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ANCIENT COINS AND THEIR MODERN FAKES: AN ATTEMPT OF PHYSICO-CHEMICAL UNMASKING

A.M. Mezzasalma[1,3], G. Mondio[1,2,3], T. Serafino[2], G. De Fulvio[4], M. Romeo[4], A. Salici[4]

[1] *Dipartimento di Fisica della Materia e Ingegneria Elettronica – Università di Messina - Salita Sperone, 31 - 98166 Messina, Italy*

[2] *Centro Siciliano per le Ricerche Atmosferiche e di Fisica dell'Ambiente Salita Sperone, 31 - 98166 Messina, Italy*

[3] *INFN – Sezione di Catania and INFN - Laboratori Nazionali del Sud*

[4]*Raggruppamento Carabinieri Investigazioni Scientifiche SS. 114, Km 6,400 – Messina, Italy*

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Corresponding author: G. Mondio (mondio@unime.it)

ABSTRACT

As a consequence of police operations in Messina (Sicily), a huge quantity of perfect imitations of ancient coins, realized by a sicilian forger, has been recently found. Such fakes have been realized by the lost wax casting technique and reproduce coins issued by different authorities in different historical epochs. In order to overcome the obvious subjectivity of the traditional (autoptical) numismatic analysis, which sometime provides contrasting interpretations, five of these fakes have been analysed by Scanning Electron Microscopy (SEM) and Energy Dispersed X-Ray Fluorescence (EDXRF). The results obtained have given information on the microstructure, the homogeneity and the elemental composition of the alloys used by the forger. Furthermore, evident traces of the chemical treatment utilized for the artificial ageing of the coins have been found. Due to the presumable and dangerous large diffusion of these sicilian fakes in the international market, the results of such analyses may certainly be of noticeable interest for Numismatics and forensic applications as well, representing a set of proofs to be used in the unmasking of analogous counterfeiting cases.

KEYWORDS: Scanning Electron Microscopy (SEM), Energy Dispersed X-Ray Fluorescence (EDXRF), Coin Fakes, Numismatics

INTRODUCTION

There are essentially two main classes of coin fakes. The first one is utilized to deceive non-numismatic people by means of rough imitations of authentic pieces and, sometime, includes coins whose style and imaging can only be ascribed to the fantasy of the forger. The second class is built up by all those counterfeits that are of such a good quality to be sometime believed authentic also from experts. This last class is obviously the most dangerous because it tries to deceive scholars, collectors as well as dealers of ancient coins, offering them perfect imitations of rare pieces with a great economic profit for the forger.

The mediterranean Middle East has been traditionally the main centre of ancient coins counterfeiting but, in the last few years, most of the very large number of fakes, found in the international numismatic market, has been proved to come from Bulgaria, Yugoslavia and Sicily.

In principle, a traditional autoptical analysis made by an expert is able to identify a forged coin. After the first easy controls concerning the weight and the style of the pieces, the numismatist will look for and will examine all the details present on its surface. In fact, the technique adopted for the realization of a fake generally leaves a number of characteristic macroscopic and microscopic traces which can be considered as the fingerprints of that particular technique. Macroscopic traces as the edges' abrasion (used to remove metal residuals), the sharpness of lettering and that one of the fine details, the relative position of one face of the coin with the respect to the other, the patinas artificially (chemically) induced to simulate the natural ageing are all examples of such fingerprints. However, depending on the forger's skill, not always an autoptical analysis gives certain results. Even if there exist today new methods of dating based, for example, on the ^{226}Ra isotopic separation from metal during the smelting processes (Liritzis 2006), few laboratories have the availability of the very sophisticated and sensitive instruments needed for such experimental analyses.

In order to give an indication of which kind of fingerprints must be sought for fakes identification, the aim of this paper is the characterization of a number of very good quality coins imitating original pieces datable from the V century B.C. up to the III century A.D. Such fakes have been obtained from the Carabinieri's Scientific Investigations Section (RIS) of Messina and are part of an enormous quantity of numismatic material recently found in a Sicilian forger's workshop and subjected to judicial proceedings. The difficulty met by experts of the Interdisciplinary Regional Museum of Messina in undoubtedly demonstrating the falsity of part of these pieces has suggested to submit five of them to physico-chemical analyses in order to find eventual microscopic fingerprints of the counterfeiting processes. The techniques used for the present work, i.e. scanning electron microscopy and X-ray fluorescence spectroscopy (Nothover 1998, Cowell 1998, Mondio et al. 2004, Bacci et al. 2006) have been extensively used in determining the compositional content of non metallic archaeological findings and that one of the alloys used by ancient mints and represent a powerful specific tool for the microscopic characterization of metallic samples.

