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RESEARCH ARTICLE

Micro-Splinters of Semi-Precious Stones on the Turin Shroud: Optical Microscopy Studies and SEM-EDX Analyses

Gérard Lucotte[1] Thierry Thomasset[2]

[1]*Institute of Molecular Anthropology, Paris, France.*

[2]*Laboratory of Physico-Chemical Analysis, UST of Compiegne, Compiègne, France.*

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Corresponding Author: Gérard Lucotte, Institute of Molecular Anthropology, Paris, France.

Abstract

We have explored, by optical microscopy and scanning electron microscopy coupled with energy dispersive X-ray, sixteen particles of semi-precious stones (peridot, chrysolite, chlorite, citrine, cornelian, garnet and jet) located in a sample of the Face area of the Turin Shroud. These particles, of different colours, are micro-splinters of their semi-precious stone counterparts. They were intentionally deposited on the Turin Shroud at different times of its story, for decorative and sacralised reasons. Some of them (peridot, chrysolite, citrine, cornelian and jet) are related to the Bible or to Christianity.

Keywords: Turin Shroud, Face Area, Semi-Precious Stones, Optical Microscopy, Scanning Electron Microscopy, Energy Dispersive X-Ray.

1. Introduction

The Turin Shroud (TS) is a well-known tissue (5) on which a body image (that of the Christ?) is imprinted. We have obtained a small triangular sticky tape that was sampled on the TS surface (corresponding to the Face of this body) and we concentrated in the past years on the study of microscopic particles located on the surface of this sticky tape (2). The term of semi-precious stones is actually obsolete (6), and is mainly replaced by that of gems. We reported here in some details, by optical microscopy studies and SEM-EDX analyses, some micro-splinters of diverse semi-precious stones (peridots, chrysolite, chlorites, citrine, cornelian, garnet and jets) founded on the triangle surface.

2. Material and Methods

The material is the small (1.36 mm height, 614 µm wide) sticky tape triangle at the surface of which all particles were deposited. The surface of this triangle was subdivided into nineteen sub-samples areas, named A to S. *Table 1* lists and describes the seven samples of semi-precious stones used as references in this study.

Table 1. *List and descriptions of the seven semi-precious stones used as references.*

Semi- precious stones	Descriptions of the samples	Geographic origins of the samples	Suppliers
Peridot	a cut-stone peridot		Atelier de Gemmologie et de Minéralogie (AGM), Les
Chrysolite	chrysolite inclusions on a basalt	Cantal (France)	Carroz, France Alain Carion, Paris
Chlorite	a chlorite rock on a quartz	Brasil	Alain Carion
Citrine	a citrine gem	Madagascar	AGM
Cornelian	a cornelian gem	India	Alain Carion
Garnet	a cut-stone pyrope variety		AGM
Jet	a polished rock	Carelia (Russia)	Alain Carion

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All the particles were previously observed (to determinate colour) by optical microscopy (both in direct and inverted positions of the triangle) using a photo-microscope Zeiss (model III,1972).

The particles were also observed, with any preparation, on the adherent part of the surface of the triangle. The observation of most of them were first conducted by SEM (Scanning Electron Microscopy), using a Philips XI Instrument (of the environmental version). GSE (Gazeous Secondary Electrons) and BSE (Back Scattered Electrons) procedures were used, the second one to better detect heavy elements. Elemental analyses for each particle observed were realized by EDX (Energy Dispersive X-ray), thismicroscope being equipped with a Bruker probe AXS-EDX (the system analysis is PGT : Spirit Model of Princeton Gamma Technology).

Particles b27, b43, j15, k42, p24 and r35 were examined with another SEM apparatus (SEM2) : a FEI model Quanta 25 of FEG, both in LFD (Large Field Detector) an CBS (Circular Back Scattering) procedures.

The cornelian sample of reference was studied by a third SEM apparatus (SEM3), an Auriga FEG-FIB (Zeiss).

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. Highly Resolutive (HR) spectras are those where the ordinates graduations are enhanced, to better see little elemental peaks.

The elemental compositions (based on each of the main elemental rays) are given for each of the samples of references and for some particles. Normal compositions in elements are those where carbon and oxygen are not taken in consideration.

Because of its symbolic importance, the r35 particle mapped for its elements. EDX mapping was obtained (power : 20kv ; distance : 9.9 mm ; acquisition time : 15 min), for each of its elements.

3. Results

We have found on the triangle surface several particles of peridots, chrysolite, chlorites, citrine, cornelian, garnet and jets. The following items describe each of them.

3.1 Peridots

Peridot is a well-known green semi-precious stone. It is a magnesium silicate mineral, which contains iron. Its chemical formula is $(Mg, Fe)_2 Si O_4$.

Figure 1 shows the characterization of the peridot stone of reference, which is a cut jewel. Its colour is green. Its spectrum contains oxygen, iron, magnesium and silicium, and a little peak of aluminium ; in its normal elementary composition magnesium, silicium, iron and aluminium are of about 42%, 31%, 26% and 0,88% respectively. Other analyses realized on peridots of more or less green colours shows that the intensity of green depends on the height of the aluminium peak.

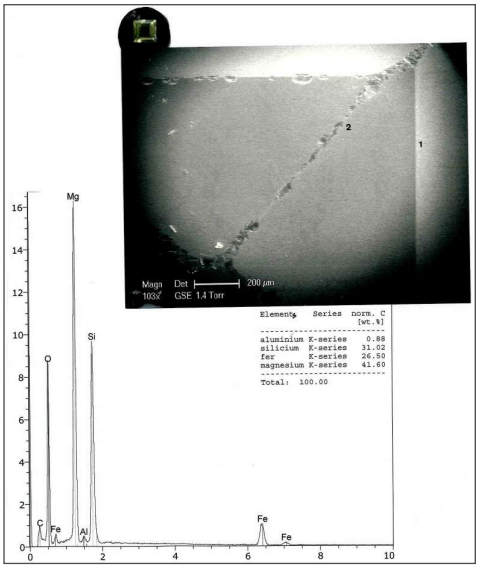

Figure 1. *The peridot of reference. Lower photograph : SEM1 photograph (103x), in GSE, of some part of the surface of this stone, showing two cuts (1 : the first cut ; 2 : the second cut). Upper photograph : optic photograph of the cut stone. Below : global spectrum of this surface. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium . Insert : the normal composition of this surface ("fer" : iron).*

We detected six particles of peridots on the triangle surface: b42 and b43, d35, g1 and r28 and r28-1.

Among them, peridot g1 is the greatest (Figure 2). It is a particle of losangic form and of a maximal dimension of about 40 µm, located in the G area of the triangle. Its spectrum is typical of a peridot (but with some carbon and calcium contamination). Its colour is clear-green in optic photography.

