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Radiolarians On The Turin Shroud : Optical Microscopy Studies And Sem-Edx Analyses

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***Abstract*—We have detected, by optical microscopy and scanning electron microscopy, twelve Radiolarians in a sample of the Face area of the Turin Shroud. They consist of rests (spicules and central pieces) of seven specimen of Hexacontium clevei, a spherical Radiolarian living in temperate marine waters. The Radiolarians detected are located in a small zone (areas F and G) of the sample, and their colours are rosy, red or brown.**

Keywords—Turin Shroud, Face Area, Radiolarians, Optical microscopy, Scanning Electron Microscopy, Energy Dispersive X-ray.

1. Introduction

The Turin Shroud (TS) is a well known linen tissue on which a body image is imprinted [**1**]. We have obtained a small triangular sticky tape that was sampled on its surface (corresponding to a part of 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**].

Some of these particles [**3**] correspond to micro-organisms (probably Cyanophycaes) having similar compositions than those of some little clays [**4**] ; most of the voluminous red phosphorites found on the sticky tape are in fact agregates of these Cyanophycaes [**5**].

In the present study we describe in details, by optic microscopy and SEM-EDX analyses, another kind of micro-organisms (Radiolarians) found on the triangle surface. Radiolarians [**6**] are spherical marine micro-organisms characterised by a skeleton of silicium.

2. Materials and Methods.

The material is the small (1.36 mm high, 61 µm wide) sticky tape triangle at the surface of which all particles were deposited. For practical reasons, the surface of this triangle was subdivided into nineteen subsample areas (named A to S).

The sample of reference is a radiolarite, of the personal collection of one of us (G.L.).

All the Radiolarians were previously observed (to determine colour) by optical microscopy, both in direct and inverse observation of the triangle, by using a photo-microscopic Zeiss (Model III, 1972).

The Radolarians were also observed, with any preparation, on the adhesive part of the surface of the triangle. These observations were conducted by SEM (Scanning Electron Microscopy), using a Philips XL instrument (of the environmental version). GSE (Gazeous Secondary Electrons) and BSE (Back Scattering Electrons) procedures were used, the second one to better detect heavy elements. Elemental analysis for each particle observed were realised by EDX (Energy Dispersive X-ray), this SEM microscope being equipped with a Bruker probe AXS-EDX (the system analysis is PGT : Spirit Model of Princeton Gamma Technology).

The central G area and the Radiolarian g5 were examined with another SEM apparatus (SEM2) : a FEI model Quanta 25 of FEG, both in LFD (Large Field Detector) and CBS (Circular Back Scattering) procedures.

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 ordinate graduations are enhanced, to better see little peaks.

Elemental compositions are given for some samples, elemental values being studied on the main elemental peaks ; in normal composition, the C and O elements are not considered.

3. Results

Are given here : the characterisations of the Radiolarians detected in the different areas of the triangle, their observations in optic microscopy, and the description of the radiolarite of reference.

3.1. Radiolarians detected in the different areas of the triangle.

These are three Radiolarians on the F area of the triangle : f27, f35 and f48'. The Radiolar f27 (**Figure 1**) is located on the upper part of the F area. Neighbouring particles are : f25, a kaolinite [**4**], and f26, a Diatom. The Radiolarian f27 is elongated with a maximal length of about 5 µm and with a maximal width of about 2.8 µm. In its spectrum, silicium is the

mean mineral peak and it contains very elevated values of iron. The f27 particle is of ovale form, with a maximal length of about 9.4 µm ; silicium is the main mineral peak of its spectrum, that contains elevated iron value.

Figure 2 shows the Radiolarian f35, located in the lower part of the F area. It is elongated, with a maximal length of about 6.3 µm and a maximal width of about 2.8 µm. Silicium is the main mineral peak of its spectrum, that contains 8.8% of iron.

Figure 3 shows some of the right lower part of the F area containing the Radiolarian f48'. The Radiolarian f48' is triangular, with a maximal height of about 7,6 µm and a maximal basis of about 5.6 µm. Neighbouring particles in this part area are : f33 and f33' : two sodic feldspars ; f39 and f40 : two marble micro-fragments [**7**] ; f43 and f48 (f48' being included in f48), two Dinophycaes ; f51 : a Diatom ; f52 : a Diatom oospore ; f53 is a calcium carbonate ; f54 are Bivalves. Silicium is the main mineral peak of the f48' spectrum, that contains 2.4% of iron.

The photograph of **Figure 4** shows some upper part of the G area containing Radiolarians g11, g12 and g13. They are three neighbouring triangular formations, located between the peridot (g1), a rounded and a tubular Diatom (g10 and g9), a greater Diatom (g20), and a red blood cell g25 [**8**]. The radiolarian g11 is triangular, with a maximal height of about 6.1 µm and a maximal basis of 3.1 µm. The Radiolarian g12 is also triangular, with a maximal height of about 5.3 µm and a maximal basis of about 3.8 µm. Silicium is the mean mineral peak of the g11 spectrum, that contains relatively elevated iron values. Silicium is also the mean mineral peak of the g12 spectrum, that contains also elevated iron values. The g9' particle is highly-rich in silicium.

The photograph of **Figure 5** shows some upper part of the G area centred on g13. The g13 radiolarian is elongated, with a maximal length of about 13.5 µm and a maximal width of about 2.9 µm. Silicium is the main mineral peak of its spectrum, that contains 38% of iron (in normal composition).

The photograph of **Figure 6** shows the median part of the G area centred on g1. Among particles surrounding the g1 peridot, four of them : g5, g27, g31 and g34 are Radiolarians.

The photograph of **Figure 7** shows the median part of the G area containing Radiolarians g27 and g31. Other neighbouring particles are : g1 : a peridot ; g28 : a glass ; g29 : a marble micro-fragment ; g30 and g33 : two clays ; g32 : a dolomite. The g27' particle is of oval form, with a maximal length of about 7.2 µm. Silicium is the main mineral peak of its spectrum, that contains an elevated iron value. Radiolarians g27 and g31 are both elongated, with a maximal mean length of about 8.9 µm and 8.8 µm, and a maximal mean width of about 3.4 µm and 2.8 µm, respectively. Silicium is the main mineral element of their spectras, which contain elevated values of iron.

The photograph of **Figure 8** shows some other central part of the G area centred on the Radiolarian g34 (g34'). Neighbouring particles in this area are g1 : a peridot ; g33 : a clay ; g36 : a glass. The Radiolarian g34 is elongated, with a maximal mean length of about 8.6 µm and a maximal mean width of about 3.1 µm. Silicium is the mean mineral peak of the g34 spectrum, that contains elevated value of iron. In a previous study [**9**] we considered g34 as a biotite, but in fact it does not have the flat structure of a phyllo-silicate.

The photograph of **Figure 9** shows another central part of the G area centred on the Radiolarian g5. It is elongated, with a maximal mean length of about 6.9 µm and a maximal mean width of about 2.4µm. Silicium is the main mineral peak of its spectrum, that contains a substantial value of iron.

The photograph of **Figure 10** shows a right part of the lower G area containing Radiolars g61 and g65. They are of triangular forms, with maximal mean heights of about 49 µm and 8.3 µm and maximal mean basis of about 3.8 µm and 6.9 µm, respectively. Silicium is the main mineral peak of their spectras, that contain some amounts of iron.

3.2. Radiolarians in optic microscopy.

The Radiolarian f27 is located near the right border of the triangle ; so it cannot be observed in optic microscopy. The Radiolarian f35 is located below an exterior mask (m1) loaded on the triangle surface, so it cannot be observed in optic microscopy.

The two photographs of **Figure 11** are taken in optic microscopy. Both depict the G area, the upper one in direct observation of the triangle surface, the lower one in inverse observation. We can detect Radiolarian in direct observation : g11 : rosy ; g12 : rosy ; g13 : red ; g27 : red ; g31 : brown ; g34 : red-brown. In inverse observation : g13 : red ; g5 : brown ; g27 : red ; g34 : red-brown.

The Radiolarian g61 and g65 are located in the right border of the triangle ; so they cannot be observed in optic microscopy.

3.3. Study of the radiolarite of reference.

Radiolarite [**10**] is a siliceous, fine grained, sedimentary rock that is composed predominantly of the microscopic remains of Radiolarians.

Figure 12 shows the radiolarite specimen of reference ; its colour is red, and its polished surface contains numerous black strips. The optic photograph below shows an enhancement of some part of one of these strips. The polished portion of this rock surface contains two parts : **1**, including the dark vein portion ; **2**, without its (being of red colour). **Figure 13** shows spectras of parts **1** and **3** ; spectrum of **1** contains iron, but spectrum of **2**.

Figure 14 shows the optic photograph of some part of another black strip of the radiolarite of reference. Different black marks (1 to 7) are visible, indicating Radiolarians of different species.

4. Discussion.

Table 1 characterises the twelve (**1**-**12**) Radiolarians in the different areas of the triangle. They are elongated (**1**, **2**, **6**, **7**, **8**, **9**, **10**) or triangular (**3**, **4**, **5**, **11**, **12**), their maximal dimensions being between 4.9 (**11**) and 13.5 µm (**6**). Silicium is the main mineral peak of their spectras, that contain elevated or very elevated iron content (but **3**, where the iron content is low). When visible, their colours are rosy (**4**, **5**), red (**6**, **7**), red-brown (**9**) or brown (**8**, **10**).