In the case of true ancient coins, the long burial in the ground usually results in a surface layers corrosion which can often penetrate the whole object. The degree of corrosion is a function both of the time and of the chemical reactivity of the elements constituting the metal. Thus, the lack of any in-depth corrosion may be one of the indicators of a counterfeited coin. Other information can also derive from the SEM observation of the alloys surface structure. Metal segregations, local crystallizations, surface irregularities and all that is a consequence of the procedure used for the realization of the pieces may suggest arguments for or against the authenticity of a coin. In fact, the treatments the latter receives during its manifacture introduce new features in the cast microstructure (La Niece, 1998) that can be put in evidence by the experimental techniques exploited in this work.

THE FAKES ANALYSED

The five fakes analysed are all imitations of true bronze coins of different epochs, issued by different authorities and, as already said in the introduction, are all coming from a stock of numismatic material subjected to a judicial inquiry. They have been produced by lost wax casting technique and are labelled in the following with letters and numbers according to their laboratory identification codes (Fig.1).

Fig. 1: Obverse and reverse of the five analysed fake coins.

BR01 – A good imitation of a bronze coin issued by *Brettii,* a population of Calabria (*Brutium*). It belongs to a set (Rutter, 2001) called "*plough*" and dated back to the second Punic War (211 – 208 B.C.). A lot of exemplars of this coin have often been found during archaeological excavations in the territories of Cosenza, Crotone and Locri even if they are sometime found also in Sicily. On the obverse it shows the head of Herakles wearing a lion's scalp and, on the reverse, the lettering *BPETTIΩN* with a proceeding feminine figure taking up a large shield.

BR02 – A counterfeiting of a bronze coin issued by *Himera* in the V century b.C. (Gabrici, 1927). On the obverse it shows a feminine head and on the reverse a set of six small globes surrounded by a crown of leaves. Such type of coin, not too much frequent in archaeological findings, is very often found in the judicial sequestrations of fakes. While some of them are roughly realized, other pieces are perfect reproductions of the originals.

BR05 – A fake, without correspondence with an authentic coin, which recently appeared in may auction sales in Internet.

BR06 - Another bronze fake which is quite a perfect reproduction of a roman sesterce of Balbinus dated 239 A.D. (Robertson, 1977). On the obverse the lettering *IMP CAES D CAEL BALBINUS AVG* is present, together with the image of the emperor with laurel wreath, mantle and cuirass. On the reverse the lettering *PROVIDENTIA DEORUM* and a figure representing the providence with a cornucopia in the left hand and a sceptre in the right one. Two letters, *S* and *C*, are positioned on the two sides of the figure. The original coin belongs to a set whose rarity is essentially due to the fact that it was issued in the short ruling period of Pupienus and Balbinus.

BR16 – A bronze imitation of a coin issued by Sextus Pompey (Crawford, 1974).

The above five examples considered, even if in principle are too few to provide good statistical results, have been selected because, being made by the same forger utilizing the same techniques and materials, can be considered as representative of the whole group of available bronze fakes.

SAMPLE PREPARATION AND ANALYTICAL TECHNIQUES USED

All the specimens have been analysed by means of a SEM Philips model Quanta 400 equipped by an EDXRF facility with a LNT-cooled Si(Li) detector utilizing an ultra thin Be window. SEM-EDXRF is a powerful experimental technique used to rapidly analyze the elemental composition of large as well as sub-micrometric sized areas of an investigated surface. The energetic electrons impact induces an ionization of the atomic core levels in the sample and the consequent emission of characteristic X-rays caused by the core holes relaxation processes. It allows quantitative and qualitative analyses of the sample surface composition and also to obtain X-ray maps of the elemental distributions in the analyzed area. All the measurements have been carried out with electron primary beam energies ranging from 25 to 30 keV, being the Si(Li) detector energy resolution about 130 eV, good enough to detect partially overlapped different X-ray lines.