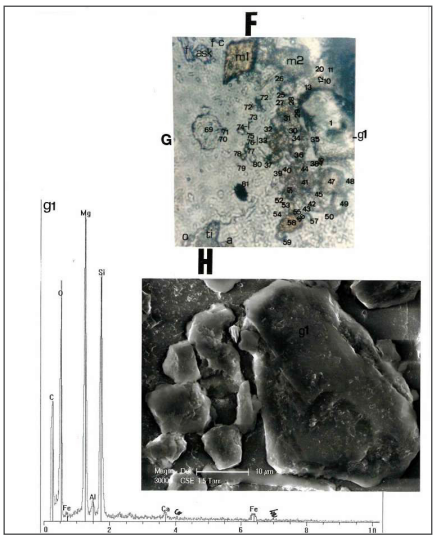

Figure 2. *The g1 particle. Upper photograph : optical microscopy photograph (1200x)showing g1 in the G area (F : lower part of the F area ; H : upper part of the H area). Lower photograph : SEM1 photograph (3000x), in GSE, of some part of the G area showing g1. Below : the g1 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Ca (two peaks) : calcium.*

The particles b42 and b43 are adjacent elongated (of about 10 µm and 25 µm of lengths) particles located in the block of particles located in the B area (Figure 3). Their smooth surfaces, where the crests are oriented longitudinally, suggest that they are micro-splinters of a cut stone. Because of the border effect of the triangle surface in that area part the b42 particle cannot be seen in optic microscopy, but the colour of the b43 extremity appears as pale-green. Figure 4 and Figure 5 show the b42 and b43 spectras; they are typical of those of peridots, althrough some contaminations by carbon, and minor contaminations of calcium, sulphur and potassium.

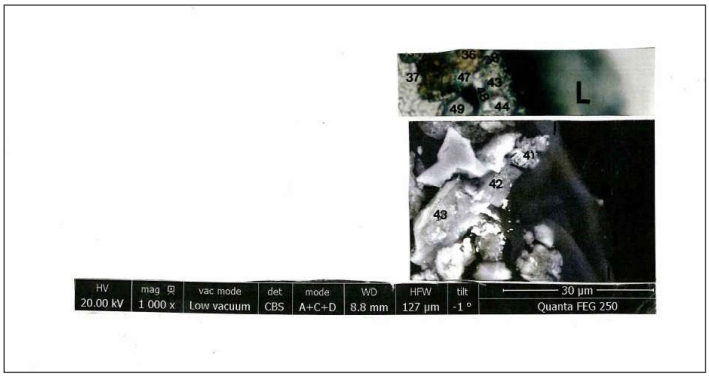

Figure 3. *Particles b42 and b43. Lower photograph : SEM2 photograph (1000x), in CBS, of some part of the right side of the B area showing b42 and b43 (l : the right limits of the border of this area side). Upper photograph : optical microscopy photograph (1200x) of some part of this right side (L : the right limit) showing b43.*

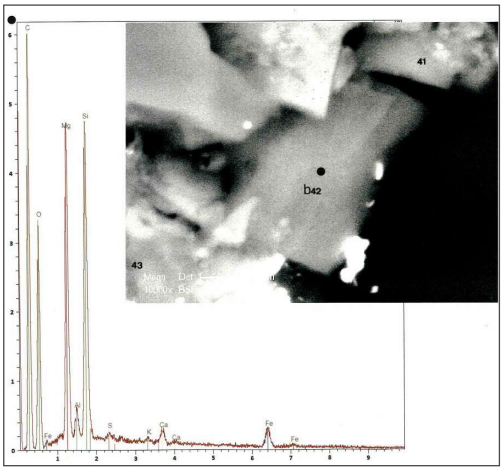

Figure 4. *The b42 particle. Above : SEM1 photograph (10000x), in BSE, of some part of the B area showing b42 (the black dot indicates the approximate surface where SEM-EDX analysis is realized). Below : the HR spectrum of b42. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; K : potassium ; Ca (two peaks) : calcium.*

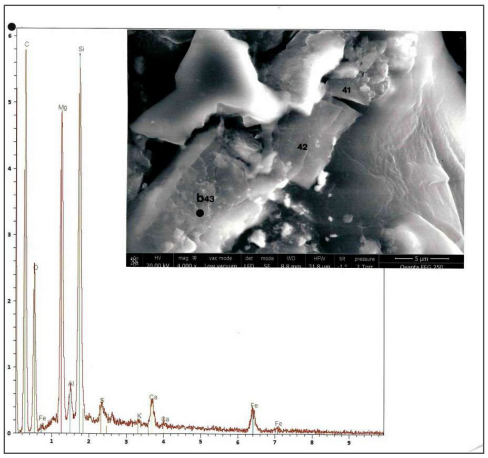

Figure 5. *The b43 particle. Above : SEM2 photograph (2000x), in LFD, of some part of the B area showing b43 (black dot). Below : HR spectrum of b43.*

The d35 particle is an elongated particle (of about 15 µm of length) located in the D area, which is green in optic photography (Figure 6). Its spectrum is typical of a peridot.

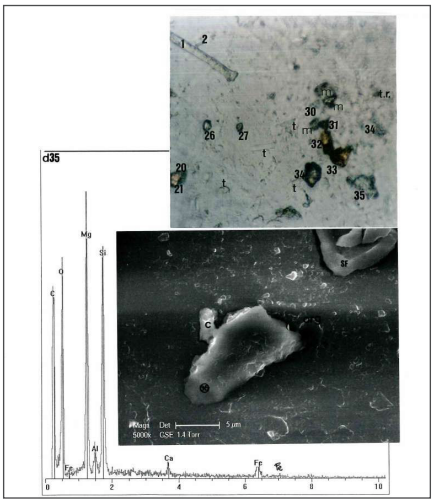

Figure 6. *The d35 particle. Lower photograph : SEM1 photograph (5000x), in GSE, of some part of the D area showing d35 (C : calcium carbonate ; org : organic sub- particle ; SF : iron sulphate). Upper photograph : inverted optical microscopy photograph (1200x) of the D area showing d35. Below : the d35 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Ca : calcium.*

The r28 particle, located in the R area, is rectangular micro-splinter of about 5µm on 2µm (Figure 7). Its spectrum is typical of a peridot (because of its proximity to the R area border, it is not seen in optic microscopy). At the right extremity, one can see a fine silica micro-blade which caused the micro- splinter. The little r28-1 particle, located below r28, is also a peridot micro- splinter.

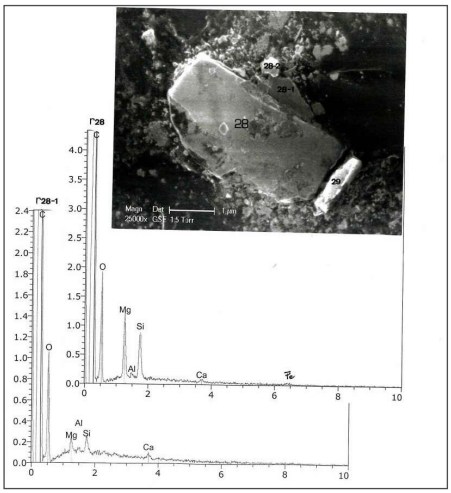

Figure 7. *Particles r28 and r28-1. Above : SEM1 photograph (25000x), in GSE, of some part of the R area showing r28 and r28-1 (r28-2 is an Ostracod and r29 a silica. Below : HR spectras of r28 and r28-1. C : carbon ; O : oxygen ; Mg : magnesium ; Al : aluminium ; Si : silicium ; ca : calcium ; Fe (traces) : iron.*

3.2 Chrysolite

The lower SEM photograph of Figure 8 shows some part of the S area containing the r35 particle. It is a relatively great particle, bipartite, the maximal length of its r35-1 part being of about 18 µm and that of its 35-2 part being of 15µm. Its spectrum taken in its common part is that of a peridot, but with a relatively important aluminium peak height and presence of chromium. The relative proportions of iron compared to chromium in its composition are of about 72% and 28%, respectively. HR spectras of six of its components (1-6 revealed in CBS (Figure 9) are approximatively the same (Figures 10 and 11) : those of a peridot aluminium-rich and with chromium (but that of component 4 contains also barium sulphate). The relative proportions of iron compared to chromium in component 6 are of about 81% and 19%.