Their locations are very limited (**Figure 15**) : three of them (**1** - **3**) are located in the F area, and the other nine (**4**-**12**) in the G area of the triangle.

Six of them (**4**-**6** and **7**-**9**) are closely linked on the triangle surface. We suspect that all the samples belong to the same species of Radiolarian : *Hexacontium clevei* (**Figure 16**), a spherical Radiolarian living in temperate waters of the oceans. This Radiolarian, of about 100 µm of dimension, is composed of a spherical central part from which start six elongated and acute spicules.

Table 2 summarises our interpretation of concerning the seven Radiolarians (groups) located on the surface of the triangle : the first specimen is the elongated spicule h27 closely linked to the central part h27'. The second is the represented by the spicule h35. The third is represented by the spicule f48'. The fourth is represented by the triangular spicules g11, g12 and g13, and by the central part g9. The fifth is represented by the elongated spicules g27, g31 and g34, the first two being closely linked to the central part g27'. The sixth is represented by the elongated spicule g5. The seventh is represented by the triangular spicules g61 and g65.

So, Radiolarians detected are in fact residual remains of only seven Radiolarians *H. clevei*, located in Areas F and G of the triangle.

5. Conclusion

We have detected, by SEM-EDX analyses, twelve Radiolarius (f27, f35, f48', g5, g11, g12, g13, g27, g31, g34, g61 and g65) on the F and G areas of the triangle. They are triangular or elongated, with maximal lengths comprised between 4.9 µm and 13.5 µm. Silicium is the main mineral peak of their spectras, and they contain generally elevated iron contents.

Because some of these are closely linked, we suspect that they are parts (spicules and central parts) of seven specimens of the species *Hexacontium clevei*, a spherical Radiolarian living in the temperate marine waters.

How explain their presences on the Turin Shroud? We hypothetized that they are fine powders of some radiolarite rock, selectioned because of its red colour (in optical microscopy the Radiolarians detected are rosy, red, or brown), and added locally to the TS surface. So Radiolarians contribute, with some clays [**5**] and other minerals [**9**], to the reddish appearance of the blood spots on the TS surface.

Conflicts of interest

The authors declare no conflict of interest regarded the publication of this paper.

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Table 1 : List and characterization of the Radiolarians detected in the different areas of the triangle

Numbers	Areas	Specimens	Forms	Lengths on widths, or heights on basis (in µm)	Silicium	Iron content	Colours
1	F	f27	elongated	5x2.8	+	very elevat-ed	not seen (N.S.)
2		f35	elongated	6.3x2.8	+	very elevat-ed	N.S.
3		f48’	triangular	7.6x5.6	+	low	N.S.
4	G	g11	triangular	6.1x3.1	+	elevated	rosy
5		g12	triangular	5.3x3.8	+	elevated	rosy
6		g13	elongated	13.5x2.9	+	very elevat-ed	red
7		g27	elongated	8.9x3.4	+	very elevat-ed	red
8		g31	elongated	8.8x2.8	+	very elevat-ed	brown
9		g34	elongated	8.6x3.1	+	very elevat-ed	red-brown
10		g5	elongated	6.9x2.4	+	elevated	brown
11		g61	triangular	4.9x3.8	+	elevated	N.S.
12		g65	triangular	8.3x6.9	+	elevated	N.S.

Table 2 : Grouping of the seven Radiolarians individuals detected

Groups	Central parts	Spicules
1	h27’	h27(**1**)
2		h35(**2**)
3		f48’ (**3**)
4	g9	g11(**4**), g12(**5**), g13(**6**)
5	g27’	g27(**7**), g31(**8**), g34(**9**)
6		g5(**10**)
7		g61 (**11**), g65(**12**)

Figure 1 : The Radiolarian f27. *Above* : SEM1 photograph (7500x), in BSE, of the upper right part of the F area showing f27 (black point and little circle indicate the approximate locations of SEM-EDX analyses). *Lower spectrum* : the HR spectrum of f27. *Upper spectrum* : the spectrum of f27'. C : carbon ; N : nitrogen ; O : oxygen ; Fe (three peaks) : iron ; Na (traces) : sodium ; Mg : magnesium ; Al :aluminium ; Si : silicium ; S (traces) : sulphur ; Cl : chlorine ; K (traces) : potassium ; Ca (two peaks) : calcium.

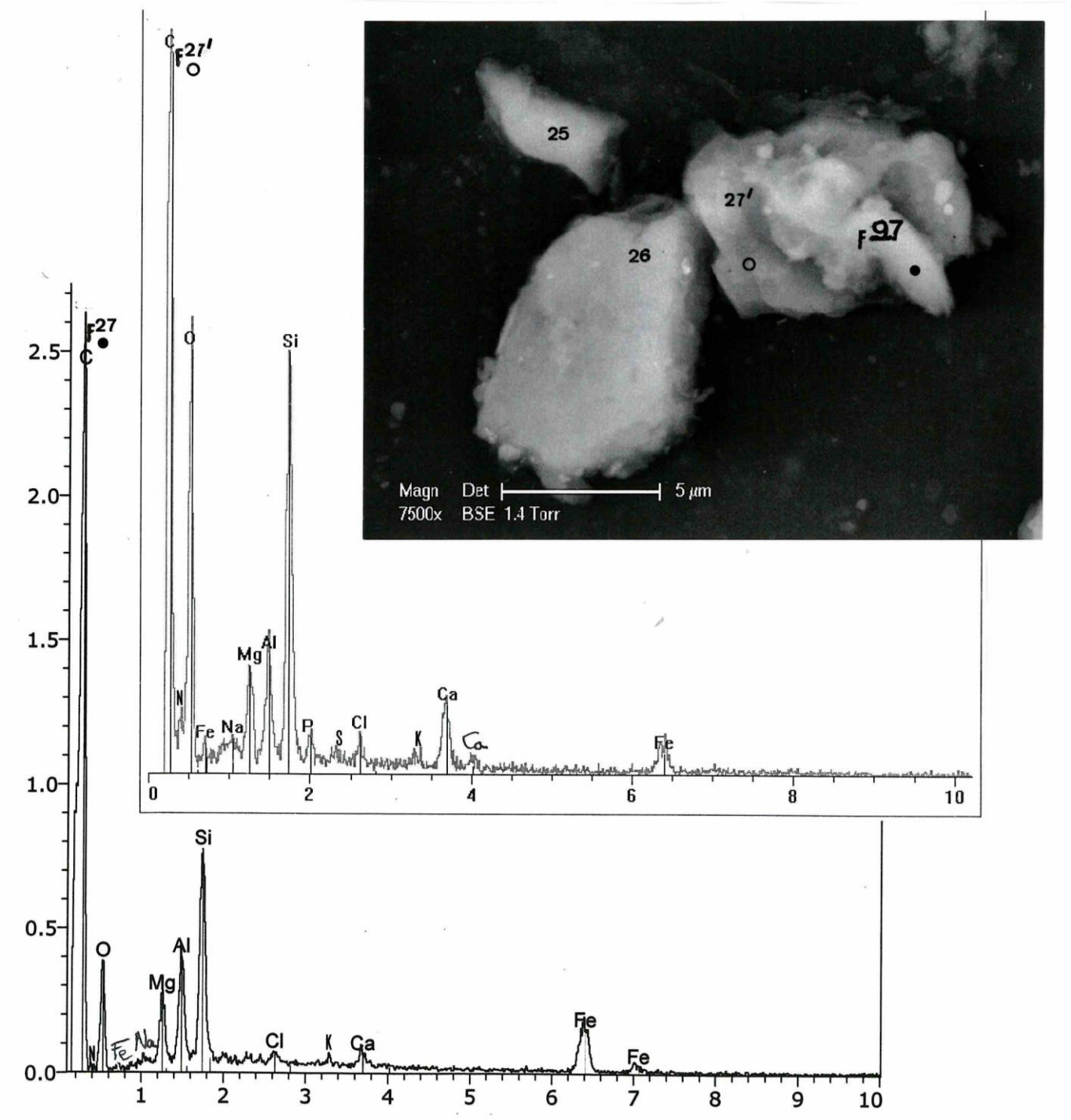


Figure 2 : The Radiolarian f35. *Above* : SEM1 photograph (25000x), in GSE, of the median lower part of the F area centred on f35. *Below* : the HR spectrum of f35. C : carbon ; O : oxygen ; Fe (three peaks) : iron, Na (traces) : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; K : potassium ; Ca (two peaks) : calcium. *Insert* : elemental composition of f35 (fer : iron).

