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Gold and Silver Particles on the Turin Shroud, Studied by Scanning Electron Microscopy and Elemental Analysis

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Abstract

We have studied by optical microscopy and by SEM-EDX some metallic particles of gold and silver adhering to a sample of the Turin Shroud. A total number of eighteen particles (and sub-particles) containing these two elements were characterized in details. Three of them (e49, b22 and h28-0) are parts of gold scales, and six (l38-1, 2, 3, 4, 7' and 12) are micro-grains of a gold powder. The three a23-1, 2 and 3 sub-particles are the metallic parts of a spot of painting. The e27 particle (of electrum) is possibly some part of a coin of a Byzantine money; possibly also, the m10 particle could be parts of a billion (a coin of money used during the Roman Antiquity).

Keywords

Turin Shroud, SEM-EDX Analyses, Gold and Silver Particles, Electrum, Billion

1. Introduction

The Turin Shroud (TS) is a well-known object in which a body image is imprinted (Marion & Lucotte, 2006). In 1978 and in 1988, Giovani Riggi di Numana took some samples and dusts of the TS (Riggi di Numana, 1988) at areas corresponding to hands, face (a 1978 sample taken from the face area was deposited by him on a special sticky-tape), feet, buttlocks and the ^{14}C area. We had access to this sticky-tape, cut up in a triangular form, and realised on it preliminary investigations concerning mineral particles (Lucotte, 2012).

I have published in 2015 some other studies on the triangle: the first one (Lucotte, 2015a) concerned linen (and other textile) fibers. The second (Lucotte, 2015b) concerned pollens (and spores) and the third (Lucotte, 2015c) red blood

cells. We published further studies on hematite, biotite and cinnabar particles on the triangle (Lucotte et al., 2016).

In the present study, I describe in details all metallic particles containing gold and silver located on the triangle surface, in a similar fashion to those found on the hairs of Holy Maria-Magdalena (Lucotte, 2019).

2. Material and Methods

The material is the small (1.36 mm high, 614 µm wide) sticky-tape triangle, at the surface of which portions of fibers, pollen grains, red-blood cells and mineral particles were deposited. More than 2500 particles can be observed at the triangle surface. For practical reasons, the surface of the triangle was subdivided in to 19 sub-samples areas (areas A to S), the E area being subdivided again in five sub-areas Ea to Ee. The positions of each particle sticking to the triangle surface were located in a double system of coordinates (in 186 adjacent squares of 50 × 50 µm) of the total surface.

All the particles described here were studied by optical microscopy and by SEM (Scanning Electron Microscopy) – EDX (Energy Dispersive X-ray) analysis.

Detected particles of interest were observed first by optical microscopy using a photomicroscope Zeiss, model III 1972. The SEM apparatus used was a Philips XL 30 instrument (an environmental version); GSE (Gaseous Secondary Electrons) and BSE (Back Scattered Electrons) procedures are used, the last one to detect heavy elements.

Elemental analysis for each particle were realised by EDX, this SEM microscope being equipped with a Bruker probe AXS-EDX (The system analysis is PGT: spirit Model, of Princeton Gamma Technology).

Each elemental analysis is given in the form of a spectrum, with kiloelectrons/Volts (ke/V) on the abscissa and elemental peak heights in ordinates.

Table 1 gives peaks and rays of the gold, silver and copper metallic elements.

Table 1. Peaks of gold, silver and copper in EDX analyses.

Metals	Rays	KeV	Main peaks
Gold	Mα	2.12	+
	Lα	9.71	
Silver	Ll	2.63	
	Lα1	2.98	+
	Lß1	3.15	
	Lß2	3.34	
	Lγ1	3.52	
Copper	Lα1	0.92	+
	Kα1	8.04	
	Kα1	8.90	

To note is that the minimal surface necessary to an EDX analysis is of 1 μm^2; so, particles which surfaces are below this limit (that is the case of the sub-particles observed) give also an EDX analysis of the surrounding substratum.

Normal (i.e. without carbon and oxygen) compositions in elements are given in %, based on analyses of each main rays.

3. Results

Particles found are those of golden alloy, of pure gold, of pure silver, of an alloy of silver and copper, and of pure copper.

3.1. Particles of Golden Alloys

3.1.1. The e49 Particle

Particle e49 is the greatest one containing gold found on the surface of the triangle. Located in the E area (**Figure 1**, above), it is an elongated particle (of more than 10 μm of length on 5 μm of width) partially covered (**Figure 1**, below) by the e50 particle and which its upper part is located at the extremity of part 2 of the linen fiber number 4 (Lucotte, 2015a).

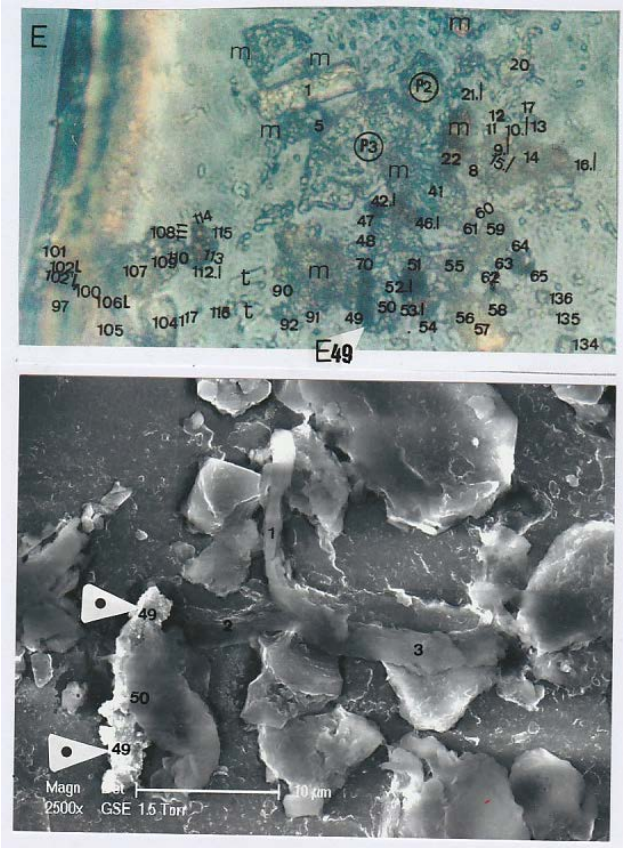

Figure 1. The e49 particle. *Above*: optical view (500×) of the E area, showing the e49 particle. *Below*: SEM photograph (2500×), in GSE, of e49; the two apparent parts (superior and inferior), designed as pointed triangles, of e49 are partially separated by the left superior part of e50 (a Cyanophycae). **1**, **2** and **3** indicate the three different parts of FL.4 (linen fiber number 4).

SEM photograph of Figure 2 shows an enlarged (6000×) view of the e49 particle. Its spectrum (Figure 2, below) shows that it is a silver/gold alloy, with a little quantity of copper (the normal composition of these elements are of 54.3%, 41.9% and 3.9% respectively).

By its form and composition, e49 is probably a scale of a silver/gold alloy.

3.1.2. The b22 Particle

Figure 3 shows the location of the b22 particle in the B area of the triangle. Figure 4 shows SEM photographs (above in GSE, and below in BSE) of the group of particles where the b22 particle is located, near the linen fiber number 3 (Lucotte, 2015a).

SEM photograph of Figure 5 shows an enlarged (10,000×) view of the b22 particle. It is a little squared particle, of about 3 μm of lateral size. Its spectrum (Figure 5, below) shows that is a gold alloy, with little quantities of silver, copper and iron (the normal composition of each of these three first elements are of 85.2%, 11.6% and 3.2%, respectively).

By its form and composition, b 22 is probably a little part of a scale of a gold alloy.