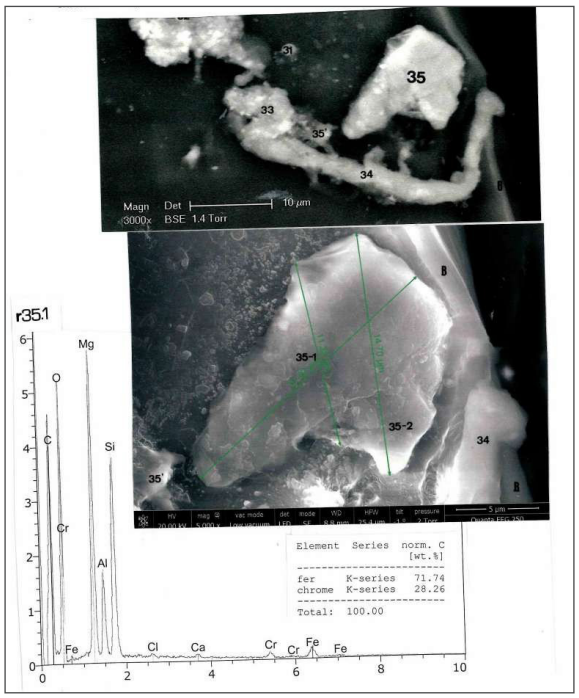

Figure 8. *the r35 particle. Upper photograph : SEM1 photograph (3000x), in BSE, of some part of the right R area showing r35 (b : right border of the triangle). Lower photograph : SEM2 photograph (5000x), in LFD, showing r35 (in two parts : r35-1 and r35-2), r35-1 being the approximate location where the SEM-EDX analysis is realized. Below : the r35 spectrum. C : carbon ; O : oxygen ; Cr (three peaks) : chromium ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Cl : chlorine ; Ca : calcium. Insert : iron / chromium composition ("fer" : iron ; "chrome" : chromium).*

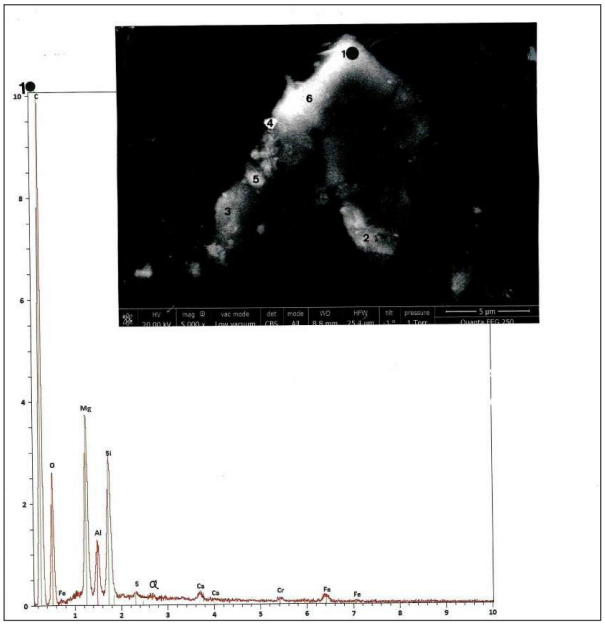

Figure 9. *The r35 particle, in CBS. Above : SEM2 photograph (5000x), in CBS, of r35 (1,2,3,4,5 and 6 are different parts of r35) ; the black dot indicates the approximate location of the SEM-EDX analysis. Below : HR spectrum of r35-1. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; Ca (two peaks) : calcium ; Cr : chromium.*

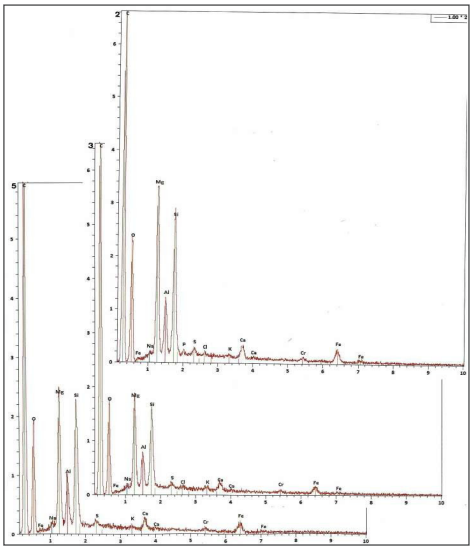

Figure 10. *HR spectras of r35-2, r35-3 and r35-5 (P : phosphorous).*

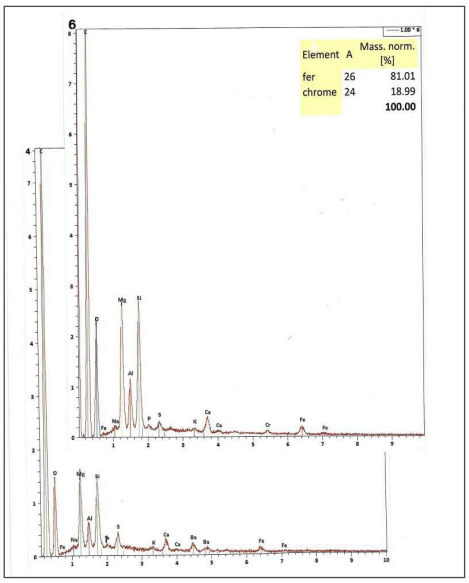

Figure 11. *HR spectras of r35-6 and r35-4 (Ba : barium). Insert iron / chromium composition of r35-6 ("fer" : iron ; "chrome" : chromium).*

Figures 12 and 13 shows results of r35 mapping. All elements (carbon, oxygen, magnesium, silicium, aluminium and calcium) are well represented ; the two last images indicate the relative contents of iron and of chromium.

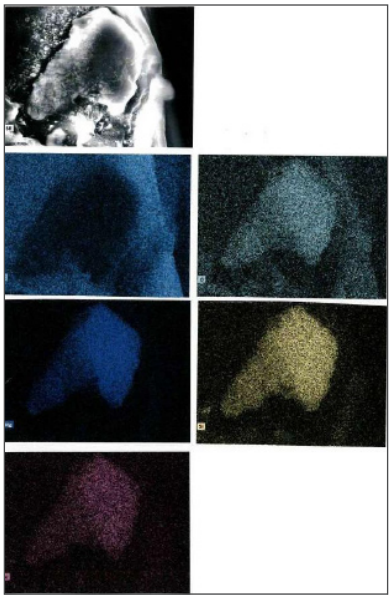

Figure 12. *Mapping of r35. SE : SEM1 photograph. C : carbon ; O : oxygen ; Mg : magnesium ; Si : silicium ; Al : aluminium.*

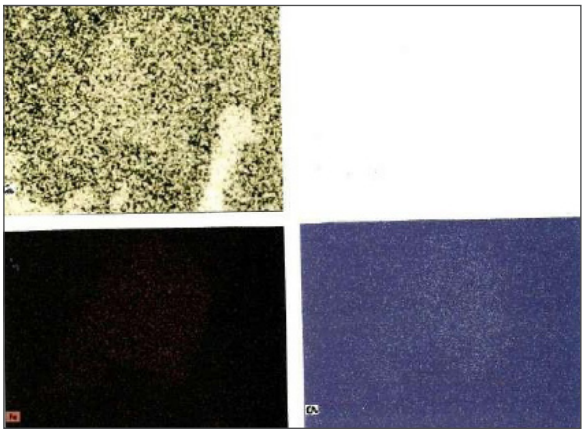

Figure 13. *Mapping of r35 (continuation). Ca : calcium ; Fe : iron ; Cr : chromium.*

Because of its proximity to the right border of the S area of the triangle, the r35 particle is only partially invisible in optical microscopy (Figure 14) ; its left extremity appears as yellow.