The software managing the coupled SEM-EDXRF system has the advantage to offer a complete range of true-standardless quantification routines that provide the same accuracy and reliability at any different microscope working condition, taking into account the different X-ray production cross-sections of the elements, the Si-detector efficiency vs. the X-ray energy and the X-ray self-absorption corrections.

Before being introduced in the evacuated measurement chamber of the scanning electron microscope, all the samples have been put in an ultrasounds cleaning bath. For the surface composition measurements, large areas of the samples have been analysed in

order to obtain reliable (not too local) average results. In this case the XRF spectra have been essentially taken in order to obtain information about the coins patina whose chemical characteristics may denounce the work of a forger.

After the surface analysis, the samples have been also cut in half in order to measure, on their transverse sections, the true bulk composition of the utilized alloys (independently from the eventual surface contaminations) as well as the in-depth distribution of the elemental components by an XRF mapping. This "not orthodox" and destructive cutting was utilized due to the certainty of the coins forgery. In case of doubt, some other technique must be obviously utilized trying to minimize the damages to the sample analysed. For example, a laser micro-ablation on the coin edge followed by a mass quadrupole spectrometry analysis could be used (Torrisi et al, 2008).

All the more intense lines of the detected elements on our coins have been chosen to visualize their distribution across the whole samples. This to check the homogeneity of the alloys and the depth of any eventual surface corrosion layer that is expected to be obviously negligible in the case of modern fakes.

RESULTS AND DISCUSSION

In tables I and II, the qualitative and quantitative results of our analyses are reported as deduced by the EDXRF spectra taken on the sections and on the surfaces of the samples. The uncertainty in the quantitative analyses is never greater than the 1% of the obtained values, as deduced by several measurements performed on the same sample area, enough large to be representative of the whole object analysed, and in the same experimental conditions. Typical fluorescence spectra obtained are shown in Figures 2 (surfaces) and 3 (sections).

Table 1: Bulk weight composition (%) of the bronze fakes analysed as measured on their transverse sections (uncertainty is less than 1%)

Sample	Cu %	Pb %	Sn %	Fe %	Ni %	Zn %
BR01	86.4	2.4	4.3	0.3	0.7	5.9
BR02	89.3	3.9	5.7	0.6	0.5	-
BR05	85.6	3.8	8.5	-	-	2.0
BR06	89.7	3.4	5.5	-	-	1.4
BR16	74.7	14.4	7.2	-	-	3.7

Table 2: Surface weight composition (%) of all the fakes analysed (uncertainty less than 1%)

Element	BR01	BR02	BR05	BR06	BR16
Ag	-	-	1.1	-	0.8
Al	0.3	-	2.0	0.1	0.5
C	19.6	8.9	-	65.0	46.0

Ca	0.5	-	1.8	0.8	0.8
Cl	0.1	3.4	5.3	0.4	0.3
Cr	-	-	-	-	0.2
Cu	58.5	40.3	48.9	19.6	26.5
Fe	0.5	0.4	1.1	0.4	1.4
I	-	-	14.7	0.8	-
K	-	-	2.5	0.2	-
Mg	-	-	2.2	-	0.6
Ni	0.3	0.2	10.4	-	0.2
O	2.7	16.1	-	6.1	6.2
P	-	2.4	0.4	-	0.4
Pb	1.2	10.4	2.3	-	3.3
S	9.2	-	-	6.0	6.4
Si	1.1	0.2	4.8	0.6	1.7
Sn	4.7	17.7	-	-	3.0
Zn	1.3	-	2.5	-	1.7