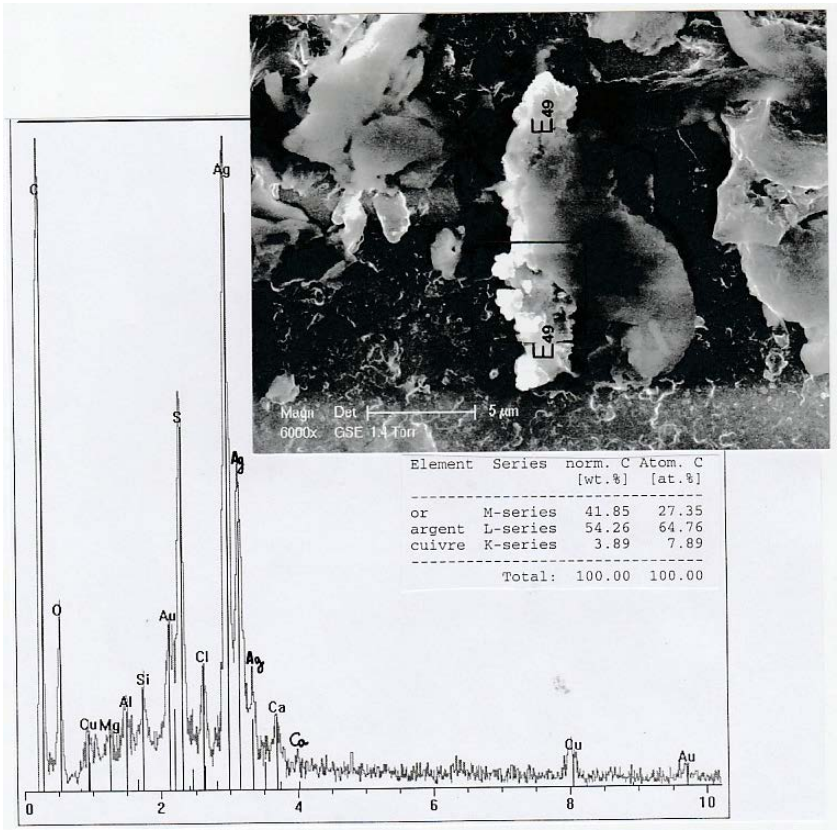

Figure 2. *Above*: SEM photograph (6000×), in GSE, showing the two parts of the e49 particle. *Below*: spectrum of e49, in the squared area of the photograph. C: carbon; O: oxygen; Cu (two peaks): copper; Mg: magnesium; Al: aluminium; Si: silicium; Au (two peaks): gold; S: sulphur; Cl: chlorine; Ag (three peaks): silver; Ca (two peaks): calcium. *Insert*: normal composition: or (gold); argent (silver); cuivre (copper).

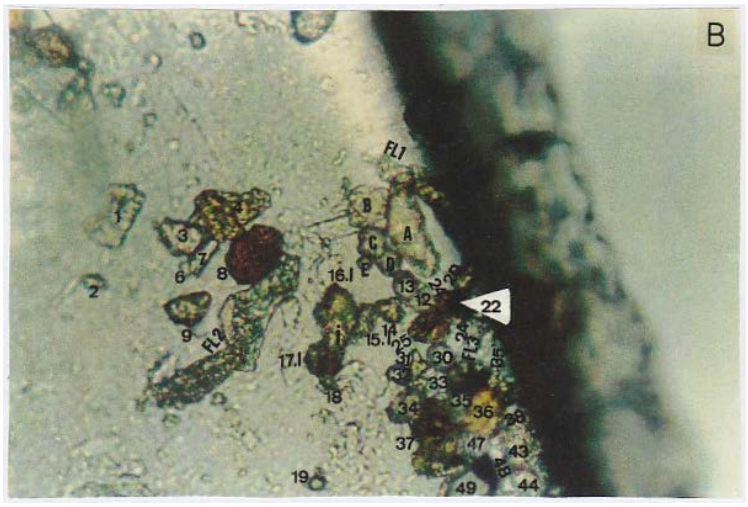

Figure 3. Optical view (1000×) of the B area of the triangle, showing the b22 particle.

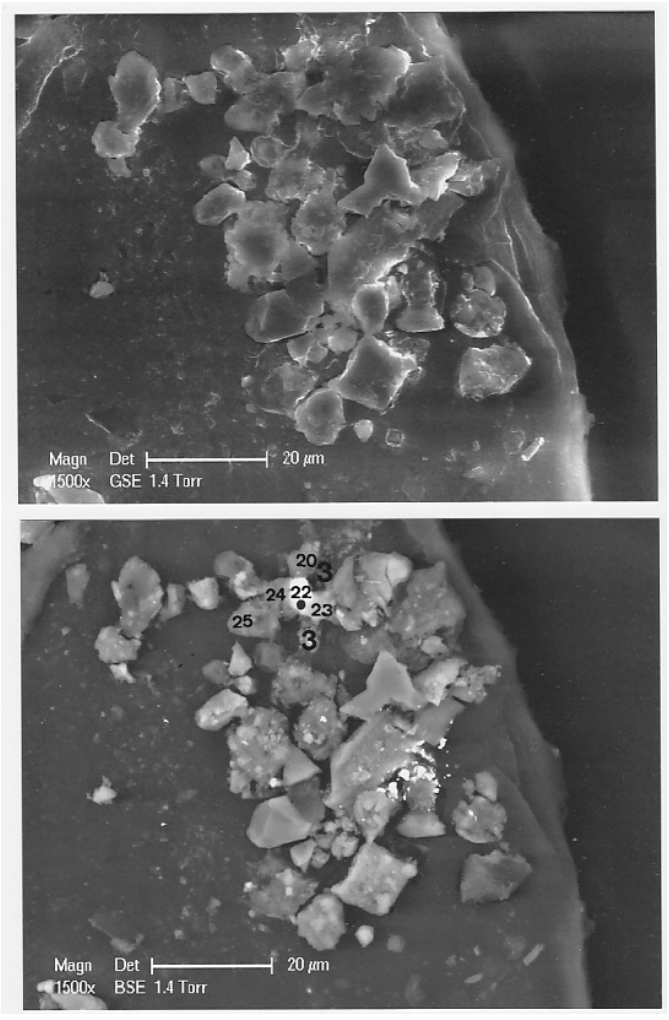

Figure 4. SEM photographs (1500×) of some part of the B area. *Above*: SEM photograph (in GSE) of this part. *Below*: SEM photograph (in BSE) of this part, showing the b22 particle. **20**: a Cyanophycae; **23**: an hematite particle **24**: a Dinophycae; **25**: a Dinophycae. **3**: the two parts of FL3 (linen fiber number 3).

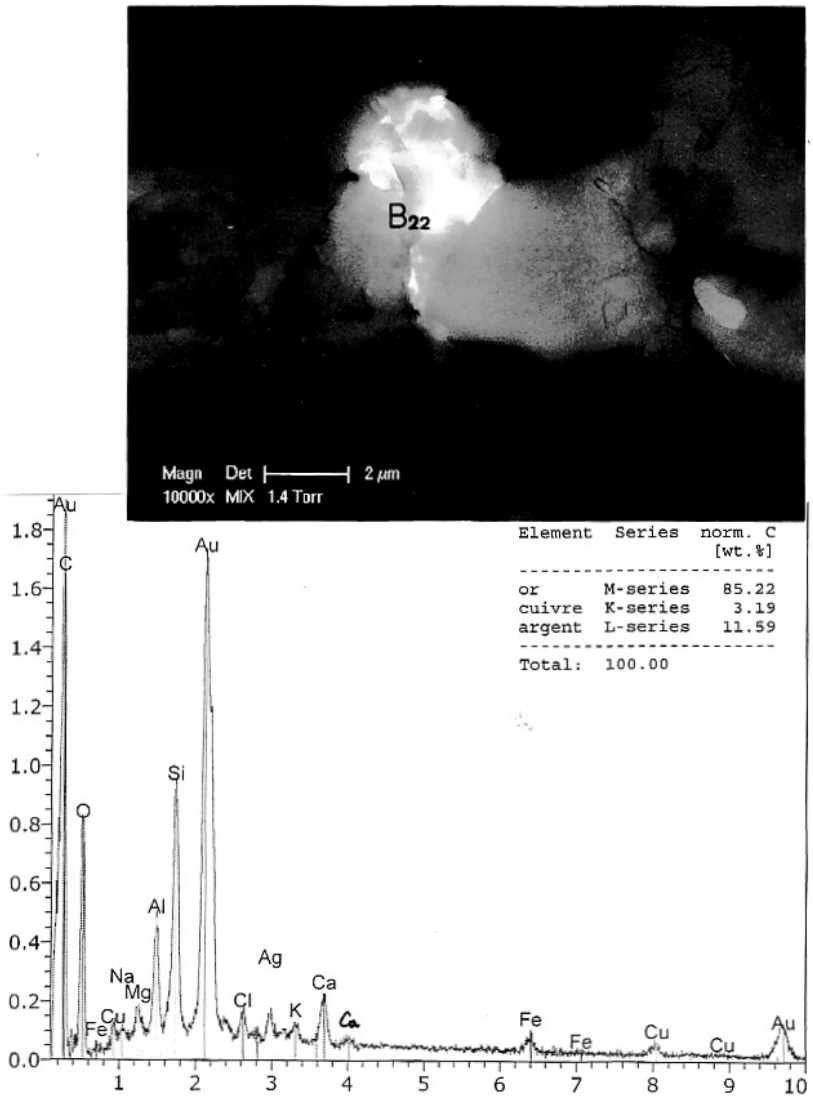

Figure 5. *Above*: SEM photograph (10,000×), in GSE + BSE, of the b22particle. *Below*: spectrum of b22. C: carbon; O: oxygen; Fe (two peaks): iron; Cu (three peaks): copper; Na: sodium; Mg: magnesium; Al: aluminium; Si: silicium; Au (two peaks): gold; Cl: chlorine; Ag: silver; K: potassium; Ca (two peaks): calcium. *Insert*: normal composition: or (gold); cuivre (copper); argent (silver).