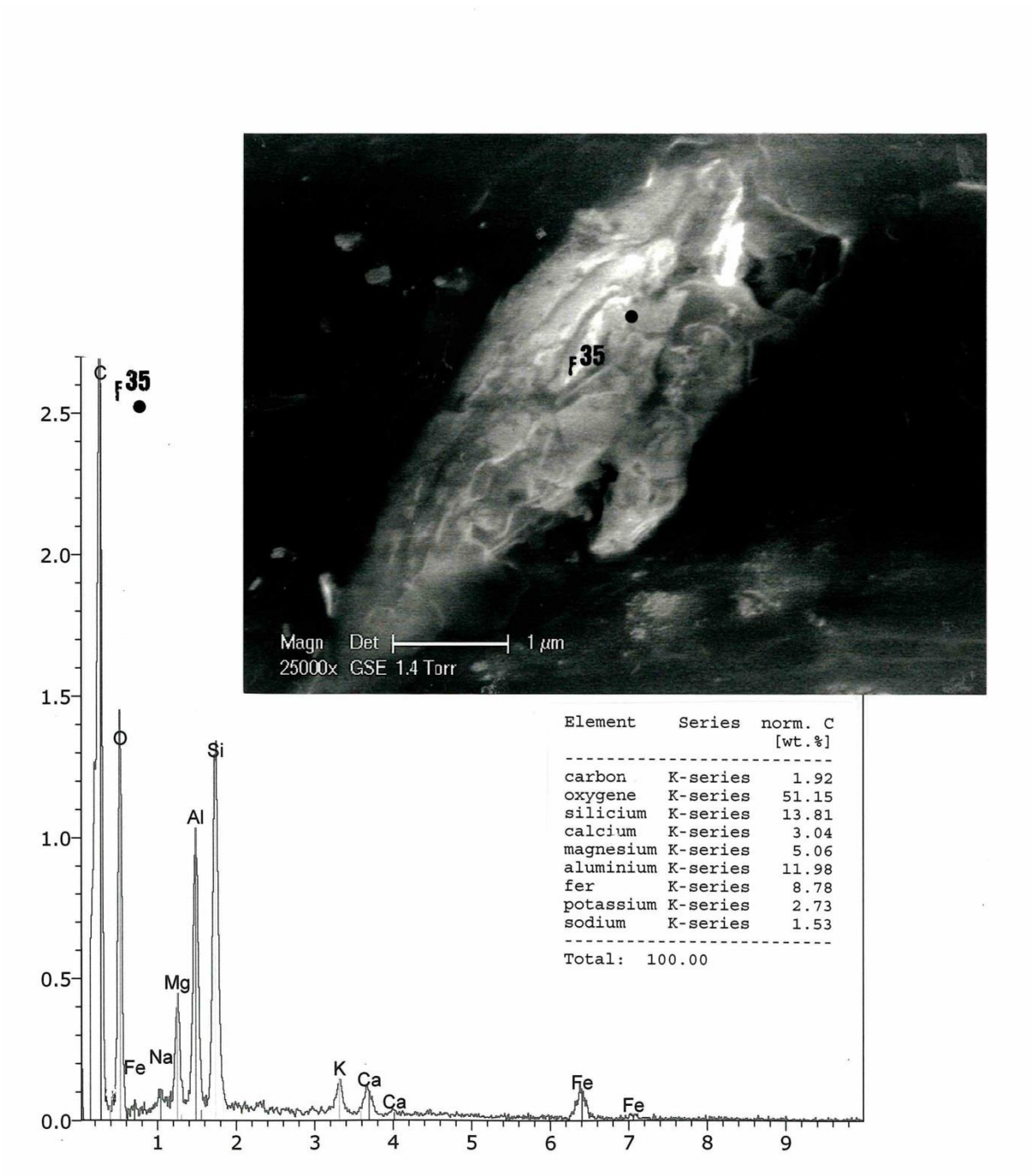
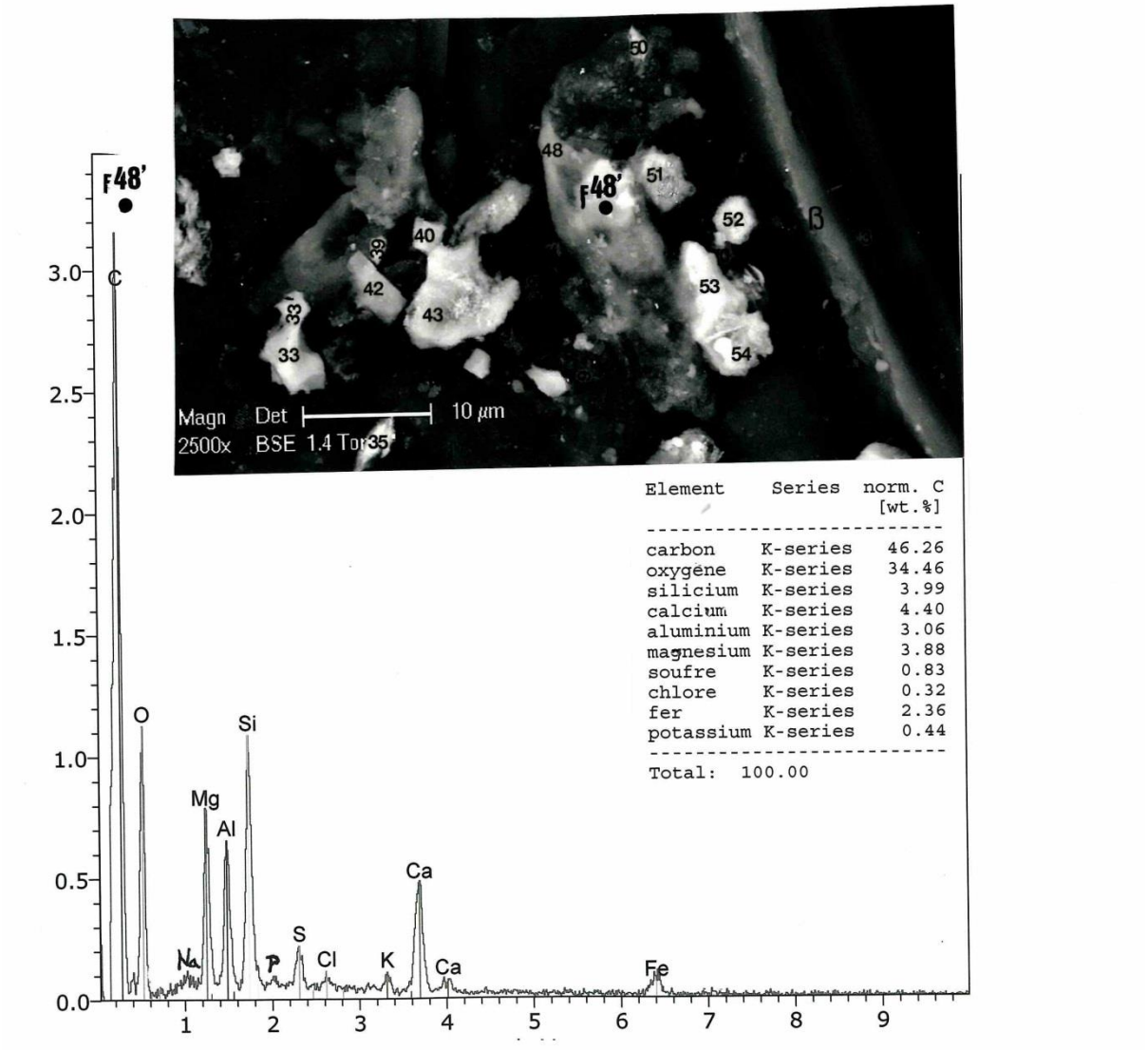


Figure 3 : The Radiolarian f48'. *Above* : SEM1 photograph (2500x), in BSE, of the right lower part of the F area, containing f48' (β : the right border of the triangle). *Below* : the HR spectrum of f48'. C : carbon ; O : oxygen ; Na (traces) : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; P (traces) : phosphorous ; S : sulphur ; Cl (traces) : chlorine ; Ca (two peaks) : calcium ; Fe : iron. *Insert* : elemental composition of f48' (soufre : sulphur ; chlore : chlorine ; fer : iron).



Element	Series	norm. C [wt.%]
carbon	K-series	46.26
oxygène	K-series	34.46
silicium	K-series	3.99
calcium	K-series	4.40
aluminium	K-series	3.06
magnesium	K-series	3.88
soufre	K-series	0.83
chlore	K-series	0.32
fer	K-series	2.36
potassium	K-series	0.44
Total:		100.00

Figure 4 : The Radiolarians g11, g12 and g13. *Above* : SEM1 photograph (5000x), in GSE, of the upper part of the G area containing g11, g12 and g13 (rad3 : g11 + g11' and g11'' ; rad2 : g12+9' ; rad1 : g13). Neighbouring particles in this area part are : g1 : a peridot ; g9 : a tubular Diatom ; g10 : a rounded Diatom ; g20 : pla. : a great Diatom ; g21 and CA : two calcium carbonates : g22 : a gypsum ; g24 : a Cyanophycae ; g25 : h : a red blood cell ; g26 : a gypsum ; *Lower spectrum* : that of g11. *Uppe spectrum* : that of g12. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Cl (traces) : chlorine ; Ca (two peaks) : calcium.