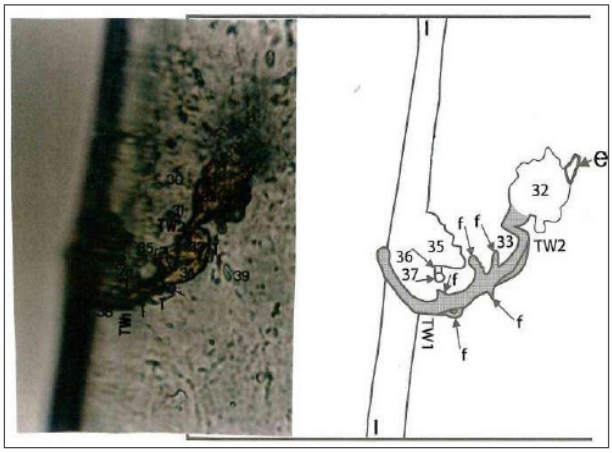

Figure 14. *Inverted optical microscopy photograph (1200x) of the lower part of the r area showing the left extremity of the r35 particle. At the right, diagrammatic drawing of this area part (l : limits of the right border of the R area ; e : fiber extremity; TW1 and TW2 : twists along this fiber).*

The Figure 15 summarizes results obtained in the chrysolite specimen of reference, a golden inclusion in a basaltic rock. The spectrum of a chrysolite crystal of this sample is that of a peridot, with a relatively important aluminium peak height and presence of chromium ; so, we demonstrated that the r35 particle is a chrysolite.

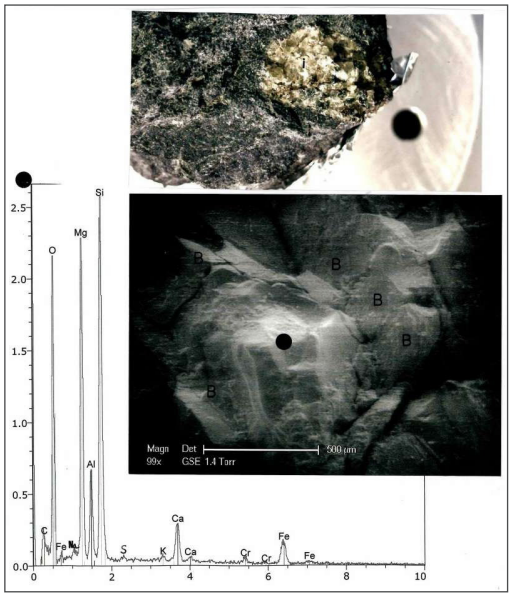

Figure 15. *The chrysolite of reference. Upper photograph : optic photograph of the sample (i : the gilded chrysolite, on the dark basalt). Lower photograph : SEM1 photograph (99x), in GSE, of a chrysolite crystal (the dark sport indicates the approximate location where the SEM-EDX analysis is realized) on basalts (B). Below: HR spectrum of the chrysolite crystal. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; K : sulphur ; K : potassium ; Ca (two peaks) : calcium ; Cr (two peaks) : chromium.*

3.3 Chlorites

The term of chlorite is a general name designating several minerals that are hydrated phyllo-silicates having the general chemical formula : (Fe, Mg, Al) 6 (Si, Al) 4 O10 (OH) 8. Chlorites are generally green. They are most often known to mineral collectors as inclusions in or coatings on quartz.

As a chlorite of reference, we have studied such inclusions deposited on the surface of a quartz stone (Figure 16) ; these inclusions are a small ofstacked up monoclinic crystals. The SEM photograph of this figure shows one of the crystal (its colour is green in optical microscopy) ; its spectrum corresponds to the nimite form of chlorite : (Ni, Mg, Fe)$_5$Al(Si$_3$Al) O$_{10}$ (OH)$_{8.}$ On its surface, once can distinguish several chlorite rollers.

The SEM photograph of Figure 17 shows a segment of such a roller. Its spectrum corresponds to the chamosite form of chlorite : (Fe, Mg, Fe)$_5$ Al (Si$_3$ Al) O$_{10}$ (OH, O)$_{8.}$

We detected four particles of chlorites on the triangle surface : b75, g86, i2 and k42.

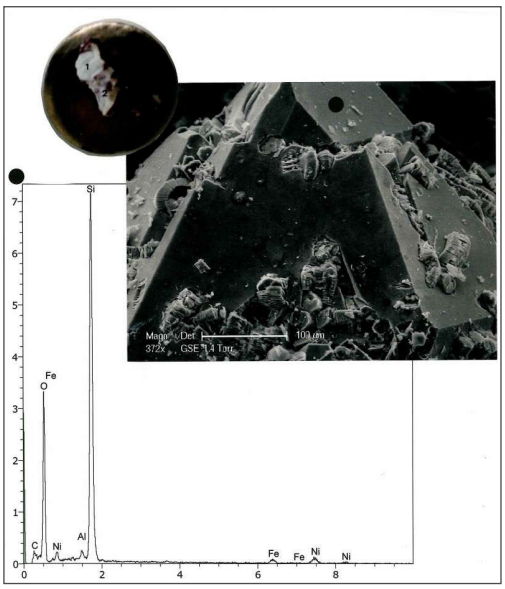

Figure 16. *The chlorite of reference. Rounded photograph : optic photograph of the chlorite (1) on a quartz (2). Lower photograph : SEM1 photograph (372x), in GSE, of the upper extremity of 1 showing the crystallin form ; the black dot indicates the approximate location where the SEM-EDX analysis is realized (r : one example of a roller). Below : the spectrum of 1. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Ni (three peaks) : nickel ; Al : aluminium ; Si : silcium.*

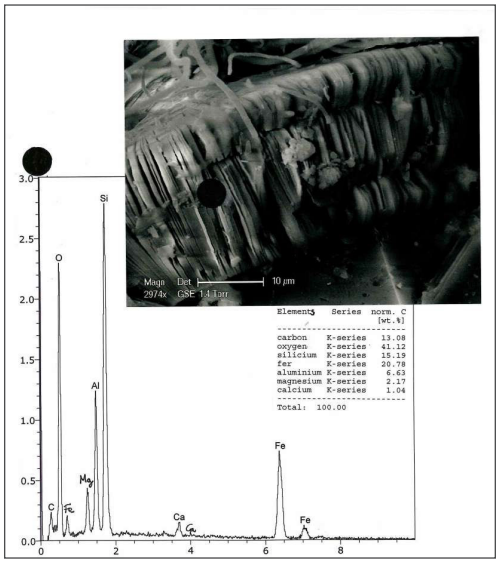

Figure 17. *Details of the roller r. Above : SEM1 photograph (297x), in GSE, of the roller (the black dot indicates the approximate location where the SEM-EDX analysis is realized). Below : HR spectrum of the roller. C : carbon ; O : oxygen ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Ca (two peaks) : calcium. Insert : elemental composition of the roller ("fer" : iron).*

The SEM photograph of Figure 18 shows the b75 particle, a typical chlorite already described (1). It is a little particle, of an approximatively quadrangular form, with a maximal dimension of about 5 µm. Its spectrum corresponds to the chamosite form of chlorite. Its colour is pale- green in optical microscopy.