3.1.3. The e27 Particle

The e27 particle is a very little particle located in the Eb area of the triangle (upper photograph of **Figure 6**). The enlarged (100,000×) SEM view of this particle shows that it is a particle of triangular form (of about 800 nm of maximal length) and with a granulous surface (lower photograph of **Figure 6**).

Its spectrum (**Figure 6**, below) shows that this particle is mainly compounded of quasi-equal parts of gold and silver (normal composition of 45.4% and 54.6%, respectively), with a little quantity of copper.

By its aspect and composition, the e27 particle is probably that of electrum, a natural metal that was used to make the earliest metal coins (dating back at least the 3rd millennium BC in Egypt).

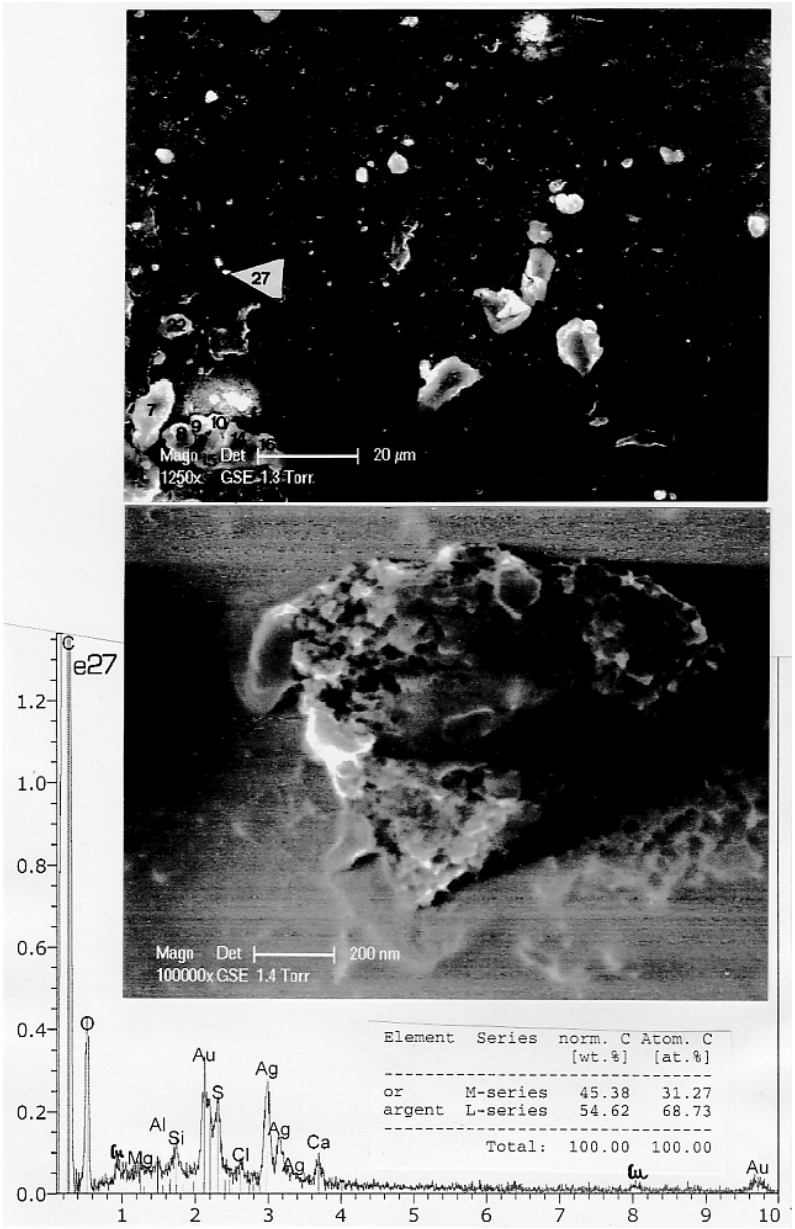

Figure 6. The e27 particle. *Upper photograph*: SEM photograph (1250×), in GSE, showing the location of the e27 particle in the Eb area. *Lower photograph*: SEM photograph (100,000×), in GSE, of this particle. *Below*: spectrum of e27. C: carbon; O: oxygen; Cu (two peaks): copper; Mg: magnesium; Al: aluminium; Si: silicium; Au (two peaks): gold; S: sulphur; Cl: chlorine; Ag (three peaks): silver; Ca: calcium. *Insert*: normal composition: or (gold); argent (silver).

3.1.4. Five Sub-Particles on the Surface of the l38 Particle

Particle l38, located in the L area, is a triangular stain of wax which external form shows reliefs of two-three adjacent parts of the linen fibers constituting the Shroud (Figure 7, above). There are numerous sub-particles (number 1, 2, 3, 4, 7', 12, 13 and 14 are indicated) on the combs of these reliefs (Figure 7, below).

Spectras of sub-particles numbered 1, 2, 3 and 4 are shown on Figure 8, and those of sub-particles numbered 7' and 12 on Figure 9. All these sub-particles

