasted for a decade, c. 390–380 BC, (Diod. 14.98.3; Tuplin 1983: 182; Shrimpton 1991: 1–3; Briant 1996: 667–668) and involved most of the kingdoms as well as the Persian king and his allies. Around the 350s there are references to the participation of the Cypriot kings in the "Great Satraps Revolt" (Diod. 16.40.5). Almost twenty years later Alexander III included Cyprus in his newly established empire (333/2 BC) (Jacoby 1980: 20), and from 321 onwards, the island became one of the most desired conquests amongst Alexander's successors. This was surely because of its rich natural resources of wood (Meiggs 1982: 379) and copper (Kassianidou 1996: 747; Kassianidou 2012: 233–235) but also because of its strategic position in the Eastern end of the Mediterranean basin in close proximity to Cilicia, Phoenicia and Egypt. Ptolemy I was the one who eventually prevailed and who proceeded to demolish the Cypriot kingdoms and kingship in the period 321–309. He established Ptolemaic control from c. 294 BC and this lasted until 58 BC.

The epigraphical documents are even scarcer than the texts, which leaves the archaeological documentation and the numismatic production of the kings of Cyprus as the principal sources for the history of the period in question. The coinage, official document of the issuing authorities, and in the case of Cyprus of the kings themselves, varies in iconographical choices and legends. Furthermore, the more or less systematic minting of gold coins from various kings and kingdoms during the entire fourth century, is a rare and interesting phenomenon. This applies not only for Cyprus, but also for the Greek world and the surrounding areas in general, at least before the rise of Philip II to the throne of Macedonia.

The pXRF analysis confirmed that the coins issued by the kings of Cyprus have a high percentage in gold that exceeds 97%. Exceptions to this observation are the gold coins issued by Evagoras I which have a low percentage of gold and an augmented percentage of silver and mainly copper. The same conclusion was reached after the analysis of coins of the same king in Paris (Markou 2011: 217–218).

Evagoras I took the throne of Salamis in 411 and, although according to Isocrates he started to restructure his kingdom from early on (Isoc. 9, 47), he was actually preparing for war. The so-called "Cypriot War" was caused by his desire for expansion that led at least three other kings to react: they approached the Great

King of Persia in order to ask for his help against Evagoras I (Diod. 14.98.2). Additional information on this war is attested in the famous trophy of Milkyaton, an inscription dated to 391, where a testimony of an alliance between Evagoras I and the Paphians, otherwise unknown, is recorded (Yon and Sznycer 1991: 811). In the beginning Evagoras I appeared strong and led the war with the help of several allies and many resources (Diod. 15.2.3 ; Theopomp. *fr.* 103.111). At some point, however, after the response of the Great King to the cry for help from the other Cypriot kings and certainly after the first confrontation of Evagoras I and the Persian king in the battle of Kition, c. 387/6 BC, (Diod. 15.3–6; Shrimpton 1991: 2), Evagoras I appeared suddenly to be in need of ships, allies and money (Diod. 15.3.3–4). According to Diodorus, he left his son Pnytagoras in charge of Salamis and of the other areas under his control, went to Egypt and presented himself in person to king Hakoris, asking him for help. The pharaoh of Egypt, however, did not provide him with enough financial support and Evagoras ended up surrendering and losing the war (Diod. 15.8.1–4).

Markou suggested that some of the low quality gold coinage of Evagoras I could be dated in that moment of his reign, during which the need to finance the war required the minting of large amounts of money for the payment of mercenaries. His inability to secure enough financial support from Egypt, however, led Evagoras to perform a double manipulation of the minted coinage. He reduced the percentage of gold in the smaller denominations and at the same time he reduced the weight of the coins. The king of Salamis did all this in order to save on gold bullion and thus be able to produce a higher quantity of coins. As a result, of course, the coins he issued were of a lower quality (Markou 2011: 262).