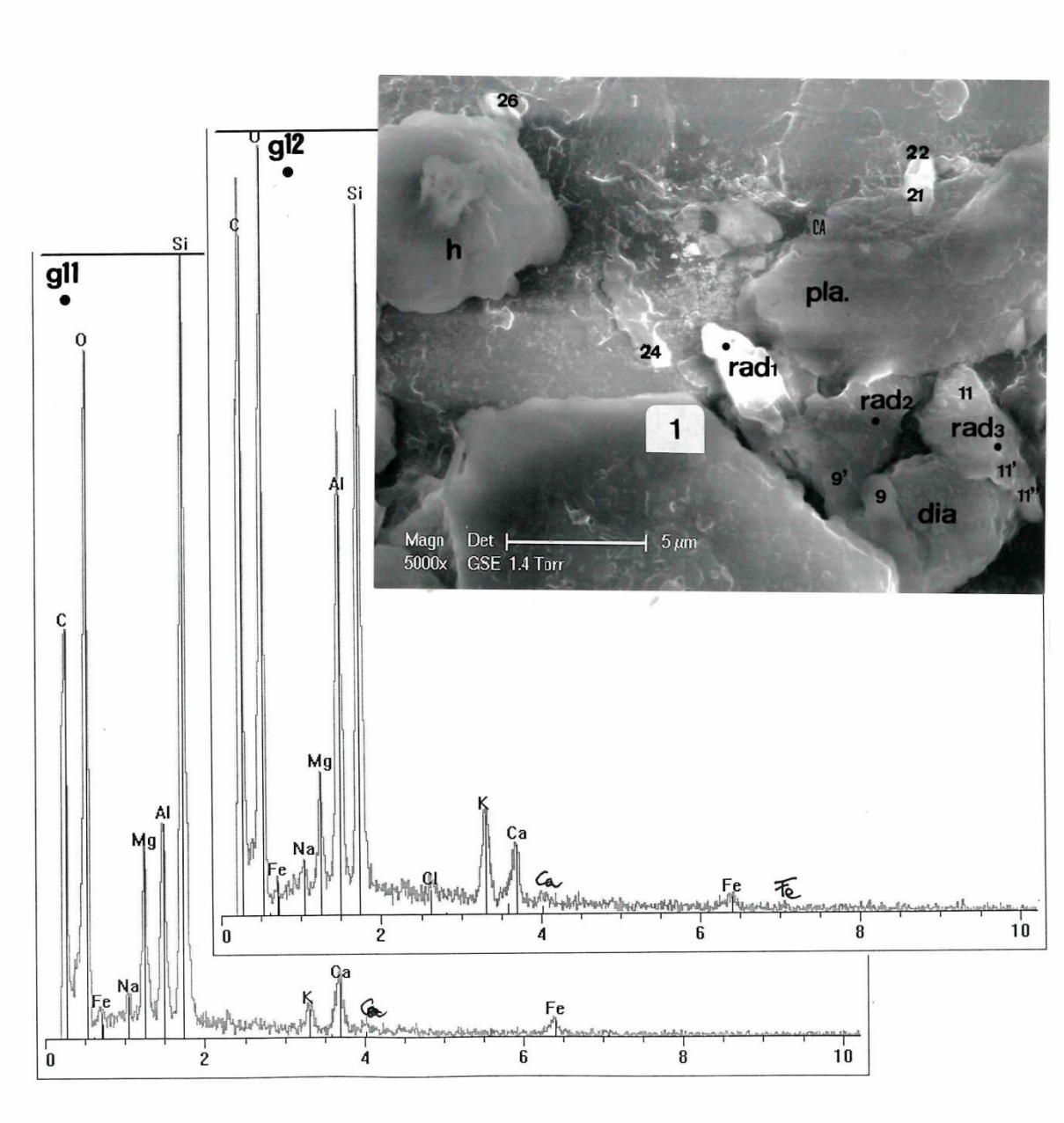


Figure 5 : The Radiolarian g13. *Above* : SEM1 photograph (10000x), in GSE, of the upper part of the G area centred on g13. (1 : a peridot ; 20 : a great Diatom). *Below* : the HR g13 spectrum. C : carbon ; O : oxygen ; Mn (two peaks) : manganese ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silcium ; Cl : chlorine ; K : potassium ; Ca (two peaks) : calcium. *Insert* : normal composition of g13 (fer : iron).

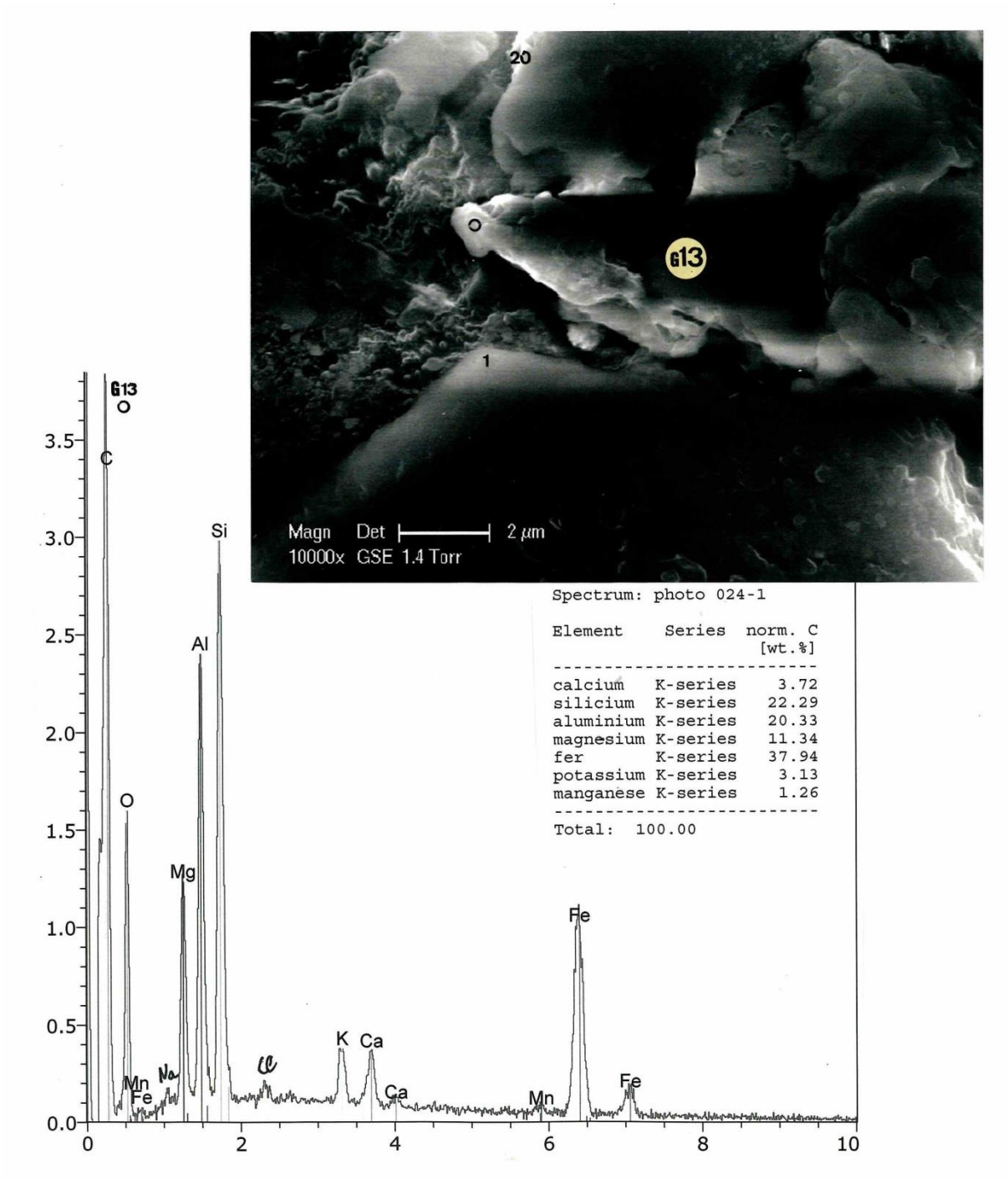


Figure 6 : The G area. SEM2 photograph (2000x), in LFD, of the G area showing Radiolarians g5, g27, g31 and g34.

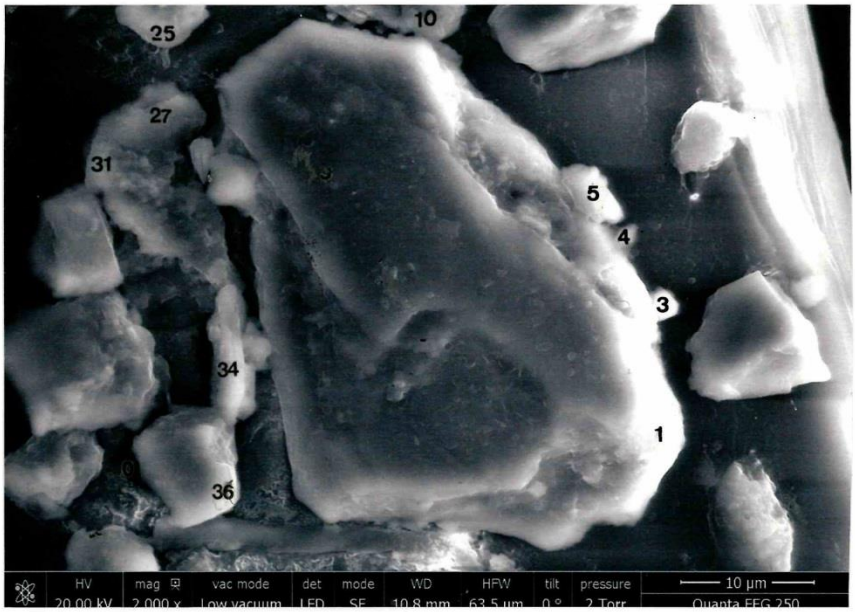


Figure 7 : The Radiolarians g27 and g31. *Above* : SEM1 photograph (6250x), in BSE, of the left median part of the G area showing g27 and g31. *Lower spectrum* : the HR spectrum of g27. *Upper spectrum* : the HR spectrum of g31. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; P : phosphorous ; S : sulphur ; Cl : chlorine ; K : potassium ; Ca (two peaks) : calcium.