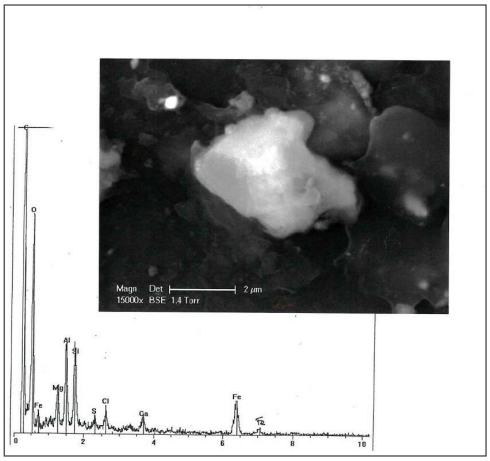

Figure 18. *The b75 particle. Above : SEM1 photograph (15000x), in BSE, of some part of the B area showing b75. Below : the b75 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; Ca : calcium.*

The SEM photograph of Figure 19 shows the g86 particle. It is a quasi-squared particle, of about 8µm of maximal dimension. Its spectrum corresponds to the sudoite form of chlorite : $Mg_2(Al, Fe)_3 Si_3 AlO_{10}(OH)_8$. Its colour is green.

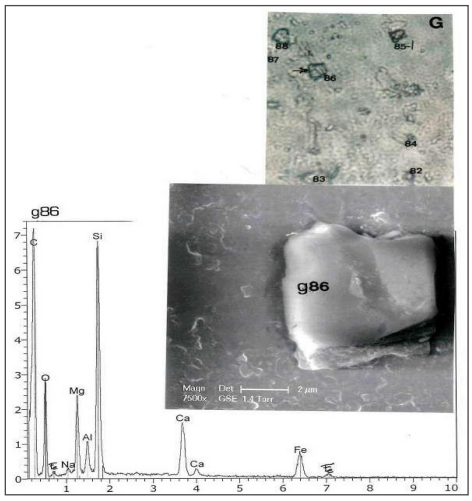

Figure 19. *The g86 particle. Lower photograph : SEM1 photograph (7500x), in GSE, of some part of the G area showing g86. Upper photograph : optical microscopy photograph (1200x) of a more extended part of the G area showing g26 (arrow). Below : the g86 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Ca (two peaks) : calcium.*

The SEM photograph of Figure 20 shows the i2 particle. It is a losangic particle, of about 5µm of maximal dimension. Its spectrum corresponds to the clinochlore form of chlorite : $(Mg, Fe)_5Al(Si_3 Al) O_{10}(OH)_8$. Its colour is green.

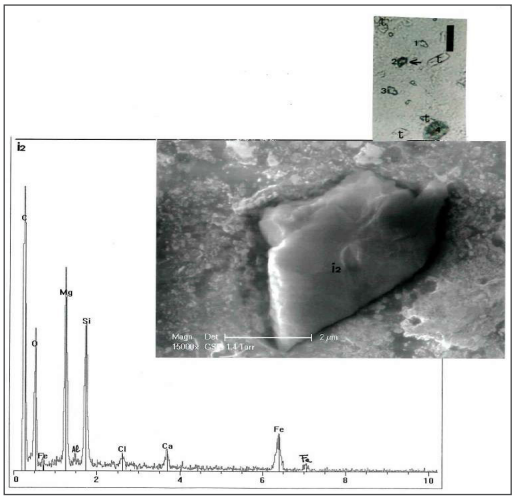

Figure 20. *The i2 particle. Lower photograph : SEM1 photograph (15000x), in GSE; of some part of the I area showing i2. Upper photograph : optical microscopy photograph (1200x) of a more extended part of the I area showing i2 (arrow). Below : the i2 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Cl : chlorine ; Ca : calcium.*

The SEM photograph of Figure 21 shows the k42 particle. It is approximately of triangular form, of about 7 µm of maximal dimension. Its spectrum corresponds also to the clinochlore form of chlorite. Its colour is yellow-green. Figure 22 shows the form and nature of the sub-particle 2 on its surface (a sulphur deposit).

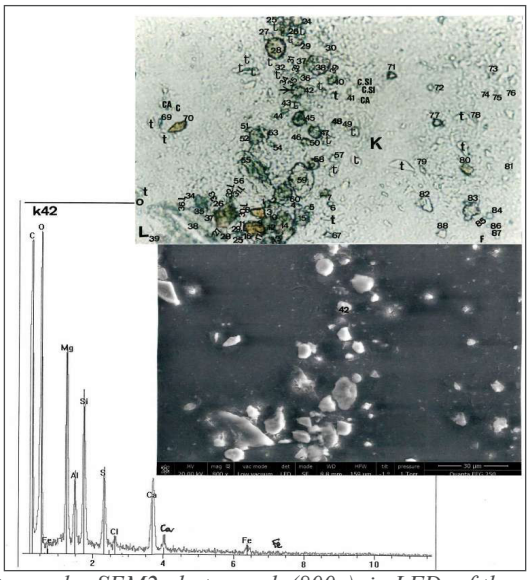

Figure 21. *The k42 particle. Lower photograph : SEM2 photograph (800x), in LFD, of the area K showing k42. Upper photograph: optical microscopy photograph (1200x) of a more extended part of the K area showing k42 (arrow). Below : the k42 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; Ca (two peaks) : calcium.*

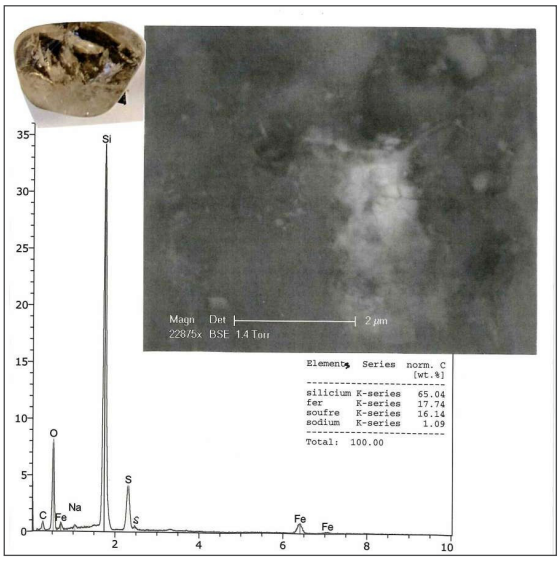

Figure 22. *Sulphur deposit on k42. Upper photograph : SEM2 photograph (8000x), in LFD, of k42. Lower photograph : SEM2 photograph (8000x) in CBS, of k42 (1 : part of the chlorite ; 2 : part of the sulphur). Below : staked spectras of 1 (in blue) and 2 (in red). C : carbon ; O : oxygen ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Ca (two peaks) : calcium ; Fe (two peaks) : iron.*

3.4 Citrine

Citrine is a quartz (SiO_2), which colour is yellow-brown. Iron gives this colour to citrine, by a mechanism of charges transfer (O^2-Fe^{3+}).