The practice was not widespread in Cyprus. For example, it is interesting to observe the coins minted by his contemporary, the king of Kition, Milkyaton, which probably date to the same period, since the trophy mentioned above celebrates his first regnal year. Milkyaton had several advantages during the same time: he provided a harbour for the Persian fleet at Kition and was in a better standing with the Persians. This allowed him an ease of movement and eventually finances. Both sets of analysis show that the coinage minted by Milkyaton has a high percentage of gold. The purity of this coinage could be explained by the source of the gold used. Furthermore, the very high percentage of gold in the smaller uninscribed denominations could offer support to the hypothesis that they were minted by Milkyaton and not by his son and successor, Pumayaton (Markou 2011: 145 and 207). Pumayaton's reign is long as, according to the epigraphic and numismatic testimonies, he is attested to have ruled for more than 46 years (362/1 –313/2 BC) (Markou 2011: 282–283, figs. 138–139). As was the custom in Phoenicia, his coinage bears the regnal year on the reverse (Elayi 1989: 213; Elayi and Elayi 2004). This provides some important information on the volume of the coinage minted and the augmented or reduced amount of coins minted in a specific year, destined to cover specific needs. For example it has been confirmed that the important activity of the mint of Kition expressed through the augmented volume of gold hemistaters produced by Pumayaton in his thirtieth regnal year (333/2 BC), coincides with the siege of Tyre by Alexander III, achieved with the help of the kings of Cyprus. It could thus suggest the absence of Pumayaton from the siege and the preparations of the king of Kition to provide help to Tyre (Six 1883, 341; Destrooper-Georgiades 1991: 256; Markou 2011: 284). All the coins analyzed in the present study date from regnal year 23 (340/39 BC) of Pumayaton's reign onwards, and four out of thirteen coins from the fortieth regnal year (323/2 BC). The chemical composition of the coins, namely their gold content, as well as the other elements traced, do not provide any additional information on Pumayaton's economic policy.

On the contrary, a truly high percentage of gold is observed on the coinage of Nikokles, the son of Evagoras I and his successor to the throne of Salamis from 374/3 BC onwards; The same high percentage has been attested in the coins of the same king analyzed in Paris (Markou 2011, 218 and 269). The gold coins issued by Nikokles have high percentages of gold and they differentiate clearly from those of his father. This can be explained by the fact that the economic policy of Evagoras I had been totally abandoned after the degradation of the kingdom of Salamis as an outcome of the Cypriot war, and the defeat of Evagoras I (Isoc. 2, 33–34). Nikokles is often presented in a negative light in the literary sources. In fact his gold coinage, which is of exceptional quality (high percentage of gold and correct weight), clearly shows that Nikokles managed to initiate an impressive numismatic reform in Salamis, characterized by a new weight standard and a coinage of a high quality. He thus managed to stabilize, and then improve, the economy of his kingdom (Markou 2011: 269). The pXRF analysis of the five gold coins of Nikokles, confirm this hypothesis, since they all present a percentage of gold that exceeds 97%.

Nikokles was succeeded by Evagoras II. The gold coinage he minted while he was king at Salamis in the decade 361–351 BC, presents still rather high percentages in gold and does not allow any conclusive hypothesis on his economic policy. The pXRF analysis did allow nevertheless the analysis of a unique surviving specimen, a 1/8 gold stater attributed with several reservations to this king, because of the unusual weight and iconography (Markou 2011: 174). The composition of the alloy differentiates this issue from the other coins of the same king studied and adds an extra question mark to the problems of attribution and authenticity that have already been raised. Unfortunately, as long as there are no other surviving coins to compare to this coin, no additional remarks can be made at this point.

The last coin analyzed from Salamis, is a gold stater, the heaviest denomination produced, issued by king Pnytagoras in the period 352/1–333/2 BC. The stater has a very high percentage of gold and offers further support to the theory that in general the higher denominations seem to be purer in gold. This is probably because they would have been definitely and more strictly controlled once outside the territory of the issuing authority. The smaller fractions on the other hand present variations in the percentage of the gold more commonly, as the manipulation of the alloy—and of the weight—is more easily performed on the fractions (Markou 2011: 219). This is also visible on the gold coins of king Sa(-) or Sta(-), dated in the first half of the fourth century, whose kingdom is still unidentified but is definitely not Marion, as was suggested in the past (Markou 2006, 53). Although only three coins attributed to this king have been analyzed in this study, it seems that the percentage of gold is more important in the hemistaters while the smaller fractions present a lower percentage of gold, that could justify the same hypothesis, as it was also the case in the coin analysis in Paris (Markou 2011: 214).

Three coins of the last king of Soloi, Eunostos, were also included in this study. Eunostos is mentioned in the ancient texts during the rivalries of the Successors for the control of Cyprus, and seems to be the only king who overcame the hostility of Ptolemy I, since he married his daughter and probably survived (Athenaeus 13, 576 e). The coinage he issued while he was king of Soloi is dated in the last decades of the fourth century BC and has a high percentage of gold.

6. Conclusions

The pXRF analysis has confirmed that the kings of Cyprus produced a high quality coinage in gold and exploited the use of the other elements, such as silver or copper, maybe to harden the alloy and—at least in some cases—to economize in precious metal. As gold was not available in Cyprus, it must have arrived in the island from various destinations and in various forms throughout the fourth century, directly in the form of gold bullion, or indirectly in the form of gold objects.