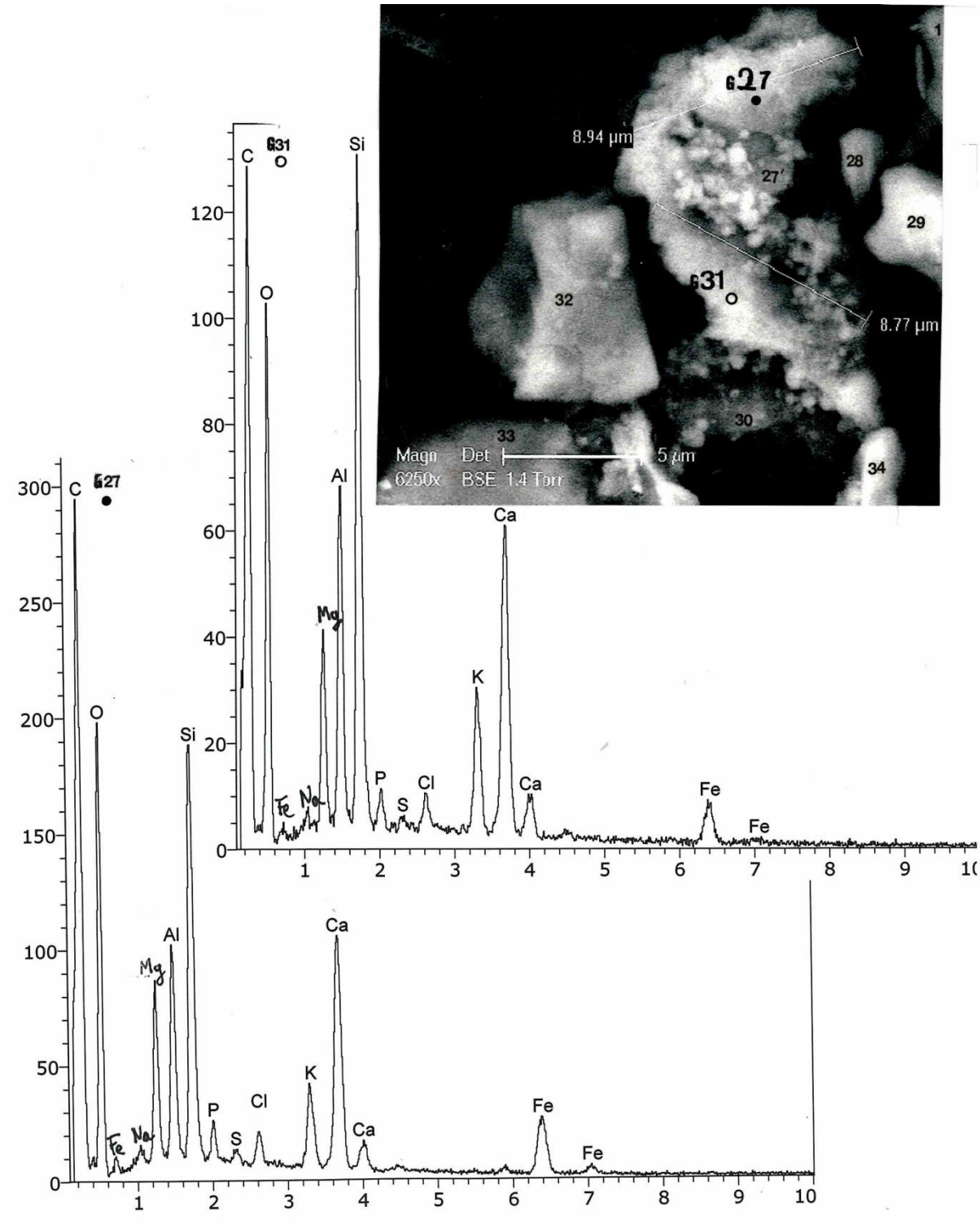


Figure 8 : The Radiolarian g34 (g34'). *Above* : SEM1 photograph (7500x), in GSE, of the left inferior median part of the G area centred on g34. *Below* : the spectrum of g34. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Mg : magnesium ; Al : aluminium ; Si : silcium ; S (traces) : sulphur ; Cl : chlorine ; Ca (two peaks) : calcium.

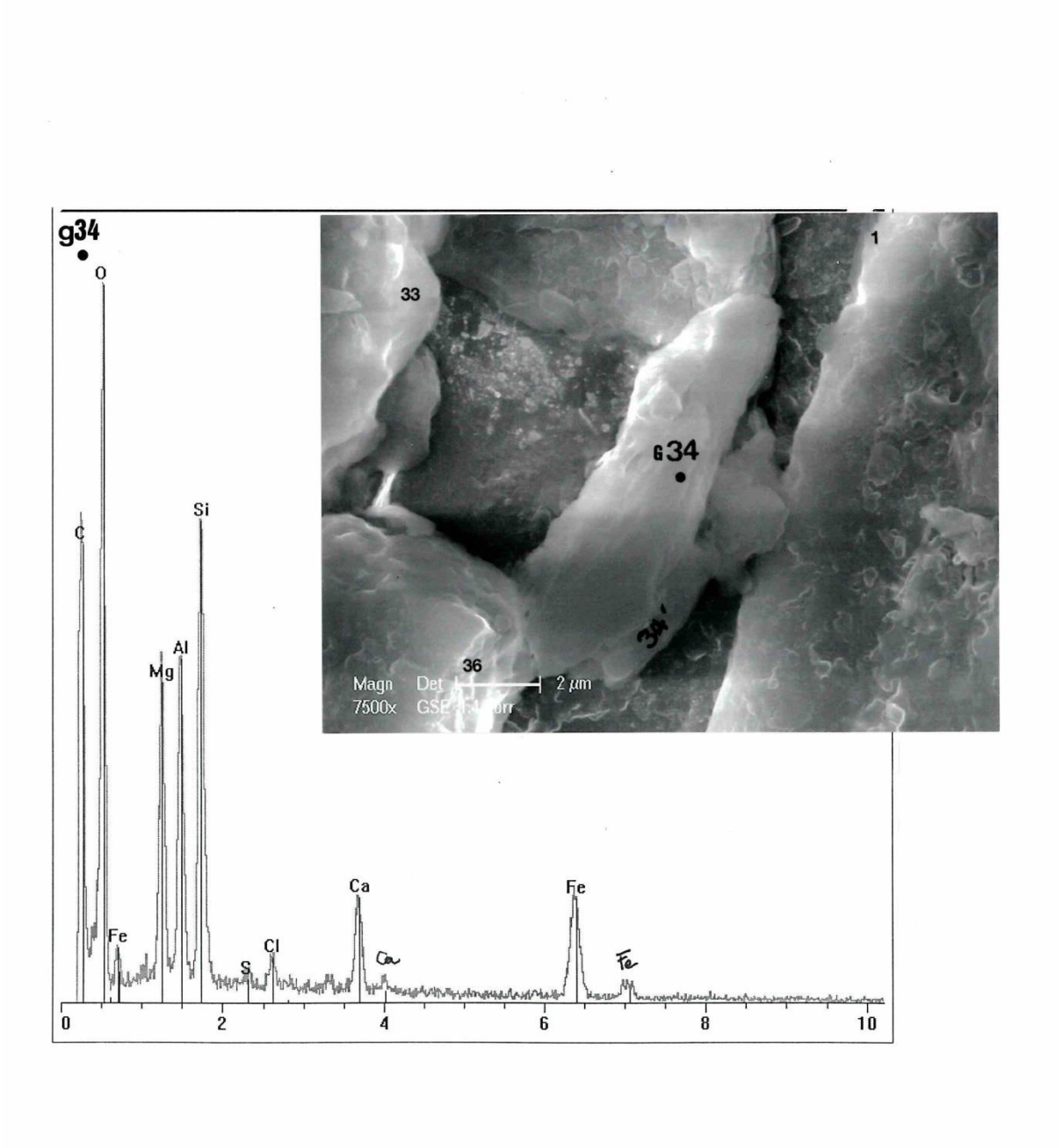


Figure 9 : The Radiolarian g5. *Above* : SEM2 photograph (16000x), in LFD, of the right median part of the G area centred on g5. *Below* : The g5 spectrum. C : carbon ; Ti (two peaks) : titanium ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; Cl : chlorine ; K : potassium ; Ca (two peaks) : calcium.

