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Provenance, manufacturing and corrosion behavior of Ancient Hellenistic coins from Egypt

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Abstract – Some copper alloy coins of the Ptolemaic period from a private collection, providing valuable evidence for both archaeometric as well as materials science and corrosion studies, have been investigated. The coins were found in the ancient city of Bubastis, known as Tell Basta, in the Nile Delta, Egypt. The coins have been examined by optical microscopy for their metallurgical structure, analysed by X-ray fluorescence and Electron Dispersion Spectroscopy for their composition, and by X-ray diffraction for the characterisation of their corrosion products. An attempt has been made to remove part of their corrosion products by mild chemical cleaning procedures. In some areas the coins are heavily corroded by chlorides, however most of the inscriptions on the coins themselves are still decipherable. Assumptions are made on the coins provenance, the production period, the manufacturing technique and the burial environmental conditions.

I. INTRODUCTION

The coins are the earliest evidence of the economic activity of human beings. When early men started to have surplus produce, they felt need of exchanging goods. In the primitive society, this exchange was done through barter, commodity for commodity or commodity for service. However, as the social structure grew complex and the needs of the people multiplied, a metallic medium, commonly accepted by all, came into use.

Minting coinage was invented in Lydia, an Iron Age kingdom of western Asia Minor, which prospered due to its natural resources and position on trading routes between the Mediterranean Basin and Asia. In late 7th century BC the Lydians employed the electrum, a naturally occurring alloy of gold and silver found in Pactolus river bed. These roughly made coins were small lumps of electrum or pure silver and gold which were stamped with a design of a lion and an ox. For high values transactions gold and silver were used, consequently the introduction of copper alloy coins was done a natural consequence for low value transactions. Moreover the Lydian King Croesus introduced the bimetallic coinage system that has been used in the Western world until the 20th century. The first copper alloy coinage can be found from 6th-5th BC in Thrace and in the Greek colonies in the Black Sea [1].

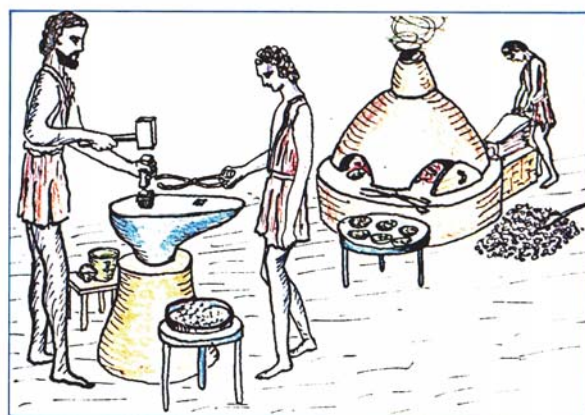


Fig. 1 - A schematic mint for coin production.

The Ptolemies (Lagidae dynasty) (323-30 BC), successors of Alexander the Great in the region of Egypt established coinage of gold and silver but also of bronze and copper for covering the need of small denomination coinage. The main mint of Alexandria created a unique coinage system, continued by the Romans [2]. In previous years Egypt was occupied by the Persian Empire and they also minted coinage in the Alexandria mint as payment to their mercenaries.

Coin production had some basic characteristics almost throughout the Ptolemy Dynasty. An interesting feature was that the denomination was not marked on the coins but the size and the material showed its worth. The recto, of the coin showed a head, mainly the ruler or a version of a ruler with god-like features and the verso, had an eagle or two eagles facing either left or right, with spread wings or not, and in many cases a cornucopia with or without the eagle, some plants were also included. Special markings also showed the provenance of the mint, the year of reign of the ruler and the mint master. Another peculiarity is the presence of a central dimple on both sides in the larger denominations that pre-existed on the flan on which the stamping is made. The very small denominations were most probably made by sawing slices from metal cylinders.

Fig. 1 shows the set up for coin minting: the furnace for heating the metal, the worker that transfers the heated flan



Fig. 2. Map of the area of Tell Basta.

to the press with the moulds of the recto and the verso coin minting and the subsequent hammering of the flan to create the coin [3].