Did Milkyaton obtain the metal for minting his gold coins directly from the Persians? Did Evagoras I obtain the gold for his coinage from the kings of Egypt? Did Pnytagoras and Eunostos produce their gold coinage with the metal that circulated in important quantities in Alexander's empire in the East, also in coined form, during his lifetime and after his death?

The pXRF method does not provide any information regarding the provenance of the gold used to produce the coins. Nevertheless, the results achieved through the use of this analytical technique are important and interesting. They lead to the conclusion that gold was not always abundant in Cyprus. Some Cypriot kings never issued gold coins, others performed manipulations of their gold coinage in order to face specific needs in a moment of crisis during their reign, and others performed numismatic reforms also through the refinement of both the weight and the alloy of their gold coinage, as is the case of Nikokles of Salamis.

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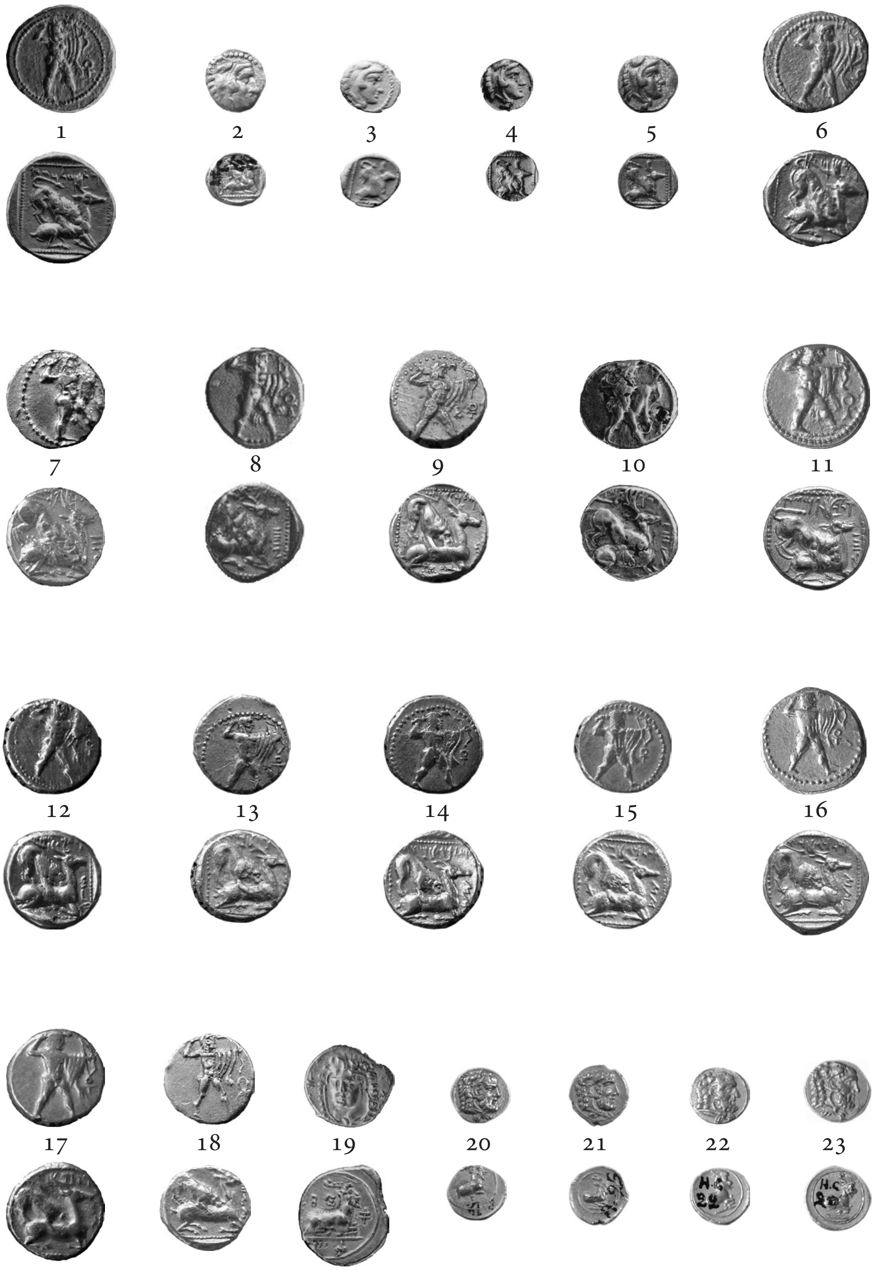
Plate 6



pXRF Analysis of Cypriot Gold Coins of the Classical Period

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