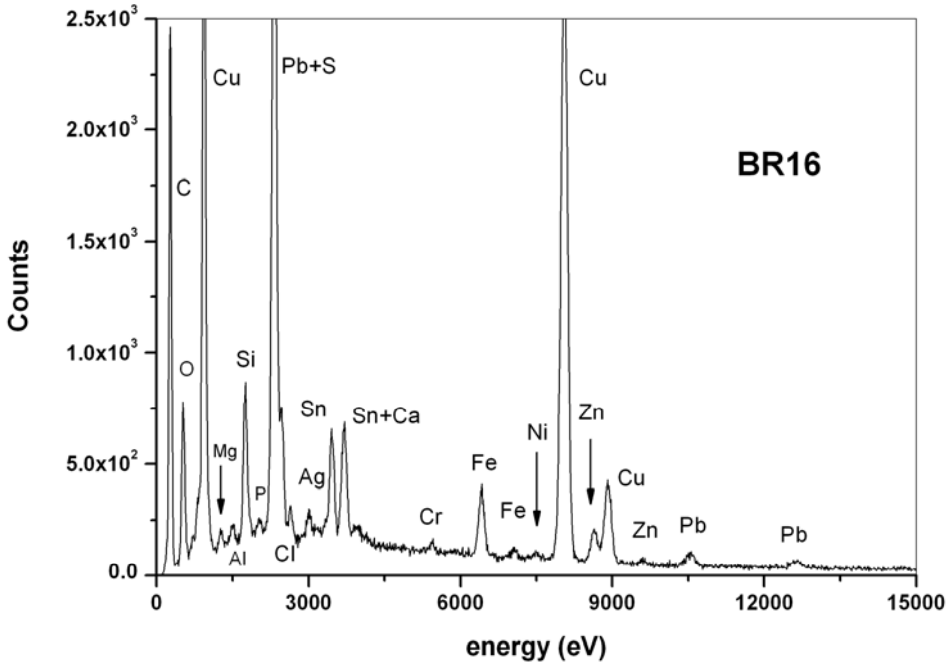

Fig. 2: EDXRF spectrum taken from the surface of bronze coin BR16

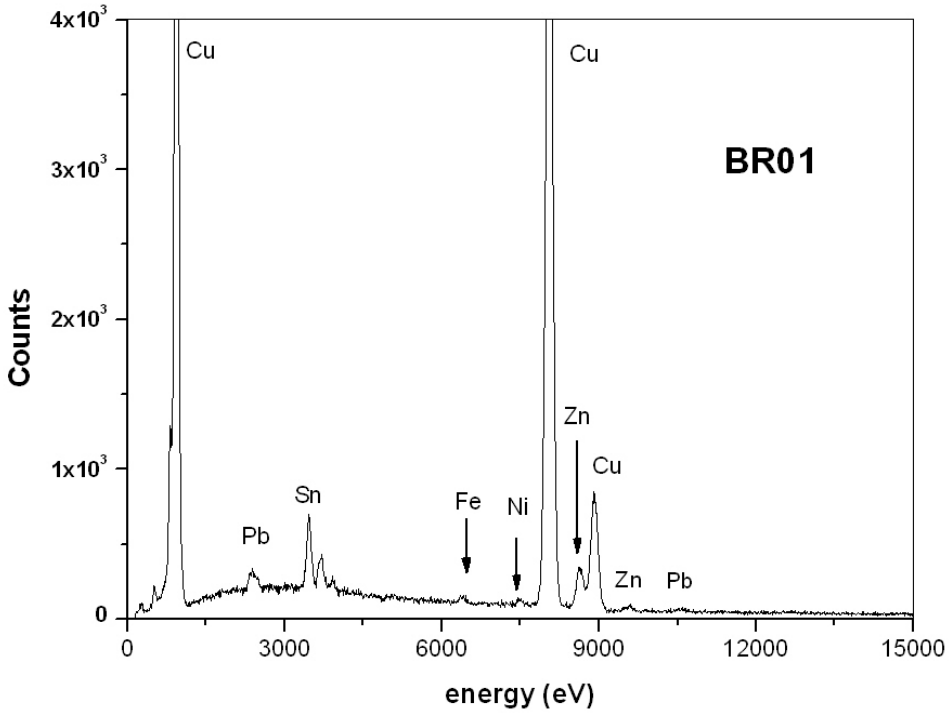

Fig. 3: EDXRF spectrum taken from the section of the bronze coin BR01

A number of atomic components has been detected on the coin faces as a result of environmental contaminations, contact with other coins, polishing and, possibly, artificial ageing. With the only exception of sample BR16 which presents the lowest value (74.7%), bulk *Cu* weight concentrations have been found on the sections ranging from 85.6 % to 89.7% with minor percentages of *Pb* (2.4 – 14.4 %), *Sn* (4.3 – 8.5 %) and *Zn* (1.4 – 5. 9 %). Only in the case of samples BR01 and BR02, impurities of *Fe* and *Ni* have been detected. No evidence of other trace elements was obtained within the instrumental detection limits.