A fundamental research on coin minting has been carried out by N. Svoronos, director of the Numismatic Museum in Athens, who studied a huge amount of coins of different periods, with respect to the provenance and chronology [4].

This paper deals with the characterization of two coins, of the Ptolemaic period from a private collection, indicated as Coin A and Coin B and their corrosion products. Their provenance is the ancient city of Bubastis or Tell Basta in the lower East part of the Nile Delta, 80 km north-east of Cairo. As a matter of facts, Tell Basta, near modern Zagazig, is the modern name of the ancient site of Per-Bastet (Bubastis) where the cat goddess Bastet based her cult, mentioned by Herodotus in his book [5].

A previous study by Ghonein and Megahed [6] investigated the chemical composition of the metal substrate and period of production of a hoard of 25 coins also found in 1998 in the Tell Basta excavations. They characterized the corrosion products and tried to clean and conserve the coins. They found that the coins were made of silver-plated copper with thick crusts of corrosion products with embedded minerals. On the coins they identified copper and silver chloride compounds, copper hydroxychlorides $\text{Cu}_2(\text{OH})_3\text{Cl}$ and AgCl , as well as CaCO_3 on the surface and goethite ($\alpha\text{-FeOOH}$) deriving from the adjacent iron artefacts.

The presence of chlorides in this area can be derived from the Canal of the Pharaohs that connected the Red Sea with the Mediterranean linked the Red Sea to the Nile

Delta in the Tell Basta area, Fig. 2. Ptolemy the II when his engineers invented the water lock, around 274 BC, made improvements to facilitate the transportation of goods from Arabia, South Eastern Asia and Africa via tug boats in the Nile to the Mediterranean ports [7].

The ultimate goal of this study is to characterize the corrosion products of the metallic artefacts in order to find tailored strategies for the conservation and restoration of cultural heritage [8-11].

II. EXPERIMENTAL PROCEDURE

Non-destructive analytical techniques and laboratory tests were employed for the coins characterization.

The elemental chemical composition of the coin alloys was measured by a portable X-ray fluorescence (XRF) device in areas free of heavy corrosion. The XRF unit is equipped with a Rh-anode, a Si-PiN diode X-ray detector (XR-100CR, Amptek Inc.) and a multichannel analyzer (MCA-8000A, Amptek Inc.). All the spectra were collected in the 40 kV mode, suitable for metals.

The corrosion products of the coins was studied by Optical Microscopy (OM) under polarized light.

The surface morphology and chemical composition were examined by a FEI QUANTA 200 Scanning Electron Microscope (SEM) coupled with Energy Dispersive Spectroscopy (EDS).

X-ray diffraction (XRD) analyses were performed by a BRUKER ADVANCE D8 diffractometer with a $\text{Cu K}\alpha$ source, in a Göbel mirror configuration, in order to identify the crystalline corrosion compounds. The operational parameters of the cathode were 40V-40A with an increment of 0.03° per step and step length 0.8 s.

III. RESULTS AND DISCUSSION

The optical images of the two coins, Coin A and Coin B, shown in Fig.3 and 4, allow to evidence their aesthetical appearance. On Coin A, the recto shows a horned Zeus head, the verso shows an eagle with spread wings facing left, the letters around it are 'ΠΤΟΛΕΜΑΙΟΥ ΒΑΣΙΛΕΩΣ', 'PTOLEMY KING' in Greek. On Coin B, the depicted head is a profile of a woman, a Kleopatra or an Arsinoe, with a K on the left, and on the verso an eagle facing left, the letters around it are 'ΠΤΟΛΕΜΑΙΟΥ ΒΑΣΙΛΕΩΣ', 'PTOLEMY KING' in Greek.

Furthermore Coin B has a buldge, which can be considered as a typical feature of castings. Both coins have the central cavity or dimple on both sides, a feature of coins produced after the reform of 260 BC by Ptolemy Soter II [3].

It is difficult to define if the cavities were present on the flans before or after they were struck, although the main opinion is that the cavity-dimple was already present on the flan. According to the British Museum catalogues of the Greek coins, Coin A and Coin B may be attributed



Fig. 3 – Optical images of Coin A.

Fig. 4 – Optical images of Coin B.

to the Hellenistic period and were probably minted in Egypt during the Ptolemy Dynasty after 260 BC [6].