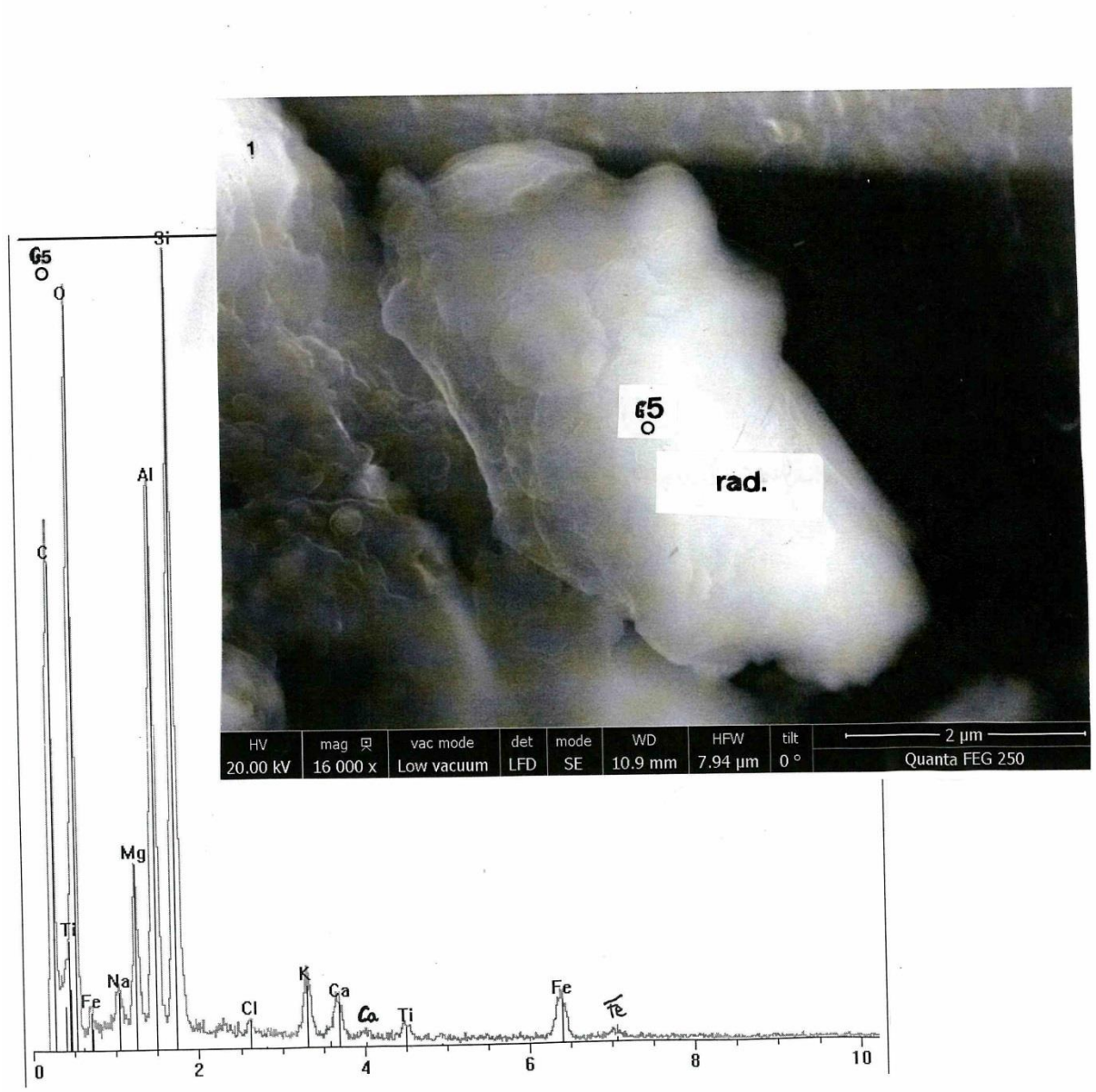


Figure 10 : The Radiolarians g61 and g65. *Above* : SEM1 photograph (25000x), in GSE, of the lower right part of the G area showing g61 and g65. *Lower spectrum* : the HR spectrum of g61 (r : right limit of border of the triangle). *Upper spectrum* : the HR spectrum of g65. C : carbon ; O : oxygen ; Fe (three peaks) : iron ; Na : sodium ; Mg : magnesium ; Al : aluminium ; Si : silicium ; P (traces) : phosphorous ; S (traces) : sulphur ; Cl : chlorine ; K : potassium ; Ca (two peaks) : calcium.

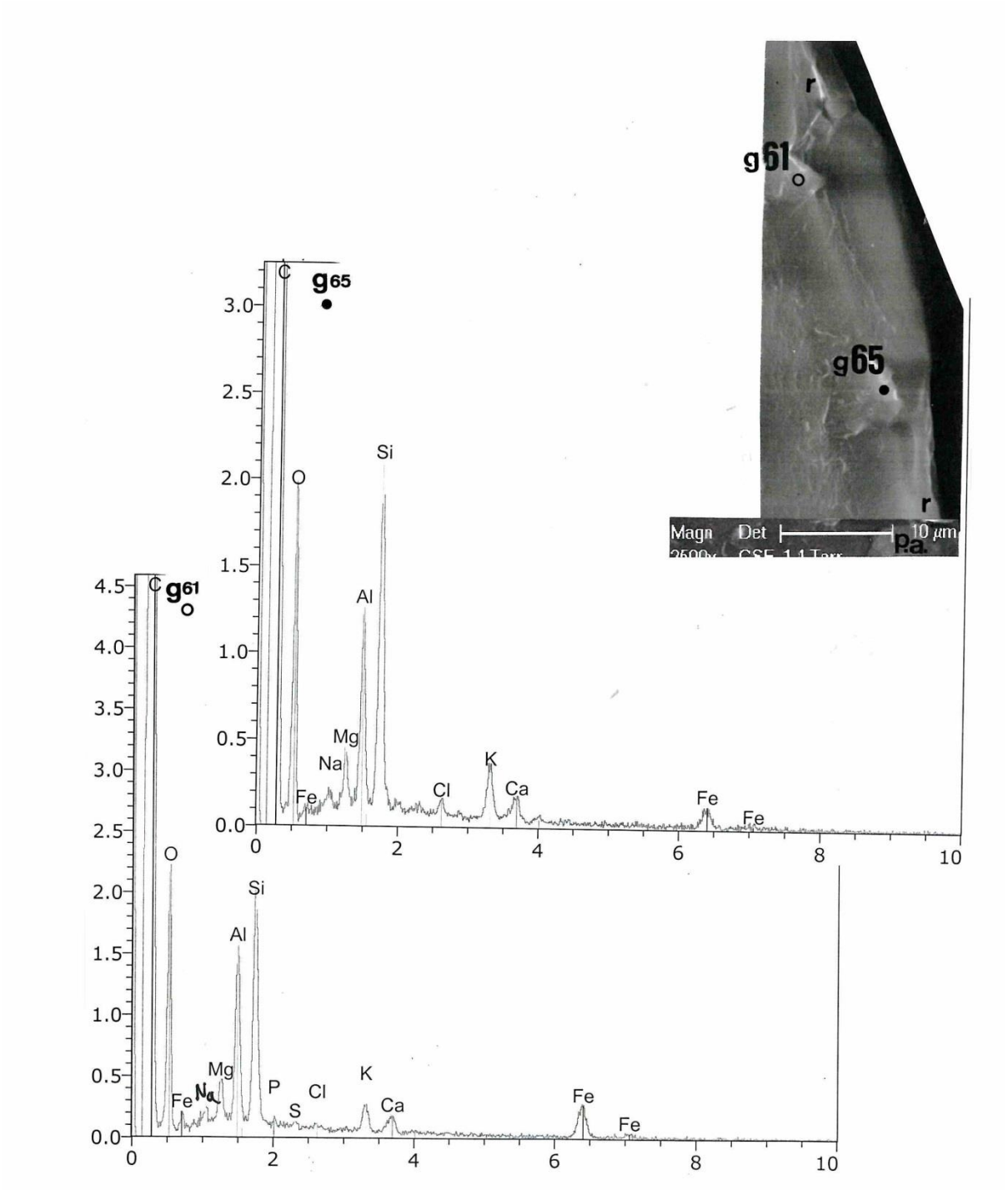


Figure 11 : Optic microscopy (1200x) photographs of the G area. *Above* : direct photograph of the G (G) area (F : lower part of the F area ; H : upper part of the H area ; r-r : right limit of the triangle border). *Below* : inverse photograph of the G (G) area.