Figure 23 shows the results of a citrine stone of reference, which is yellow-brown. The citrine spectrum, at the level of iron inclusions, is that of a quartz with iron (and sulphur). In the normal composition of this sample, we found the following percentages of elements : silicium (65%), iron (18%), sulphur (16%) ; there are sodium traces (about 1%).

We found only one citrine particle (l18) on the triangle surface. The SEM photograph of Figure 24 shows some superior part of the L area containing l18. Other neighbouring particles in that area are : l17 and l19, that are two previously undescribed lapis lazuli (4) ; l20, an albite ; l21, a PVC plastic. The l18 particle is triangular, with shredded outlines and of about 6 µm of maximal dimension. Its colour is yellow in optical microscopy. Its spectrum is that of the quartz with iron (and sulphur) ; presences of relatively elevated peaks of calcium and of chlorine in the spectrum is due to calcium deposits on its surface and PVC plastic contamination.

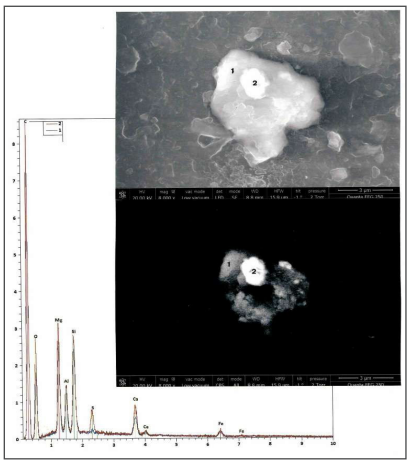

Figure 23. *The citrine of reference. Above, left : optic photograph of the sample. Above, right : SEM1 photograph (22875x), in BSE, showing iron inclusions in the sample. Below : spectrum of the sample, in iron inclusions. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na (traces) : sodium ; Si : silicium ; S (two peaks) : sulphur. Insert : normal composition of the sample ("fer" : iron ; "soufre" : sulphur).*

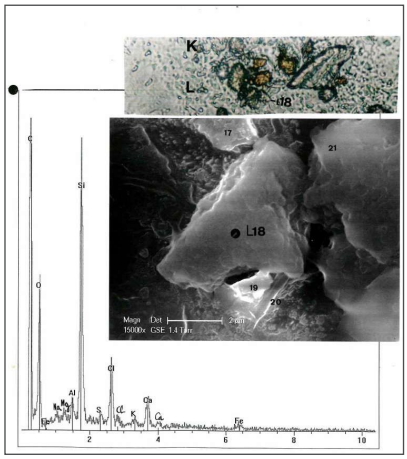

Figure 24. *The l18 particle. Lower photograph : SEM1 photograph (15000x), in GSE, of the upper part of the L area showing l18. Upper photograph : optical microscopy photograph (1200x) of this upper part of the L area showing l18. Below : the l18 spectrum at the black spot. C : carbon ; O : oxygen ; Fe (two peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl (two peaks) : chlorine ; K : potassium ; Ca (two peaks) : calcium.*

3.5 Cornelian

Cornelian is a red chalcedony (a quartz variety). Its red colour seems caused by iron oxide.

In fact, many commercial cornelians are agates red-coloured by some solution of iron nitrate ; it is the reason why we selected here as sample reference a cornelian showing two red intensities; Figure 25 and Figure 26 summarize results obtained on this cornelian sample of reference. The stone is made up of two parts : part 1, of low red intensity, and part 2, of high red intensity ; SEM-EDX analyses of these two parts show that HR spectrum of part 1 has calcium and iron elements as traces only, while that of part 2 contains substantial amounts of these two elements, in addition to sodium, magnesium, sulphur, chlorine, potassium and titanium traces.

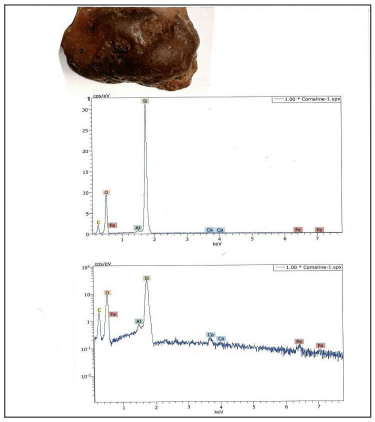

Figure 25. *The cornelian of reference. Above : optic photograph of the sample and its two parts : 1 and 2. Below : spectrum and HR spectrum of part 1 (cps/eV) : blows by eV ; keV :kiloelectrons / Volts ; "cornaline" : cornelian). C : carbon ; O : oxygen ; Fe (two peaks) : iron ; Al : aluminium ; Si : silicium ; Ca (two peaks) : calcium.*

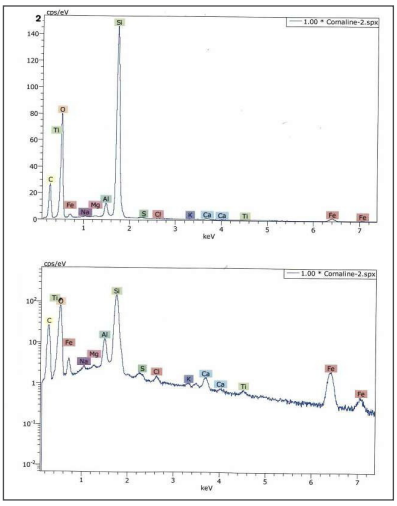

Figure 26. *Spectrum and HR spectrum of part 2. C : carbon ; Ti (two peaks) : titanium ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; K : potassium ; Ca (two peaks) : calcium.*

We found only one cornelian particle (h35) on the triangle surface. The SEM photograph of Figure 27 shows some part of the H area containing h35. Other particles in that area are : h34 a quartz ; h36, a calcite ; h33, a PVC plastic ; h31, a clay ; h38, a calcium carbonate ; h39 , an Ostracod ; h40 , a steatite ; h41, a gypsum. The h35 particle is elongated and with a maximal dimension of about 12 µm. Its spectrum corresponds to that of a cornelian with iron traces. Its colour is brown, with a red centre.