In the case of modern forgeries, alloys with a relatively high degree of elemental purity are utilized and, concerning the trace elements, the bulk composition of the produced coins is usually "off" with respect to that one of the authentic ancient ones. Even if our fakes show bulk concentrations of the main metals varying in not suspicious ranges, the poor presence of trace components is far from being similar to that one of the authentic coins of the same epoch. The bronze alloys used by the ancient mints generally show a large number of trace elements such as *Fe*, *Ni*, *Ag*, *Sb*, *Mn*, *Ti*, *Co* and *As,* some of them often being natural impurities of the main metals used (Calareso et al 1998, Carter et al 1980).

The EDXRF mapping of the sections has also shown a very noticeable bulk homogeneity of the bronze alloys as it can be seen, for example, for the fake BR06 (Fig. 4). The atomic species are

homogeneously distributed all over the section in going from the obverse to the reverse of the coin. No evidence of in-depth corrosion or oxidation, as expected in the case of an authentic ancient piece, has been observed.

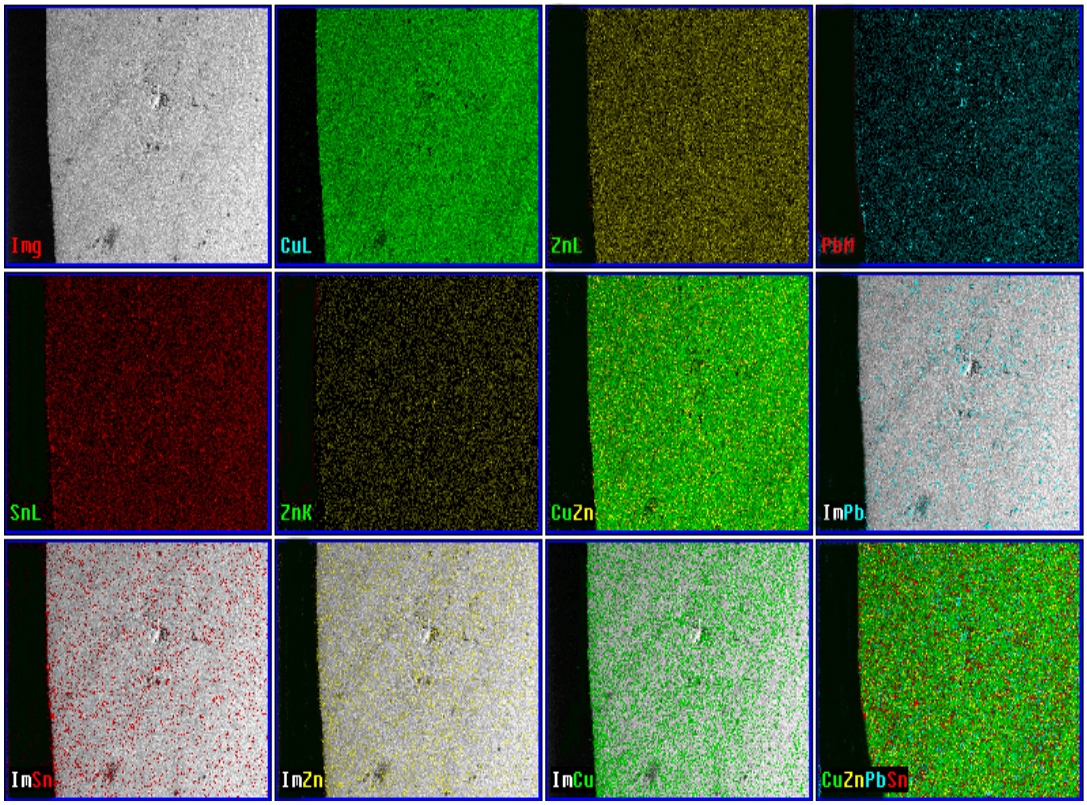

Fig. 4: XRF mapping of atomic components on a transverse section of the fake BR06. The horizontal extension of the images nearly correspond to the coin thickness (about 3 mm). In the upper left corner of the figure the topographic image of the sampled area (Img) is shown as seen by backscattered electrons. Other maps refer to the distributions of single elements (detected by their characteristic K, L and M X-ray lines) and their superimpositions onto the sampled area as indicated by the labelling