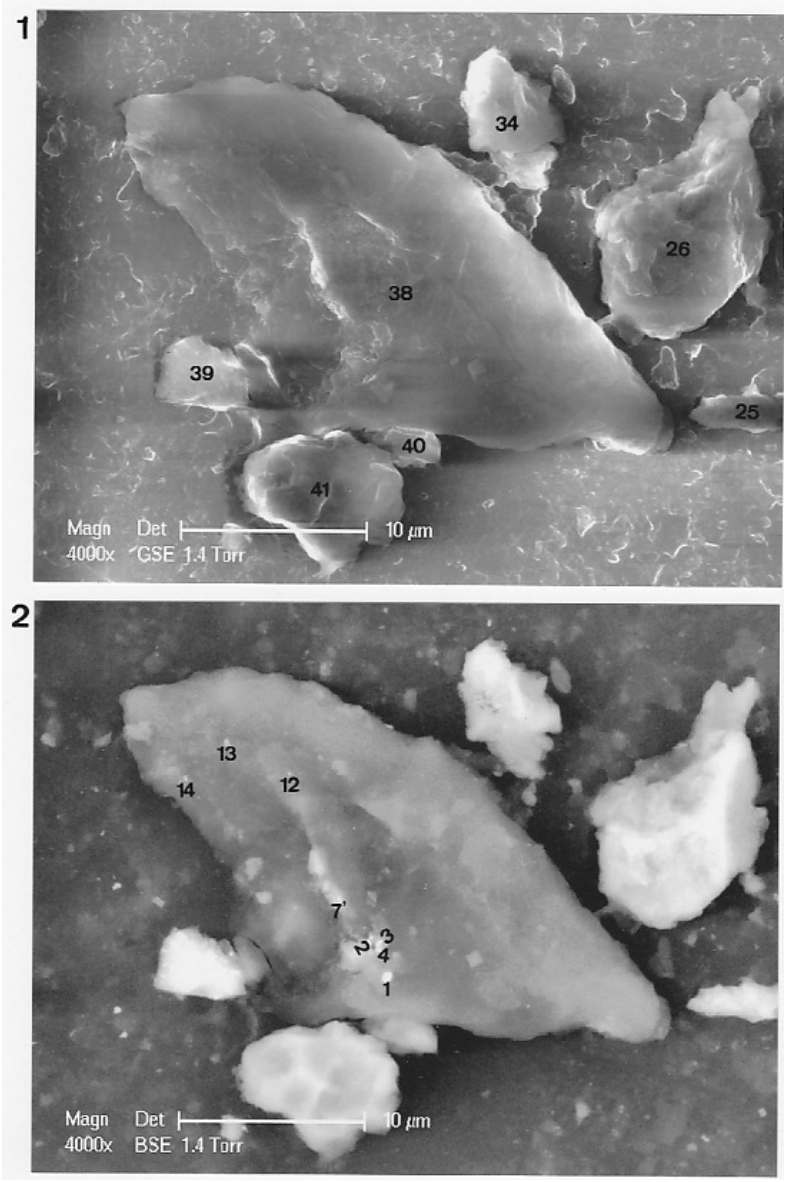

Figure 7. Sub-particles of a golden alloy loaded on the l38 particle. *Above* (**1**): SEM photograph (4000×), in GSE, of the l38 (located in the L area) and other adjacent particles: l26 (a feldspar), l34 (a calcium phosphate); l 39 (an hematite); l 40 (a silice) and l41 (a quartz). *Below* (**2**): SEM photograph (4000×), in BSE, of the l38 particle, showing the sub-particles 1, 2, 3, 4, 7', 12, 13 and 14.

(of less than 1 µm of diameter) are of golden alloy with silver (but 7 and 12), with a little quantity of copper (sub-particle 7' is rich in silicium).

These six sub-particles are micro-grains of a golden alloy powder, trapped in the wax of the l38 particle.

3.1.5. Three Sub-Particles on the Surface of the a23 Particle

The a23 particle, located in the A area (**Figure 10**, above) is of ovaloid form, with a greater dimension of about 6 µm). Its spectrum (**Figure 10**, above) is very rich in aluminium, and had gold and copper (**Figure 10**, below).

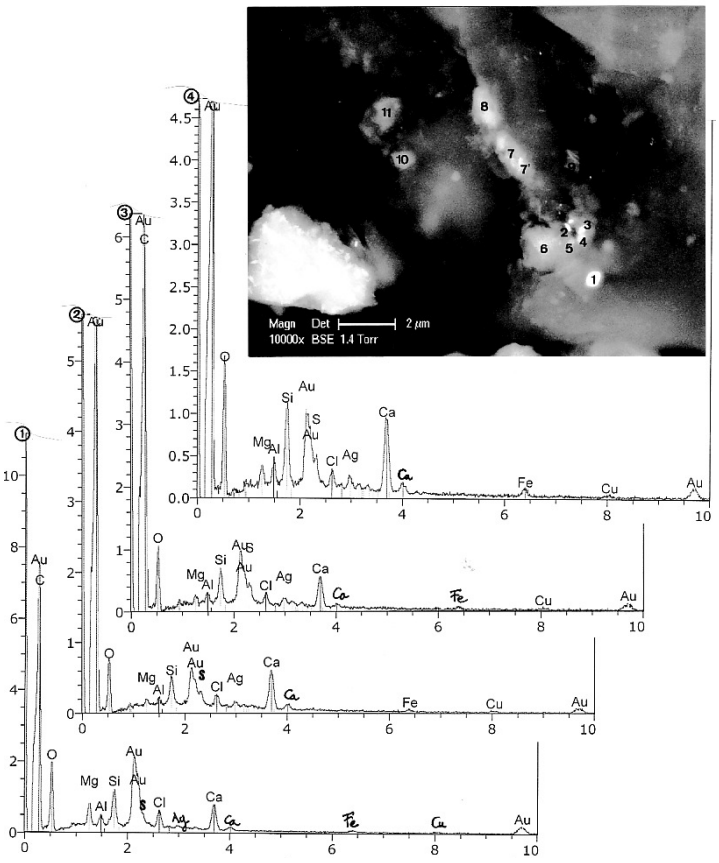

Figure 8. *Above*: SEM photograph (10,000×), in BSE, of the part of the l38 particle showing sub-particles 1, 2, 3, 4, 5, 6, 7', 8, 9, 10 and 11. *Below*: spectras of sub-particles 1, 2, 3 and 4. C: carbon, O: oxygen; Au (four peaks): gold; Mg: magnesium; Al: aluminium; Si: silicium; S: sulphur; Cl: chlorine; Ag: silver; Ca (two peaks): calcium; Fe: iron; Cu: copper.

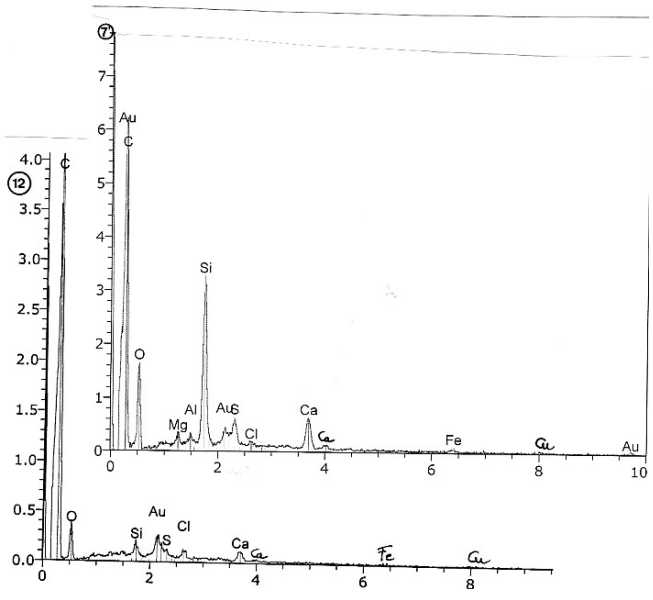

Figure 9. Spectras of sub-particles 7' and 12. C: carbon; Au (three peaks): gold; O: oxygen; Mg: magnesium; Al: aluminium; Si: silicium; S: sulphur; Cl: chlorine; Ca (two peaks): calcium; Fe: iron; Cu: copper.

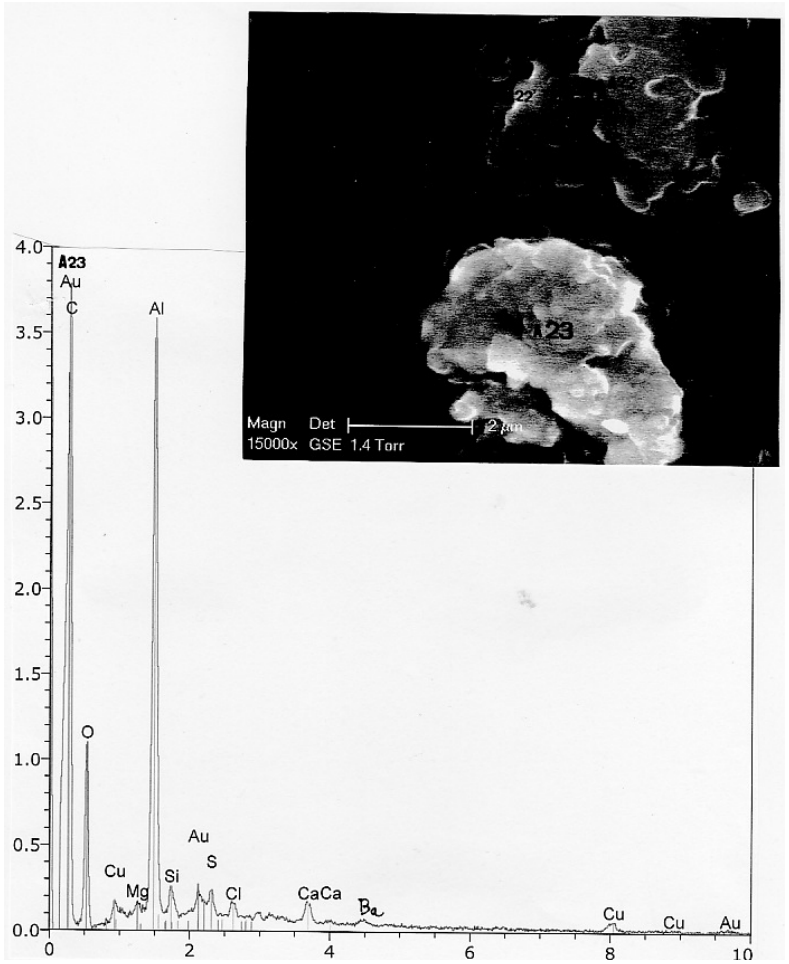

Figure 10. *Above*: SEM photograph (15,000×), in GSE, of the a23 particle (a22 and a22' are other similar particles). *Below*: spectrum of a23. C: carbon; Au (three peaks): gold; O: oxygen; Cu (three peaks): copper; Mg: magnesium; Al: aluminium; Si: silicium; S: sulphur; Cl: chlorine; Ca (two peaks): calcium; Ba: barium.