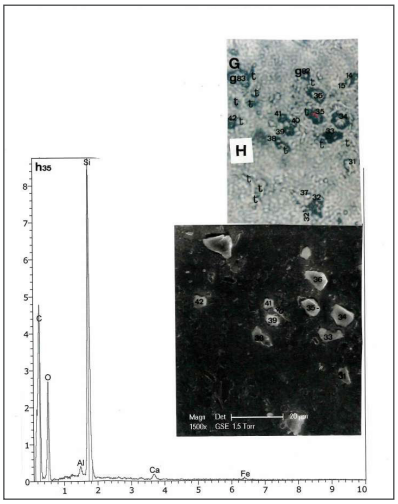

Figure 27. *The h35 particle. Upper photograph : optical microscopy photograph (1200x) of some part of the H area showing k35. Lower photograph : SEM1 photograph (1500x), in GSE of the upper part of the H area containing h35. Below : the h35 spectrum. C : carbon ; O : oxygen ; Al : aluminium ; Si : silicium ; Ca : calcium ; Fe : iron. At its left is shown the spectrum of the h34 particle (a quartz), for comparison.*

The h35 particle is of a peculiar hardness : under repeated SEM-EDX analyses, its moved (under the electron beam of the SEM apparatus) in inverted position in the corresponding H part. Figure 28 shows the original and shifted (“d35”) positions of the h35 particle after repeated SEM-EDX analyses.

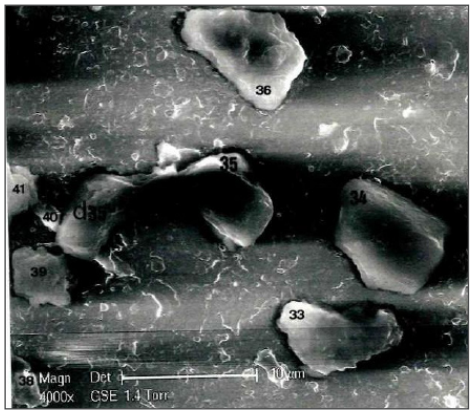

Figure 28. *SEM1 photograph (4000x), in GSE, of some part of the H area where the h35 particle has moved (35 and d35 indicate respectively the original and the moved positions of h35).*

3.6 Garnet

The SEM photographs of the Figure 29 show some part of the B area near the right border of the triangle containing the b27 particle. It is a rounded particle of about 12µm of diameter. Its colour is yellow-red. Its spectrum is that of an alumina-silicate iron rich.

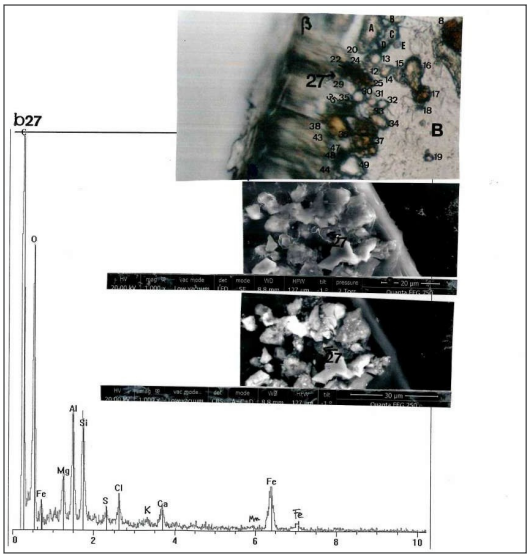

Figure 29. *The b27 particle. Upper photograph : inverted optical microscopy photograph (1200x) of some part of the B area near the right border showing b27 (β : the right border). Lower photograph : SEM2 photographs (1000x), the upper in LFD and the lower, in CBS, of some part of the B area near the right border showing b27 (arrows). Below : the b27 spectrum. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; K : potassium ; Ca : calcium ; Mn (traces) : manganese.*

Figure 30 shows results obtained concerning the garnet cut jewel of reference (a pyrope variety of garnet). Its colour is red-brown. Its spectrum is that of an alumino-silicate iron-rich. Its normal composition has the following percentages of elements : iron (46%), silicium (24%), aluminium (20%), magnesium (5%), calcium (4%), manganese (2%), titanium (traces of 0.5%). Because of the similarities between the two spectras, we consider that the b27 particle is some form of the garnet variety similar to the pyrope.

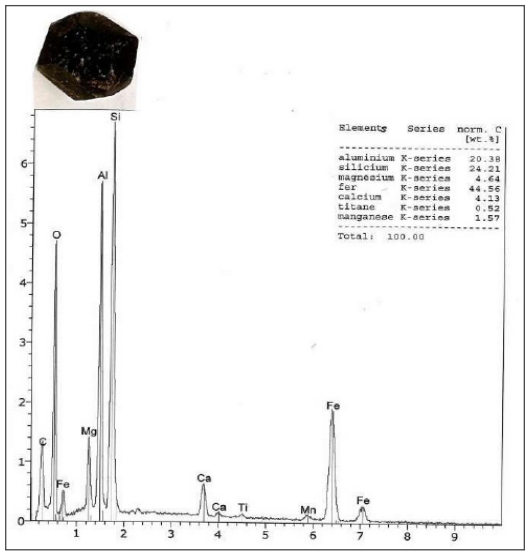

Figure 30. *The pyrope variety of garnet used as a reference. Above : optic photography of the sample. Below : spectrum of the sample. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Ca (two peaks) : calcium ; Ti : titanium ; Mn : manganese. Insert : the normal composition of the sample ("fer" : iron ; "titane: titanium).*

3.7 Jets

Jet is a bituminous coal polishable, of an intense black tint. Figure 31 shows that characterization of the jet stone of reference. Its is black. Its spectrum had essentially carbon and oxygen peaks. Its compositionis of 77% of carbon, of 17% of oxygen, and of traces of aluminium, silicium, calcium, iron, sulphur and chlorine.

We found only two jet particles (j15 and p24) on the triangle surface.

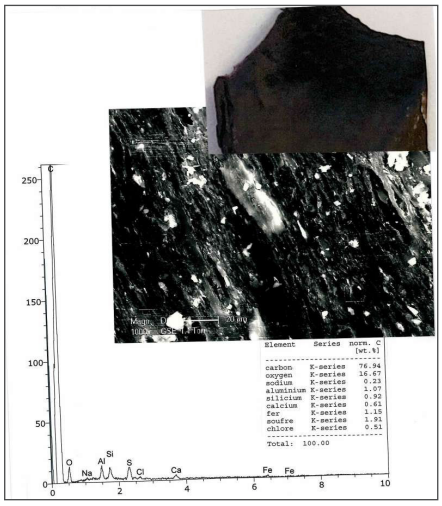

Figure 31. *The jet of reference. Upper photograph : optic photograph of the sample. Lower photograph : SEM1 photograph (1000x), in GSE, of some part of the sample surface showing numerous strips of polishing. Below : global HR spectrum of this part. C : carbon ; O : oxygen ; Fe (two peaks) : iron ; Na (traces) : sodium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl (traces) : chlorine ; Ca : calcium. Insert : elemental composition of the sample ("fer" : iron ; "soufre" : sulphur ; "chlore" : chlorine).*

The SEM photograph of Figure 32 shows some part of the J area containing j15. It is a triangular, with about 10 µm of basis and 6 µm of height. Its spectrum contains essentially carbon and oxygen peaks. It is black in optical microscopy.