Furthermore, elemental EDXRF maps carried out on the bronze fakes' surfaces have shown that, with the exception of samples BR02 and BR05, they are characterized by large areas mainly covered by Carbon, Copper and Sulphur, surrounding relatively clean emerging islands of the metal alloy. In Fig. 5 the elemental maps for the sample BR06 are shown as acquired from an area of about 270 μm x 210 μm. Particularly interesting is the comparison between the maps obtained for different characteristic X-rays of the same element as in the case of CuK (8.04 keV) and CuL (0.93 keV). Such a comparison underlines the difference between two types of Copper atoms. While the lower energy emissions (CuL) are related to more superficial atoms, the higher energy ones (CuK) come also from deeper regions of the sample, this reflecting the homogeneous metal bulk distribution.

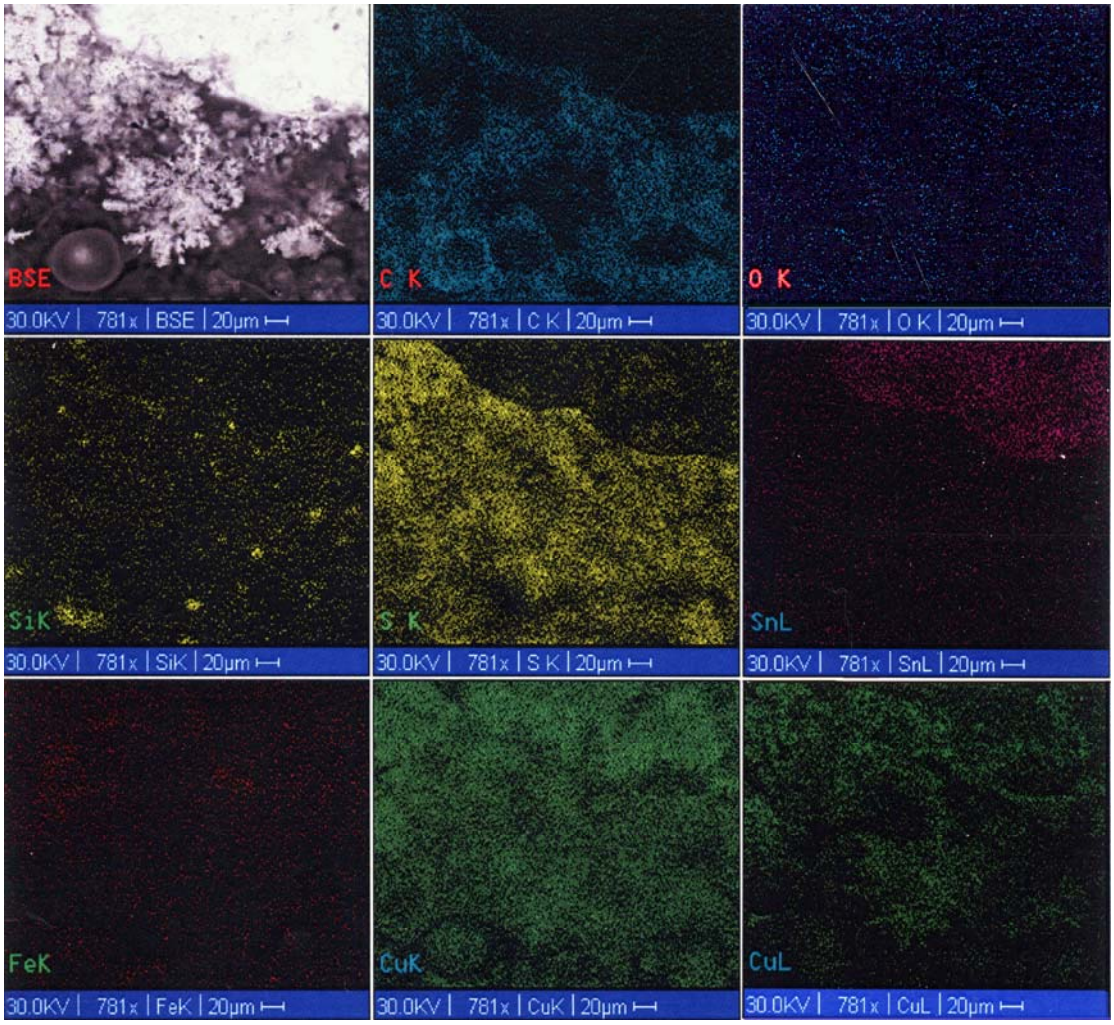

Fig. 5: Elemental XRF maps taken over a large area of the BR06 coin surface. The light island in the right left corner of the image (BSE) represents an enough clean part of the coin surface where Cu, Sn and impurities of Fe are present. All the other parts of the coin are covered by a C film with a number of dendritic formations (built up by Cu, S and O) on top. The more energetic fluorescence emissions CuK and FeK come also from deeper regions of the sample and are nearly homogeneously distributed on the examined area. On the contrary, CuL emissions describe surface Cu distribution and, in particular, Cu atoms belonging to the dendritic formations. Si may derive from surface polishing and finishing procedures.

Particularly, in the case of fakes BR01 and BR06, a lot of dendritic structures (Fig. 6) have been found lying free on the top of their surfaces (trapped in the coin surface roughness). This fact denounces a freshly formed material, impossible to be found on an authentic ancient coin where each chemical formation is expected to be embedded in the solid and compact patina layer. On the contrary, such structures can be easily displaced and sometime also broken (as in the case of the structure showed in Fig.6) by the impact of the microscope electron beam. Their largest dimension is of the order of some tens of microns.