In BSE, the a23 particle shows numerous sub-particles on its surface (Figure 11, above); three of them, numbered 1, 2 and 3, are studied as examples for elementary composition. Spectras of sub-particle 1 (Figure 11, below) and of sub-particles 2 and 3 (Figure 12) are the same than that of the a23 particle.

These sub-particles are those of a modern gold/copper alloy loaded on an aluminium substrate; the whole constitutes a spot of organic material, probably a spot of painting (as shown by the presence of barium sulphate).

3.2. A Sub-Particle of Pure Gold

Particle h28, located in the H area of the triangle, is a complex between an aluminosilicate clay that is iron and titanium rich and a calcium phosphate mineral loaded with sulphur and chlorine (Figure 13). The golden sub-particle 0 is a thin micro-blade (of about 300 nm of length) of gold, deposited at one edge of a titanium micro-particle.

It is probably some part of a scale of pure modern gold.

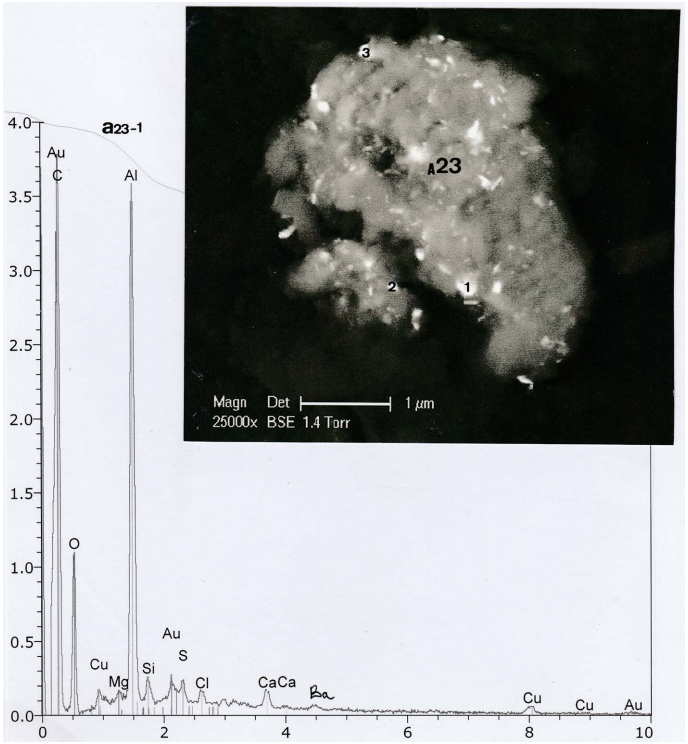

Figure 11. *Above*: SEM photograph (25,000×), in BSE, of the a23 particle; 1, 2 and 3: sub-particles on a23. *Below*: spectrum of sub-particle 1. C: carbon; Au (three peaks): gold; O: oxygen; Cu (three peaks): copper; Mg: magnesium; Al: aluminium; Si: silicium; S: sulphur; Cl: chlorine; Ca (two peaks): calcium; Ba: barium.

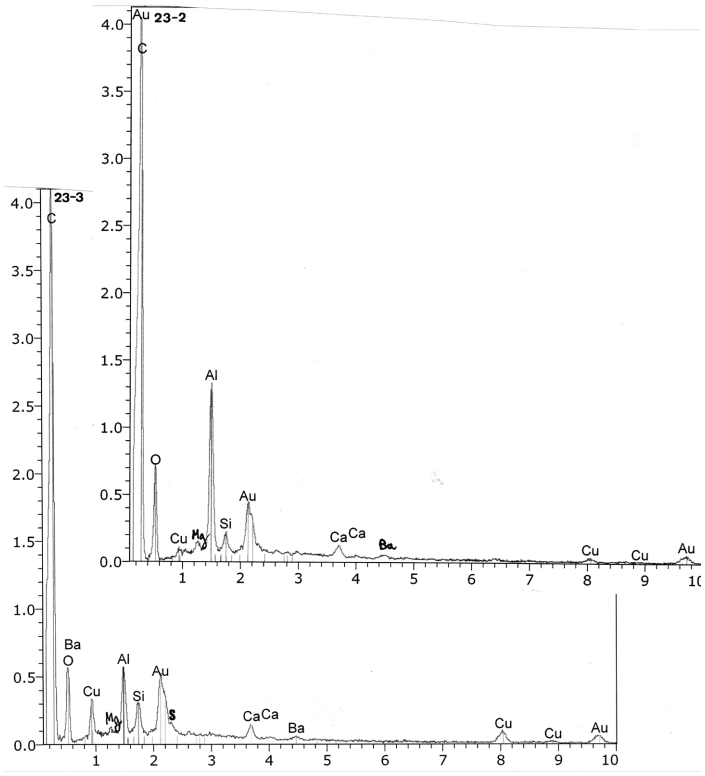

Figure 12. Spectras of sub-particles 2 and 3.

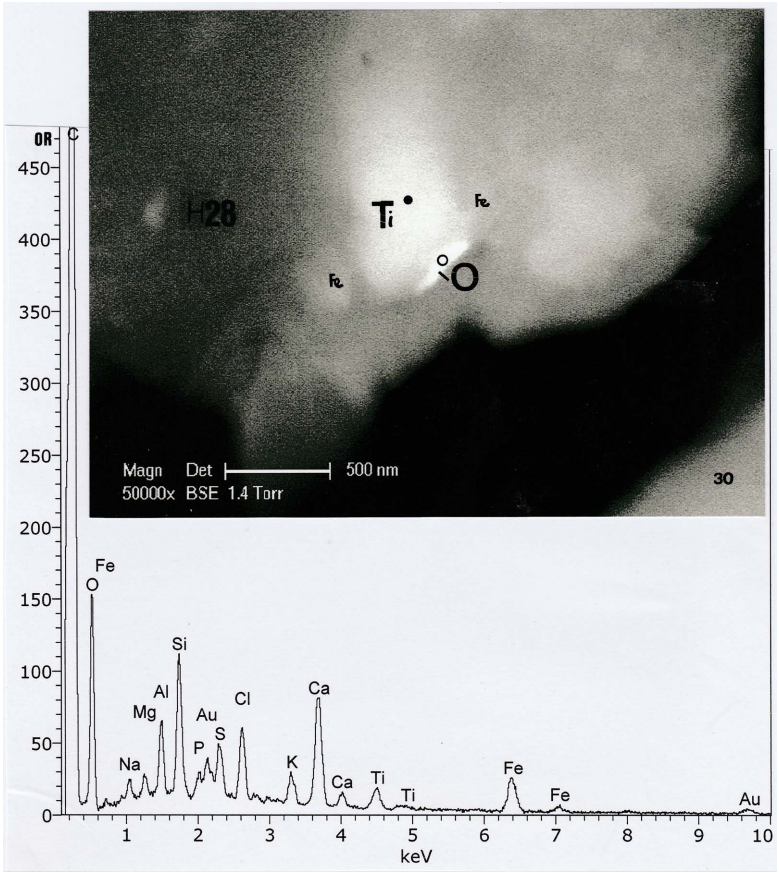

Figure 13. *Above*: SEM photograph (50,000×), in BSE, of the lower part of the h28 particle (30: some part of the h30 particle). Ti: titanium sub-particle; Fe: iron sub-particles; o: gold sub-particle. *Below*: spectrum of the o sub-particle. C: carbon; O: oxygen; Fe (three peaks): iron; Na: sodium; Mg: magnesium; Al: aluminium; Si: silicium; P: phosphorous; Au (two peaks): gold; S: sulphur: Cl: chlorine; K: potassium; Ca (two peaks): calcium; Ti (two peaks): titanium.