Dealing with the corrosion profile of the coins, they both seem to have been subjected to similar environmental conditions during burial. The coins are in a rather good conservation state and most of the inscriptions are still visible despite the presence of powdery green corrosion products.

For Coin A, the recto basically covered by oxides, is better preserved than the verso, covered by green powdery products, meanwhile both sides of Coin B exhibit a more uniform corrosion.

Table 1 shows the average chemical composition of the two coins obtained with the XRF measurements.

Coin A is constituted of quaternary Cu-Sn-Pb-As alloy with high tin content, while Coin B is constituted by a ternary bronze, Cu-Sn-Pb, with high lead content. Both alloys contain traces of iron and are well homogenized as can be deduced from the small deviations between the ten sets of measurements performed and not reported for brevity. The high Pb content can be explained with the use

Table 1. Average elemental composition (weight %) of the two coins by XRF

Coin	Fe	Cu	As	Sn	Pb
A	0.035	83.29	0.39	13.09	3.19
B	0.21	76.44	0.00	7.41	15.82

of less precious alloying elements as a result of the gradual devaluation of coinage during the Hellenistic period. These changes are typical of economic decadence of the empires of the ancient world.

The corroded surfaces were analysed by XRD, the diffractograms are shown in Fig.5. Cuprous oxide, cuprite, is present on both coins, together with chloride compounds, as nantokite, CuCl, and clinoatacamite, Cu₂(OH)₃Cl.

These compounds are related with *bronze disease* of copper alloys and their presence indicates a potential threat if the artefacts are exposed to environments with high

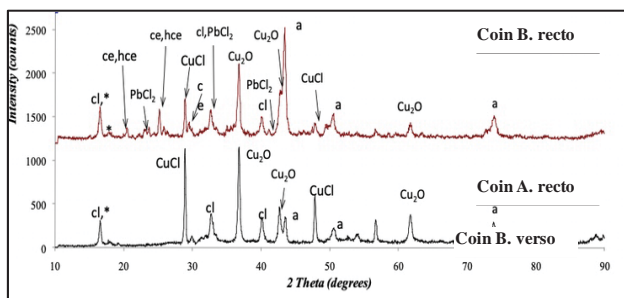


Fig. 5 : XRD diffractograms of the two coins with the codes of the chemical compound identified. a: cuprite Cu_2O ; nantokite CuCl ; cl: clinoatacamite $\text{Cu}_2(\text{OH})_3\text{Cl}$; cotunnite PbCl_2 ; ce: cerussite PbCO_3 ; hce: hydrocerussite $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$; *copper chloride hydroxide hydrate $\text{Cu}_7\text{Cl}_4(\text{OH})_{10}\text{H}_2\text{O}$;

relative humidity (RH) and abundant oxygen supply. These compounds are related with *bronze disease* of copper alloys and their presence indicates a potential threat if the artefacts are exposed to environments with high relative humidity (RH) and abundant oxygen supply. The main difference between the two coins are the lead-based corrosion products, chlorides and carbonates, identified on Coin B: PbCl_2 ; cerussite, PbCO_3 ; hydrocerussite, $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$. There are no substantial differences between recto and verso. No tin compounds or soil minerals were found. Chloride compounds were the main corrosion products identified on coins recovered from burial in Tell Basta region [6], because of the ground water salinity.

On the other hand, the overall appearance of the two coins, the absence of mineralized crusts and soil compounds, the fine powdery copper hydroxychlorides do not testify the authenticity of the artefacts without further investigations.

The surface examination with the optical microscope (OM) allowed to identify the corrosion patterns. For Coin A, the copper oxides and copper hydroxychlorides appear in different morphologies depending on the examined area.

The surface examination with OM allowed to describe the corrosion patterns. In micro-scale the copper oxides and copper hydroxychlorides appear in different morphologies depending on the examined area in case of Coin A. The oxide layer covering the recto exhibits an epitaxial growth, Fig. 6 (A). The accumulated copper compounds on verso are probably quite recently formed and give the impression of an 'active' surface, Fig. 6 (E,F). Coin B is covered by a more compact patina with better adhesion, Fig. 7 (A). Alteration zones with mixed oxides, chloride compounds and soil elements can be seen in Fig. 7 (B).