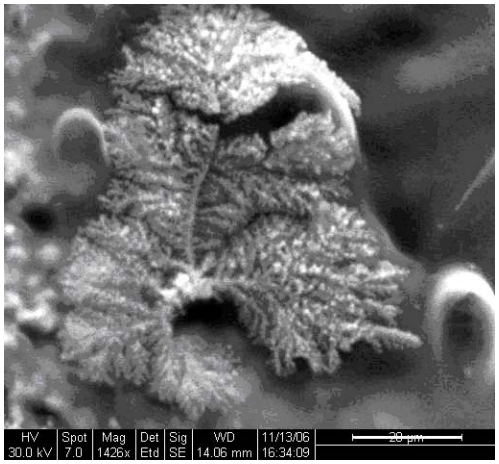

Fig. 6: Image of a characteristic dendritic growth lying on the surface of fake BR06 as revealed by backscattered electrons (BSE). The dendrite is broken in its upper part by the impact of the microscope electron beam.

A local XRF spectrum (D-BR06) of these objects presents a composition essentially built up by *Cu*, *S* and *O* as shown in Fig. 7 where a comparison is reported with the spectrum taken over the full sample area. The elements found suggest that the dendrite is a *Cu-S-O* based compound, this being also supported by the Cu*L*, S*K* and O*K* maps of Fig. 5 where the elements distribution roughly reproduces (especially CuL) the location and the shape of a dendritic structure. Unfortunately, it was not possible to have an precise information about the stoichiometry from EDXRF spectroscopic data, due to the characteristic X-rays coming also from Copper, Sulphur and Oxygen lying under and/or near the analysed object and belonging to natural after-casting formations of copper oxide (Cu_2O) and sulphides (Cu_xS_y) on the coin's surface. In any case the deduced stoichiometry is in good agreement with that one of Copper Sulphate.

In this experimental frame, it must be also considered that one of the most used recipes for fakes artificial ageing utilizes a solution composed by penthydrated $CuSO_4$ together with HNO_3 and NH_4Cl in distilled H_2O. In this solution, warmed up until 80-90°C, the just produced fakes (at about 100 °C) are immerged. Such a bath gives them an artificial patina with an "antique green" colour and a deceptive antiquity appearance. Drops of the above $CuSO_4$ solution on clean bronze surfaces may form dendritic structures with the same characteristics of those observed in our fakes. In fact, as revealed by the same forger during the police inquiry, this was just the ageing technique he adopted in counterfeiting his coins.