3.3. Particle and Sub-Particles of Pure Silver

3.3.1. The j72 Particle

Photographs of **Figure 14** show SEM (80,000×) views, in GSE and in BSE, of the j72 particle, located in the J area of the triangle. It is a small (of about 600 nm of length) elongated particle, with a granulous surface; most of the granules are bright-to-electrons, that indicates their heavy nature.

The j72 spectrum (**Figure 15**) is mainly compounded of silver; this particle is so of pure modern silver.

3.3.2. A Sub-Particle on the Edge of the i57 Particle

The i57 particle (**Figure 16**) is a quasi-rectangular particle, of about 10 μm of length, located in the I area. Its composition shows that it is an aluminosilicate clay, with some quantities of iron.

The *ag* sub-particle, bright-to-electrons, is located at the upper side of i57. The *ag* spectrum is mainly compounded of silver, with some traces of sulphur and chlorine. This *ag* sub-particle is a local deposit of pure silver on i57.

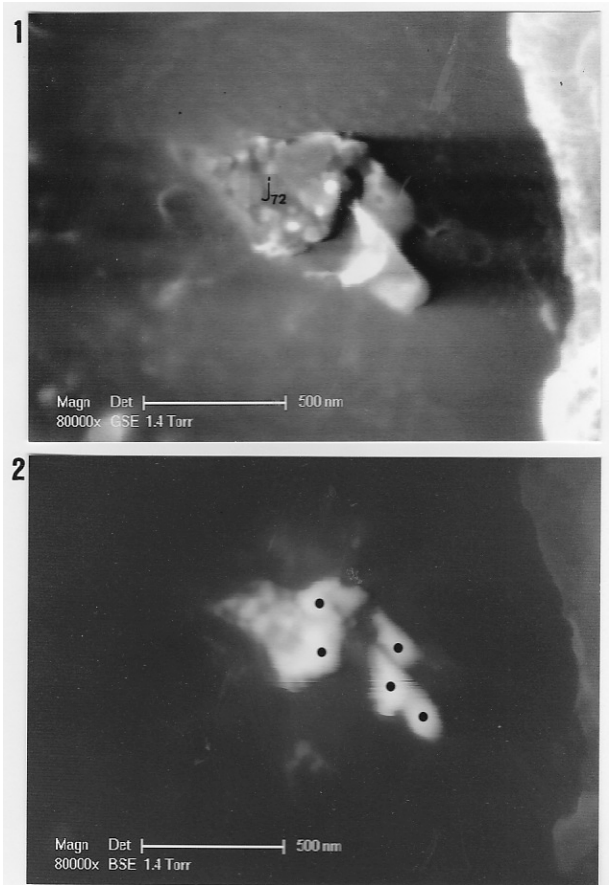

Figure 14. The j72 particle. *Above* (**1**): SEM photograph (80,000×), in GSE, of j72. *Below* (**2**): SEM photograph (80,000×), in BSE, of j72. (the five black dots indicate the granules where EDX analyses are realized).

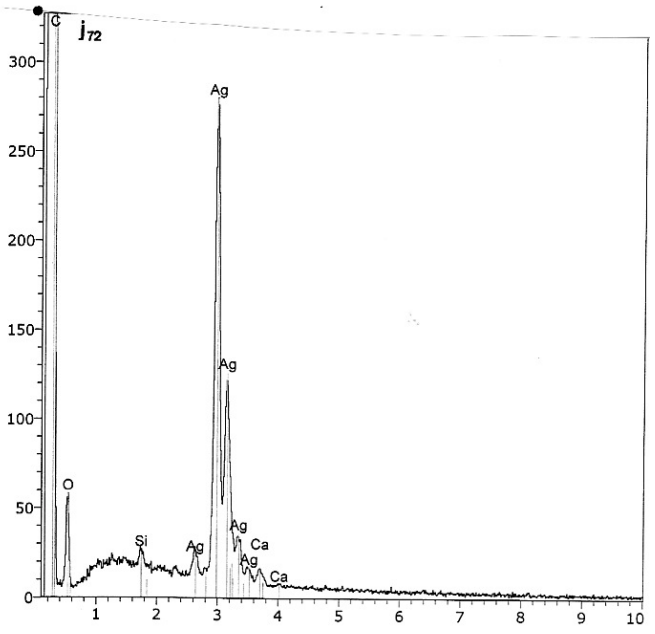

Figure 15. The j72 spectrum (in a dot). C: calcium; O: oxygen; Si: silicium; Ag (five peaks): silver; Ca (two peaks): calcium.

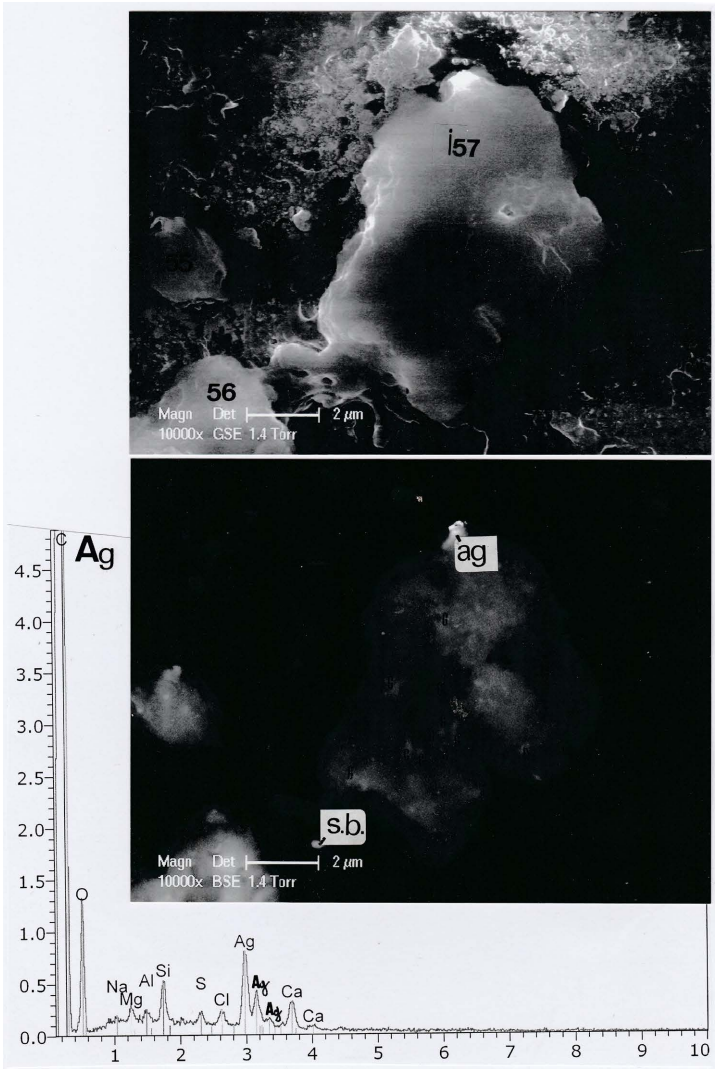

Figure 16. The i57 particle. *Upper photograph*: SEM photograph (10,000×), in GSE, of the i57 particle (i55, a lapis lazuli, and i56, a Coccolith, are adjacent particles) in some part of the I area. *Lower photograph*: SEM photograph (10,000×), in BSE, of i57 (s.b.: barium sulphate micro-particle; G: little sub-particles of iron; *ag*: the *ag* sub-particle. *Below*: The spectrum of ag. C: carbon; O: oxygen; Na: sodium; Mg: magnesium; Al: aluminium; Si: silicium; S: sulphur; Cl: chlorine; Ag (three peaks): silver; Ca (two peaks): calcium.

3.3.3. A Sub-Particle on the f13-f14 Particle

The f13-f14 particle, located in the F area, is a squared particle (of about 10 µm of side) mainly compounded of calcium phosphate (Figure 17).

The sub-particle 1, bright-to-electrons, is loaded in the center of the f13-f14 surface. Spectrum of sub-particle 1 contains silver, with some peaks of sulphur and chlorine. This sub-particle is a local deposit of silver sulphide (Ag_2S) and chloride on f13 - f14.