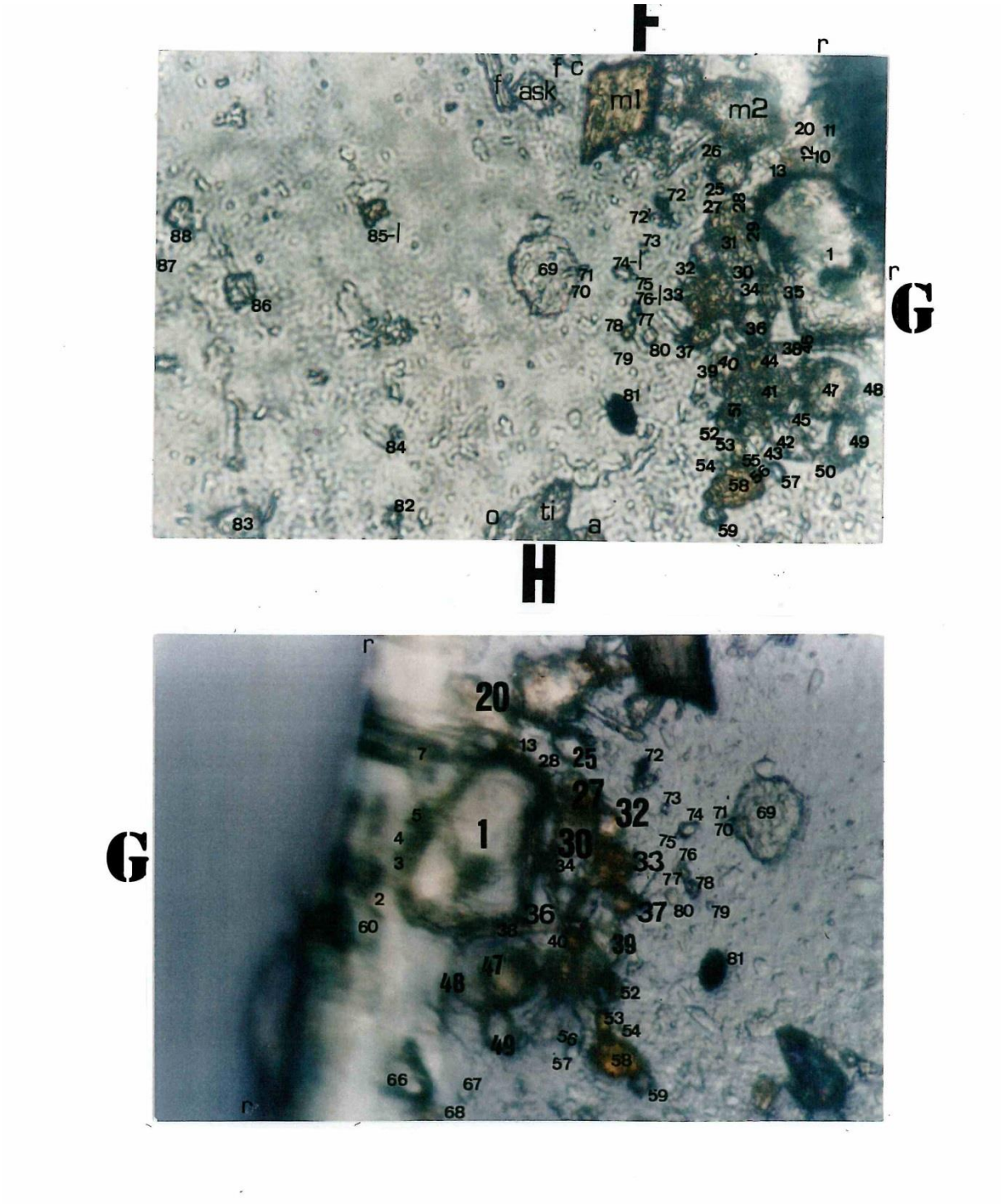


Figure 12 : The radiolarite of reference. *Upper photograph* : optic photograph (5x) of the radiolarite (s : a black strip). *Lower photograph* : optic microscopy photograph (300x) of some part of s. **1** : approximate location of the SEM-EDX analysis in s ; **2** : approximate location of the SEM-EDX analysis out of s.

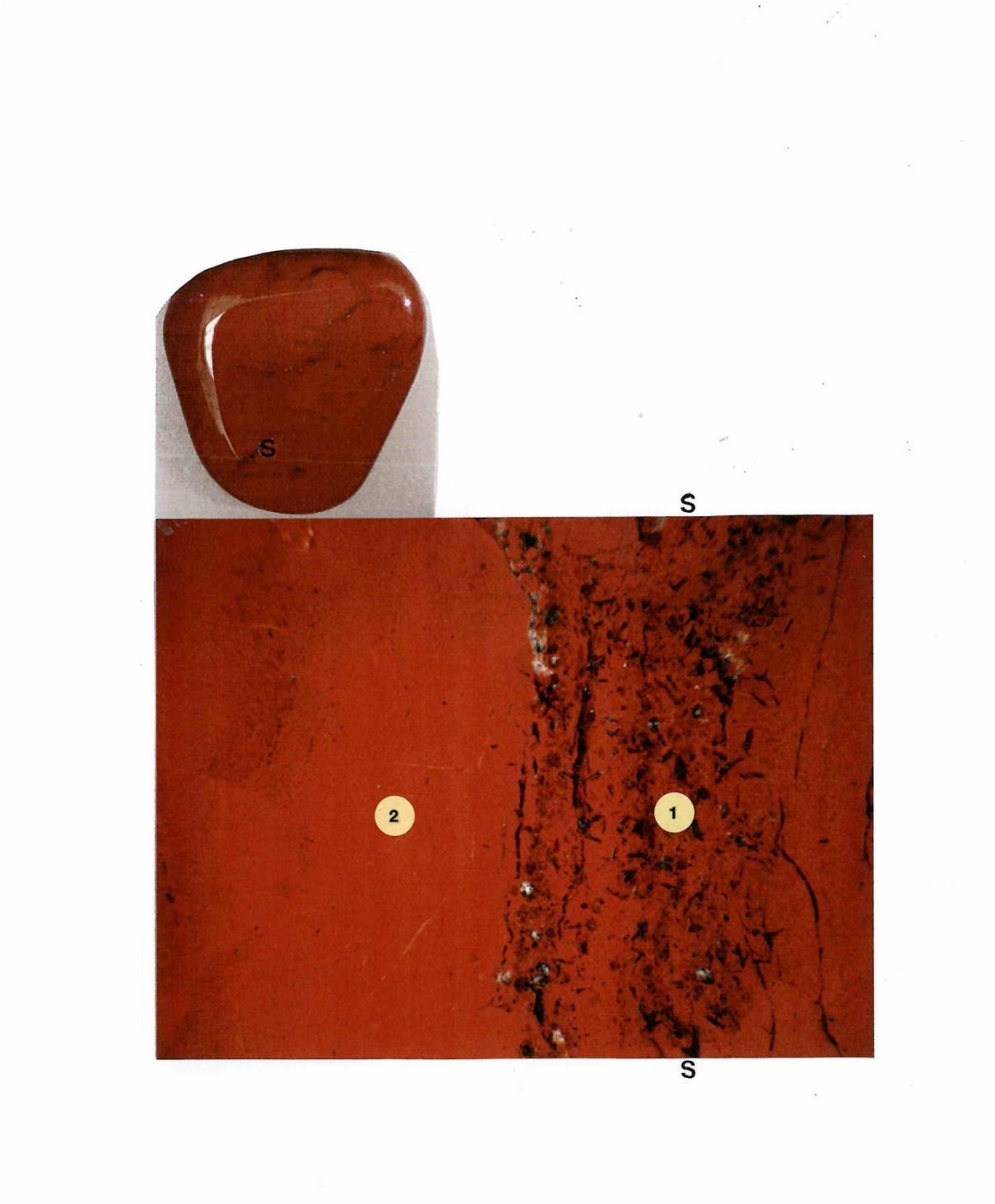


Figure 13 : Spectras of **1** and **2**. *Upper spectrum* : that of **1**. *Lower spectrum* : that of **2**. C : carbon ; O : oxygen ; Fe (three peaks) ; Si : silicium. *Inserts* : normal compositions of silicium and iron (fer) in **1** and **2**.