The morphology and chemical composition of the corroded surfaces of the two coins were studied by SEM-EDS, Fig. 8.

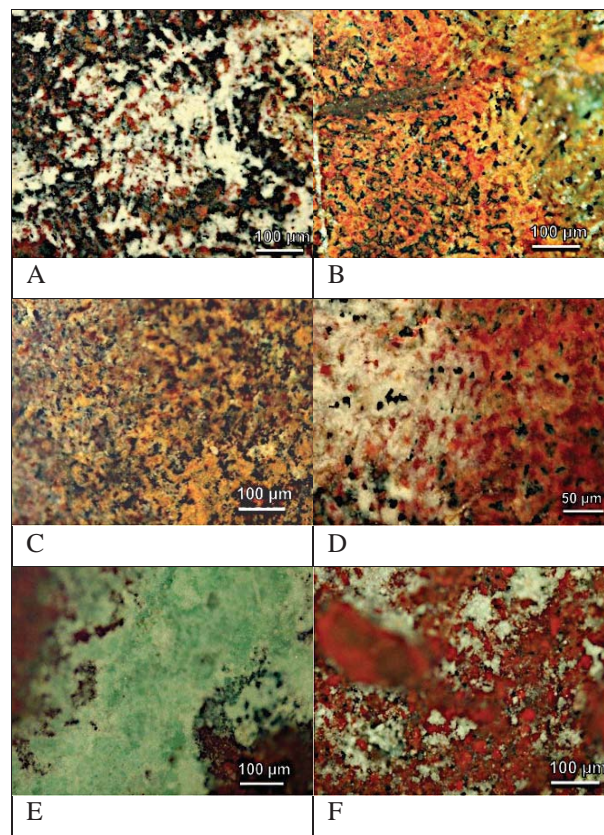


Fig. 6: Coin A - OM images under polarized light. Recto: (A) less corroded area near center; (B) area etched with FeCl_3 solution; (C) interface of an area etched with FeCl_3 and the unetched oxide layer; (D) area etched with 10%v/v HCl solution. Recto: (E), (F) corrosion products .

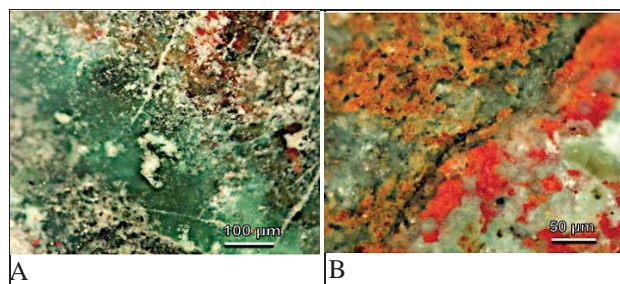


Fig. 7: Coin B - OM images under polarized light: the corrosion products on recto (A) and verso (B).

The EDS quantification results, shown in Table 2, confirm, apart from Cl, the presence of elements from the burial context as Mg, Al, Si, P. Sn is detected in significant concentration locally, while Pb content does not exceed 0.4%.

Coin B patina has a higher chloride content in contrast with the other soil elements whose concentrations are below 1%.