3.4. Particles of an Alloy of Silver and Copper

3.4.1. The p39 Particle

The p39 particle (Figure 18), located in the P area of the triangle, is a rounded

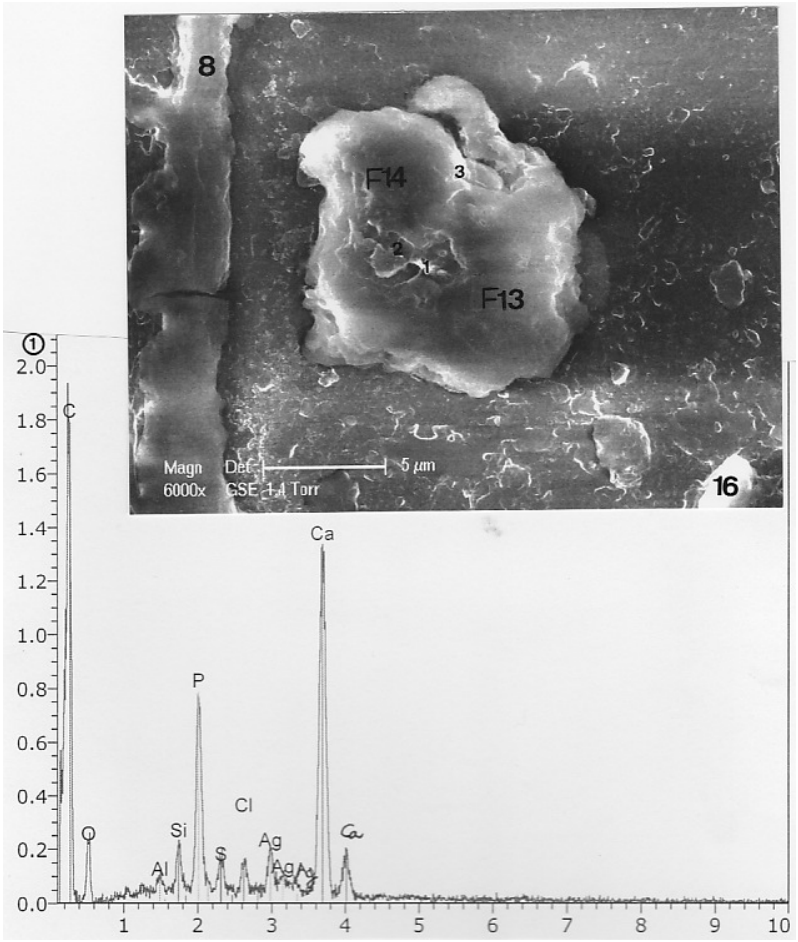

Figure 17. The f13 - f14 particle. *Above*: SEM photograph (6000×), in GSE, of the f13-f14 particle (f8: a Diatoms; f16: an hematite; 1, 2 and 3: sub-particles loaded on the f13-f14 surface. *Below*: spectrum of the sub-particle 1. C: carbon; O: oxygen; Al: aluminium; Si: silicium; P (a great peak): phosphorous; S: sulphur; Cl: chlorine; Ag (three peaks): silver; Ca (two peaks): calcium.

particle of about 7 µm of diameter. Its composition shows that it is an alumino-silicate clay with iron (relatively rich in chlorine, that indicates PVC plastic). Silver is present in this particle, together with copper.

3.4.2. The m10 Particle

The m10 particle (**Figure 19**), located in the M area, is a little rounded particle of about 2 µm of diameter. Its composition shows that this particle is mainly a mixture of copper and silver (with a little quantity of lead), the silver in its being sulphured.

This composition is similar to that of a billion (typically of 64% of copper, 35% of silver and lead traces), which was devalued pieces used in particular during the Roman Antiquity.

3.5. A Sub-Particle of Pure Copper

As an example of a sub-particle of pure copper, **Figure 20** shows the spectrum of

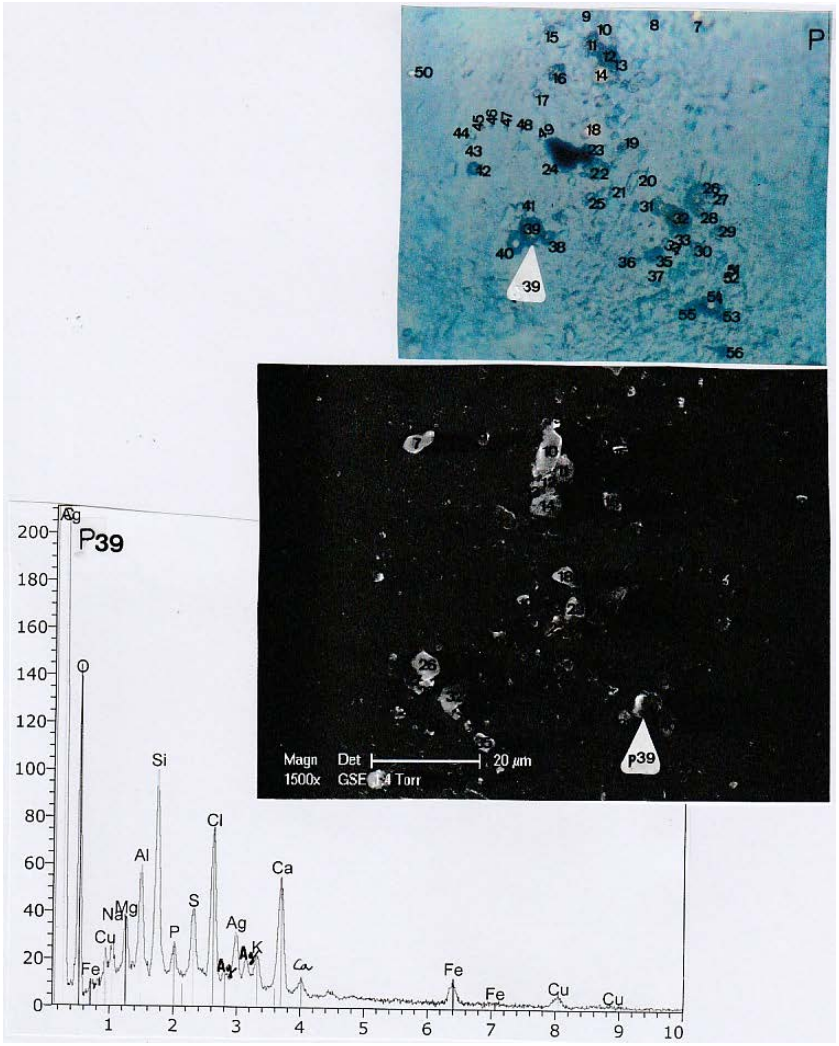

Figure 18. The p39 particle. *Upper photograph*: Optical inverted view (1000×) of the P area, showing the p39 particle (p38: a calcium phosphate; p40: a spore) *Lower photograph*: SEM photograph (1500×), in GSE, of some part of the P area where p39 is located. Below: the p39 spectrum. C: carbon; O: oxygen; Fe (three peaks): iron; Cu (three peaks): copper; Na: sodium; Mg: magnesium; Al: aluminium; Si: silicium; P: phosphorous; S: sulphur; Cl: chlorine; Ag (three peaks): silver; K: potassium; Ca (two peaks): calcium.

sub-particle 3 loaded on particle f13-f14. This spectrum shows that it is a sub-particle of pure copper, on a calcium phosphate background.

4. Discussion

A number of thirteen particles or sub-particles studied have gold in their compositions (Table 2). Only one of them (the sub-particles h28-0) is of pure gold, and the others are of gold/silver/copper or gold/copper alloys. Particles e49, b22 and sub-particle h28-0 are parts of golden scales of gold leafs; a 23-1, 2 and 3 are probably sub-particles of a golden alloy involved in painting.

Sub-particles l38-1, 2, 3, 4, 7' and 12 are grains of a powder of golden alloys that are trapped in a wax.