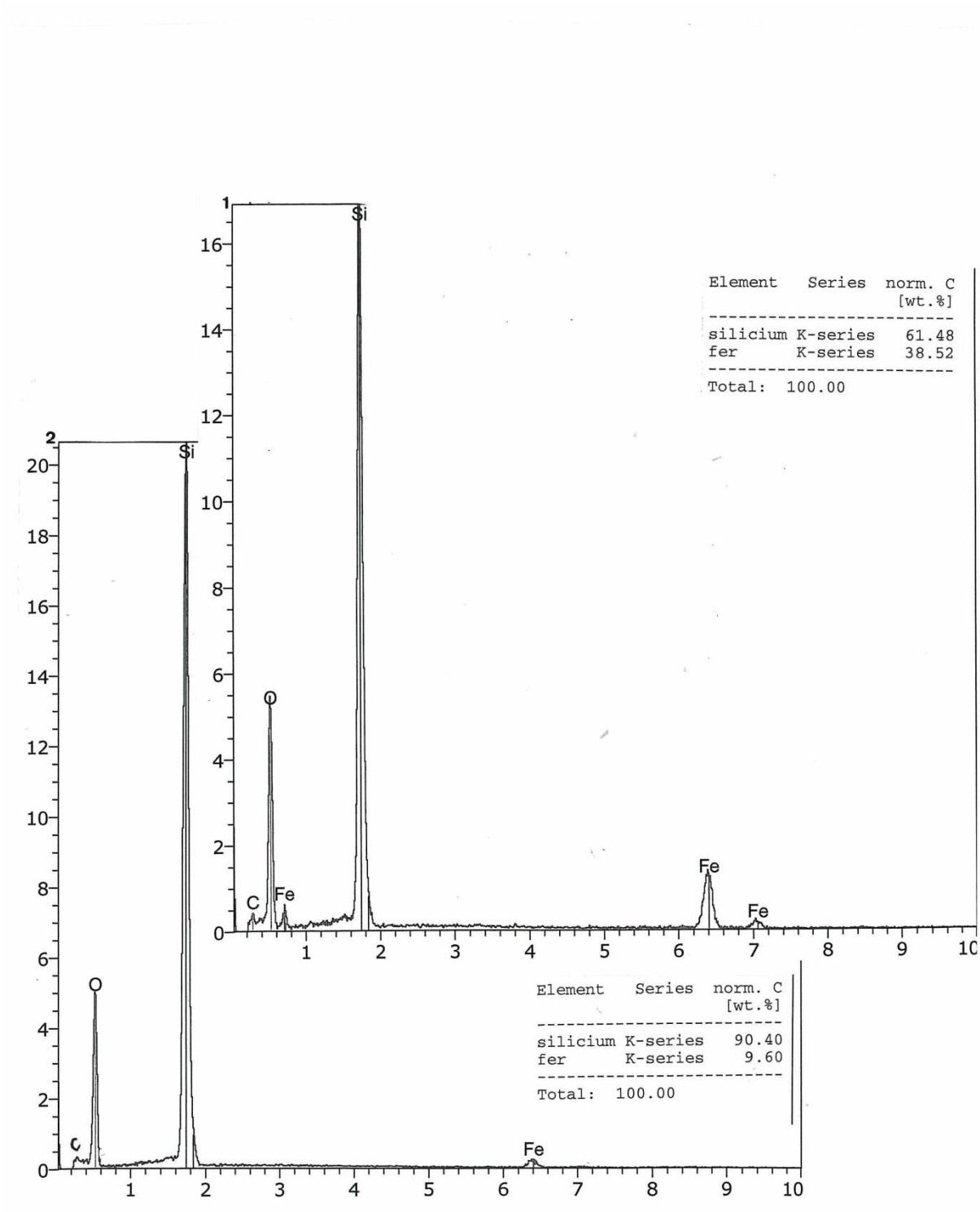


Figure 14 : Optic microscopy of photograph (700x) of some another strip part of the radiolarite of reference showing various (1-7) species of Radiolarians.

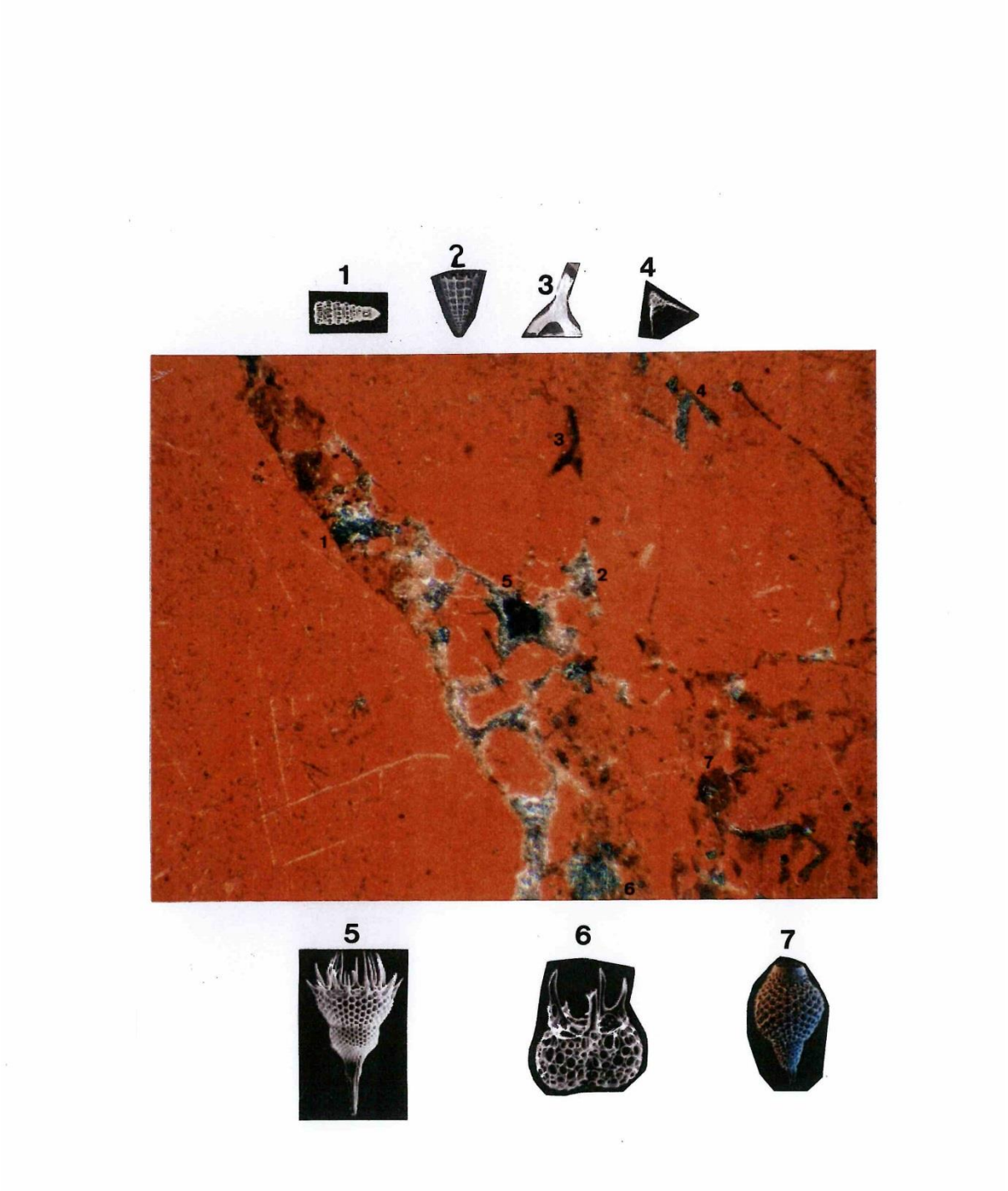


Figure 15 : Locations (black spots) of the twelve (**1**-**12**) Radiolarians in the F and G areas of the triangle.

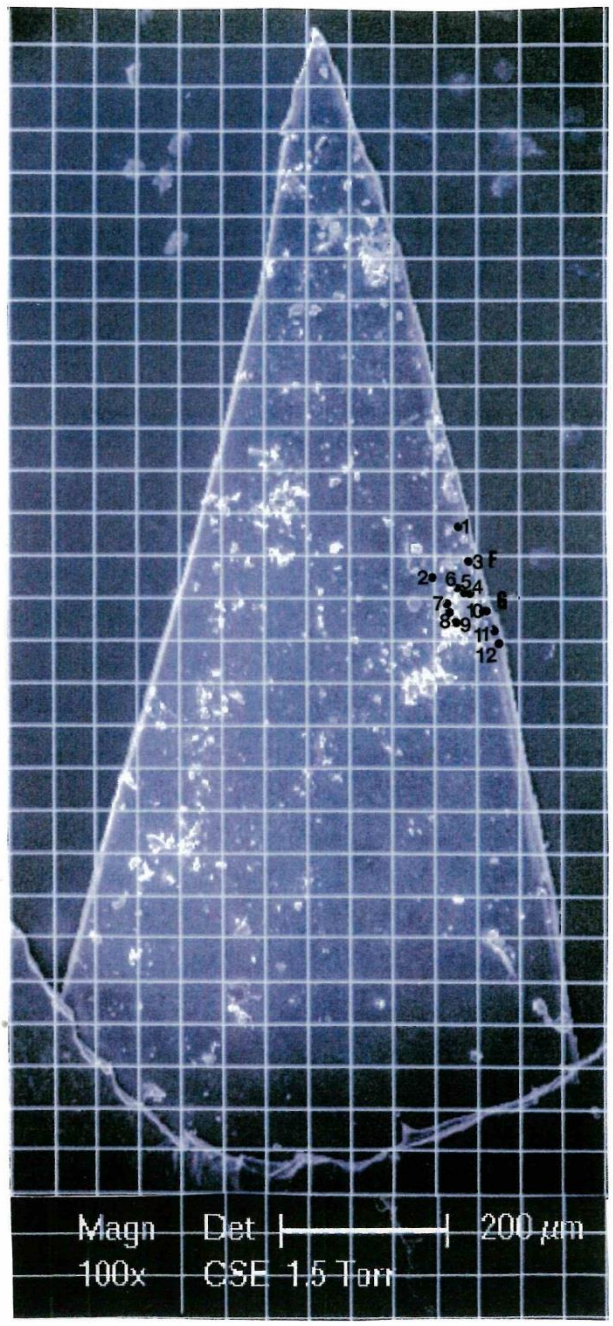


Figure 16 : Optic microscopy photograph of the Radiolarian *Hexacontium clevei* (O : central part ; s : spicules), of a diameter of about 100 µm.