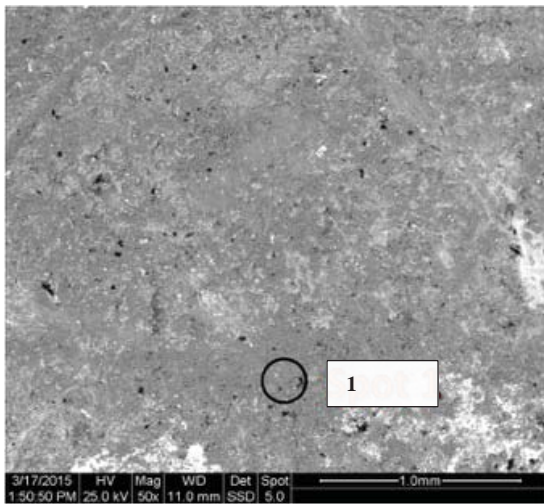
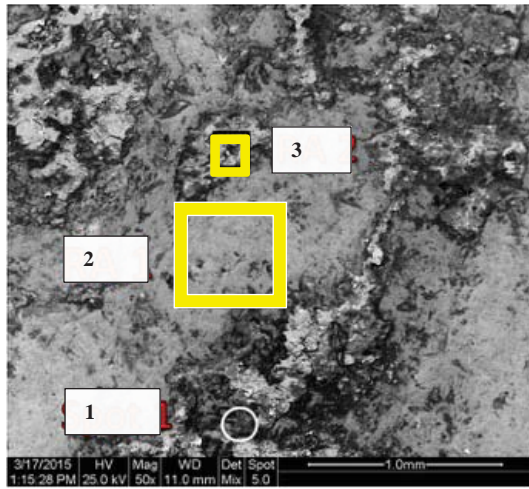


Fig. 8: SEM images of Coin A (top) and Coin B (bottom), with the indication of the areas analyzed by EDS in Table 2

The comparison of the XRF results with the normalized alloying elements concentrations of corroded surfaces facilitates the interpretation of the patina growth as a function of the alloying elements concentration of the coins metal substrate. Surface is extensively enriched in Sn and substantially enriched in Pb. In case of *Coin B* a Cu enrichment is observed.

Table 2. Chemical composition (wt%) of the corroded surfaces of coins. See Fig. 5.

Coin	Coin A				Coin B	
	Area	1	2	3	Area	1
C K	-	-	-	-	-	-

O K	71.0	63.5	75.1	54.8	63.5	62.5
MgK	1.5	1.6	1.3	1.2	0.2	0.6
AlK	2.8	0.9	4.1	1.3	0.4	0.0
SiK	7.1	2.8	12.3	1.8	0.9	0.6
P K	0.3	0,1	0.4	0.5	0,1	0,2
ClK	1.7	1.7	0.8	17.0	14.9	16.1
K K	-	-	1.5	0.2	0.5	0.4
SnL	3.4	6.5	0.1	0.2	0,2	0,2
CaK	-	-	-	-	0.4	0.2
FeK	0.7	0.3	1.1	0.2	0.2	0.1
CuK	11.1	22.2	3.2	22.3	18.3	18.4
PbL	0.3	0.4	0.1	0.4	0.6	0.6
Total	100	100	100	100	100	100

Table 3. Chemical composition (wt%) of the surfaces of the coins calculated from EDS data. See Fig. 5.

Coin	A				B	
	Area	1	2	3	Area	1
Cu	58.3	61.6	68.1	0.2	87.1	88.5
Pb	5.3	3.8	7.5	-	9.9	8.7
Sn	33.3	34.0	2.9	0.2	2.5	2.3
Fe	3.1	0.6	21.5	22.3	0.7	0.6
Total	100	100	100	100	100	100

IV. CONCLUSIONS

Two coins of copper alloys originating from Bubastis, Egypt, were studied in terms of historic background and corrosion products. After a bibliographic review, the two coins were identified as Ptolemaic coins produced in Egypt, probably from the Alexandria mint, after the coinage reform of 260 BC.

A series of non-destructive analytical techniques for chemical and microstructural characterization were utilized.

Coin A is made of a Cu-Sn-Pb-As alloy with high tin content. Coin B is made of a Cu-Pb-Sn alloy with very high lead content. Both of them were produced by casting without any following annealing treatment. The degradation conditions of coins in the post-burial condition, are not bad, no mineralized crusts were observed. Oxides and chloride-containing compounds, chlorides and hydroxychlorides, were detected and the presence of soil elements was limited.

The above-mentioned characterizations help in defining a tailored strategy for the restoration and conservation of the artefact. As first intervention, the excavated coins almost always need to be thoroughly washed and dried to prevent further corrosion, as done in this case. Even though an equilibrium situation is achieved in the ground, this

equilibrium is destroyed when the coins are excavated and exposed to a new environment. Furthermore, this corrosion layer often obstructs the image stamped on the coin; to examine the coin's stamp, the corrosion products must be removed meanwhile a good patina is protective and cannot be removed.

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