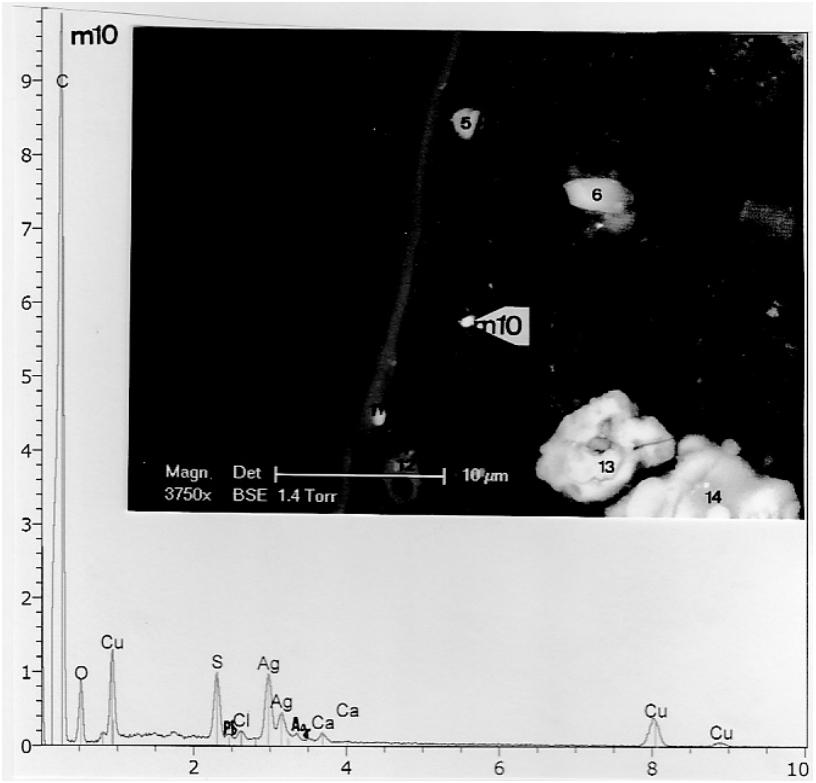

Figure 19. The m10 particle. *Above*: SEM photograph (3750×), in BSE, of the m10 particle (m5 and m6: montmorillonite particles; m11: a calcite particle). *Below*: the spectrum of m10. C: carbon; O: oxygen; Cu (three peaks): copper; S: sulphur; Pb (traces): lead; Ag (three peaks): silver; Ca (two peaks): calcium.

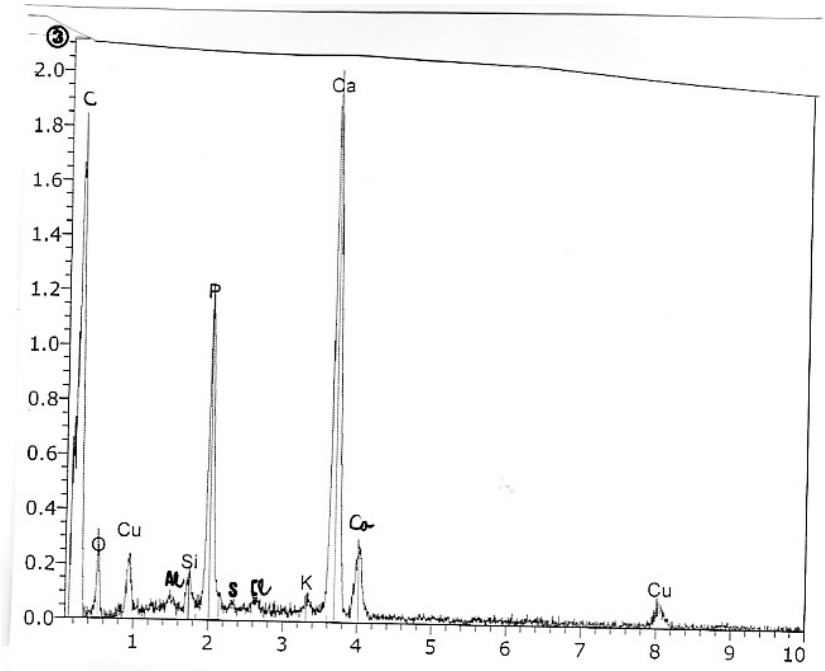

Figure 20. Spectrum of sub-particle 3, loaded on particle f13 - f14. C: carbon; O: oxygen; Cu (two peaks): copper; Al: aluminium; Si: silicium; P: phosphorous; S: sulphur; K: potassium; Ca (two peaks): calcium.

Table 2. Characterisation of particles containing gold.

Numbers	Areas	Particles/ sub-particles	Forms	Dimensions	Compositions	Linked to linen fibers	Distinctive Features
1	A	a23-1	angulated	200 nm	gold/copper	no	sub-particle of a23
2	A	a23-2	angulated	150 nm	gold/copper	no	sub-particle of a23
3	A	a23-3	angulated	100 nm	gold/copper	no	sub-particle of a23
4	B	b22	squared	L = 7 µm l = 2 µm	gold/silver/copper	near the LF3	
5	Eb	e27	triangular	l = 650 nm h = 900 nm	silver/gold/traces of copper	no	electrum
6	Ec	e49	elongated	L = 12µm l = 5 µm	silver/gold/copper	at the part 2 of LF4	
7	H	h28-0	elongated	L = 275 nm l = 80 nm	Pure gold	no	
8	L	l38-1	rounded	0.5 nm	gold/silver/copper	no	in the wax of l38
9	L	l38-2	elongated	250 nm	gold/silver/copper	no	
10	L	l38-3	elongated	250 nm	gold/silver/copper	no	in the wax of l38
11	L	l38-4	rounded	250 nm	gold/silver/copper	no	in the wax of l38
12	L	l38-7'	elongated	250 nm	gold/copper	no	in the wax of l38
13	L	l38-12	spherical	250 nm	gold/copper	no	in the wax of l38

Table 3. Characterisation of other particles containing silver.

Numbers	Areas	Particles/ sub-particles	Forms	Approximate dimensions	Compositions	Distinctive features
1	F	F13-f14-1	elongated	1 µm	silver sulphide and chloride	sub-particle on f13-f14
2	I	I57-ag	pentagonal	1.3 µm	silver	Part of a colorant
3	J	j72	in two parts	700 nm	pure silver	
4	M	m10	ovoid	1 µm	copper/silver alloy (Pb traces)	billion
5	P	p39	approximatively pentagonal	7µm	silver/copper alloy	in a PVC plastic

Particle e27 is possibly some part of a coin of the famous Byzantine electrum (Fanti & Furlan, 2019).

Five other particles or sub-particles have also silver in their compositions (Table 3). Three of them (particle j72 and sub-particles f13-f14-1 and i57*ag*) are of pure silver, and the two others (m10 and p39) are of a silver/copper alloy.

The m10 particle is possibly a part of a billion, a coin of copper mainly, that was used during the Roman Antiquity.

5. Conclusion

Recently, Fanti & Furlan (2019) studied the composition of gold alloy micropar-

ticles from the Turin Shroud and compared it with that of gold Byzantine coins minted during the VII-XIII Centuries.

SEM-EDX studies of the triangle sample of the TS permit me to detect a total number of eighteen particles (or sub-particles) that contain gold and silver. Most of those containing gold are in fact of gold/silver/copper or gold/copper alloys, and among the five that are also of silver two of them are of a silver/copper alloy.

This indicates that the TS, at some moments of its story, was decorated by objects compounded of particles of gold and silver. What are these objects of precious metals? Among the golden particles, the sub-particle h28-0 only is of pure gold; three particles on five that are compounded of silver (particle j72 and sub-particles f13-f14-1 and i57-*ag*) are of pure silver. Particles e49 and b22 (of a gold/silver/copper alloy) are likely parts of scales of gold leafs (by its form, sub-particle h28-0 is probably also a part of a gold scale). Sub-particles l38-1, 2, 3 and 4 (of a gold/silver/copper alloy) and sub-particles l38-7' and 12 (of a gold/copper alloy) are micro-grains of golden alloys that are parts of a gold powder. The three a23-1, 2 and 3 sub-particles (of a gold/copper alloy) are the metallic parts of a spot of painting.

The e27 particle is compounded of electrum; this sort of particle could be some part of a coin of Byzantine money (according to Fanti & Furlan, 2019). In the same way, the m10 particle, of a copper/silver alloy, with lead traces, could be part of a billion (a money coin used during the Roman Antiquity). So, only a minor proportion (2 on 18) of TS particles containing gold and/or silver could correspond to parts of coins of moneys. Most of the particles and sub-particles I found on the TS were parts of scales of gold leaf and powders that were used for some sacralised and decorative reasons.

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Conflicts of Interest

The author declares no conflicts of interest regarding to publication of this paper.

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