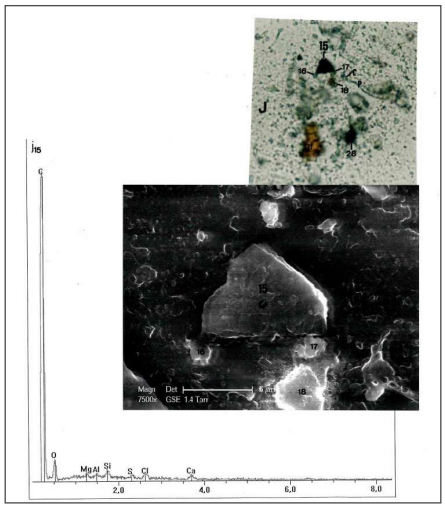

Figure 32. *The j15 particle. Upper photograph : optical microscopy photograph (1200x) of some part of the J area showing j15. Lower photograph : SEM1 photograph (7500x), in GSE, of the J area part containing j15. Below : the j15 spectrum. C : carbon ; O : oxygen ; Mg : magnesium ; Al : aluminium ; Si : silicium ; S : sulphur ; Cl : chlorine ; Ca : calcium.*

When the maximal intensity of the electron beam of the SEM apparatus was applied to some part of the j15 particle, this structure remains intact (Figure 33), that is very astonishing for an organic particle.

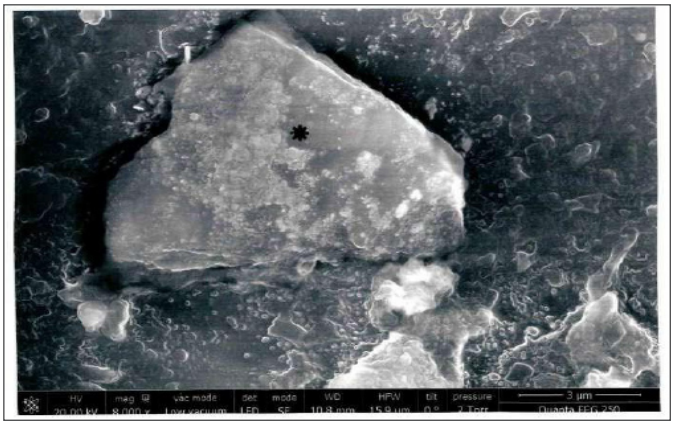

Figure 33. *SEM2 photograph (8000x), in LFD, of the j15 particle showing its resistance to X-rays (star : the impact zone of maximal irradiation).*

The SEM photograph of Figure 34 shows some part of the P area containing p24. It is approximately triangular, with about 6 µm of basis and 9 µm of height. Its spectrum contains essentially carbon and oxygen peaks. It is black in optical microscopy.

As j15, the p24 particle is resistant to electrons (Figure 35).

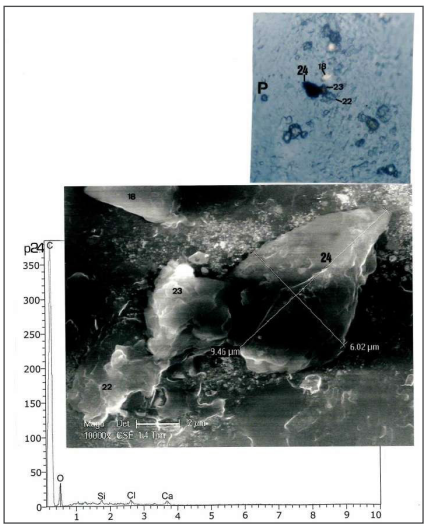

Figure 34. *The p24 particle. Above : inverted microscopy photograph (1200x) of some part of the P area showing p24. Lower photograph : SEM1 photograph (10000x), in GSE, of the P area part containing p24. Below : the HR spectrum of p24. C : carbon ; O : oxygen ; Si : silium : Cl : chlorine ; Ca : calcium.*

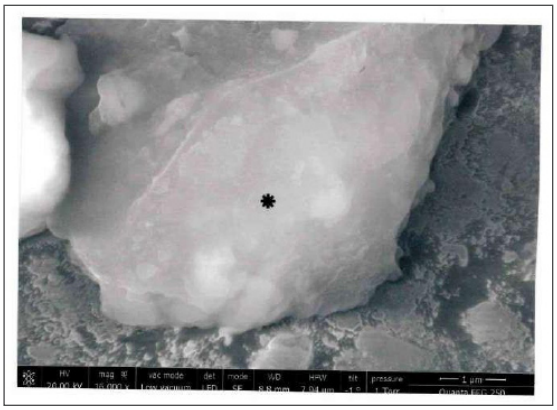

Figure 35. *SEM2 photograph (16000x), in LFD, of the p24 particle showing its resistance to X-rays (star : the impact zone of maximal irradiation).*

4. Discussion

There is a total number of sixteen micro-splinter particles of semi-precious stones detected on the triangle surface (Table 2) : six peridots, one chrysolite, four chlorites, one citrine, one cornelian, one garnet and two jets.

Table 2. *List and characterisations of the sixteen micro-splinter Particles of semi-precious stones detected on the triangle surface.*

Semi- precious stones	Particles	Colours
Peridot	b42, b43, d35, g1,r28, r28-1	green
Chrysolite	r35	yellow
Chlorite	b75, g86, i2,k42	green
Citrine	l18	yellow
Cornelian	h35	red
Garnet	b27	Yellow-red
Jet	j15, p24	dark

These particles are too small to constitute gems : they are gem micro- splinters, sold from their gem counterparts, intentionally deposited on the TS at different times of its story. In their descriptions, we have tested the hardness of some of them (for the cornelian and the jets) and their micro- splinter appearances (for the peridots).

Chlorites are semi-precious stones which were the object of very ancient trades. Citrine is a yellow

quartz, used today in rings and pendants. Garnet are typical Middle Age gemstones, often reported in the literature as "escarboucles".In the Bible, carnelian is the first stone of the breastplate (Exodus 28 : 17 ; 39-10), representing Ruben ; it is also the first among the stones of the King of Tyre (Ezekiel 28:13).

A direct reference of the chrysolite to the body of the Christ was in Daniel (10:6) : "his body was a the chrysolite." In the Bible, chrysolite represents the tribe of Zabulon ; it stands fourth in the enumeration of Ezekiel 28:13 and is given in the seventh foundation stone of the celestial city in Apocalypse 21:20.

Some of the semi-precious stones are highly evocative of the Christianity ; jet was a popular stone of choice for rosaries during the early days of the Catholic Church : for centuries the Catholic Church has believed that peridot symbolized moral purity, and to this day Catholic Bishops wear peridot rings. Citrine was adopted by popes as the gem of their rings since the XVI century.

So, these semi-precious stones particles are indicative of such ancient traditions, it is very difficult to date their deposits on the TS. An exception is the peridot particles, for which we have evidences that, during the Middle Age, the crusaders brought many peridot jewels to Europe from the Middle East. In fact peridot jewellery dates as far as the second millennium BC : these ancient Egyptian gemstones come from deposits in a small island in the Red Sea called Topazios (now known as St John's Island, or Zabargad).

5. Conclusion

We detected sixteen particles of semi-precious stones (peridots, chrysolite, chlorites, citrine, cornelian, garnet and jets) on the surface of the triangle. These particles are micro-splinters, intentionally deposited on the Turin Shroud at different times of its story. Their colours is those of their sold semi- precious stones counterparts. Like of some gold and silver particles (3), they were deposited on the Turin Shroud for decorative and sacralised reasons. Some of them (peridots, chrysolite, citrine, cornelian and jet) are clearly related to the Bible or to Christianity. The possible dating of peridot deposits on the Turin Shroud could be during the Middle Age.

Conflicts of Interest

The authors declare no conflicts of interest regarding to the publication of this paper

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