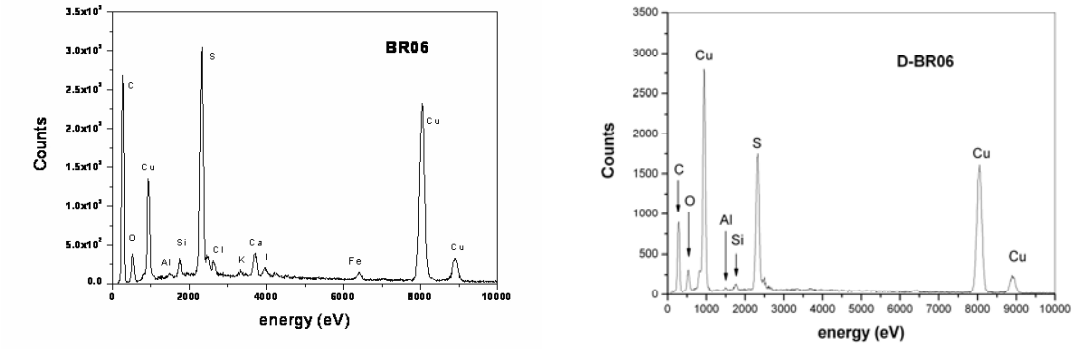

Fig. 7 (a,b): EDXRF spectrum taken on the surface of fake BR06 (left) and in correspondence (right) of the CuSO4 dendritic formation.

The chemistry used in these cases may be also of different nature. Sometime, also the chemical solutions used for bronze gun barrels blackening are exploited for this type of treatments leading to same effects.

On the basis of these considerations, the presence of Copper Sulphate on our fakes can be ascribed to a chemical ageing treatment and this induce us to state that the finding of the dendrites must be considered as a proof of such counterfeiting procedure and may represent a typical fingerprint against the authenticity of similarly treated pieces. It must be remarked that, when considered without any other type of analysis, the presence of dendrites is not always to be considered as a definitive proof against the authenticity of a piece. In fact, this type of fingerprint may also be the proof of the renewal of the antiquity appearance of an authentic ancient coin after the elimination of its original patina as a consequence of a drastic cleaning of the surfaces. However, in both cases, a counterfeiting has been made by the forger with the aim to deceive his potential purchasers.

Some other elements (*Ca, K Cl, I, P*) detected on our coins surfaces must be considered the result of contamination effects due to the exposure to the environment. The *Al* and *Si* traces seem to denounce the use of abrasives (Al_2O_3 , *SiC*) commonly used for surfaces polishing and finishing. In fact, abrasive powders of Aluminum Oxide and Silicon Carbide, are generally used in distilled water mixtures, being the choice of their particles size depending on the mean dimensions of the surface irregularities produced by the production technique adopted. The use of such mechanical polishing techniques on our fakes has been evidenced by a morphological analysis of their faces where a great number of grooves have been found. Typical grooves show widths up to 5 microns and lengths up to several tens of microns.

Furthermore, surface irregularities, cavities and bubbles, commonly referred to as "casting porosity" and "casting bubbles" have been also, as usually, observed on the surface of our fakes as remnants of the use of the lost wax casting technique.

CONCLUSIONS

The aim of this work has been the physico-chemical characterization of a group of bronze fakes in order to put in evidence the elemental composition of the used metal alloys and all those characteristics considerable as "counterfeiting fingerprints".

All the coins have been subjected to a scanning electron microscopy analysis by which they have been studied both on their surfaces and on their sections. Even if reproducing the macroscopic characteristics of coins belonging to different epochs and issues, the bulk composition of each type of alloy was found very similar and poor of all those numerous trace elements generally characterizing the materials utilized by the ancient mints. Particularly interesting has been the information deduced by surface and bulk studies on our fakes. X-ray fluorescence maps have allowed us to check the homogeneity of the utilized alloys which resulted to be not compatible with that one characteristic of authentic ancient coins. Artificial ageing techniques have been identified due to the presence of dendritic microstructures produced by the chemistry util-

ized by the forger to give the fakes a deceptive antiquity appearance. Details have been finally put in evidence by the surfaces morphology, consisting in the usual presence of a number of grooves produced by mechanical abrasion used for surface polishing and refining of the pieces.

In conclusion, due to the presumable and dangerous large diffusion of these sicilian fakes in the international numismatic market, we think that the results reported in this work may be of some interest also in the wide field of forensic applications.

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