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MULTIDISCIPLINARY APPROACH FOR THE CONSERVATION OF AN ETRUSCAN HYPOGEAN MONUMENT

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Abstract

Tomba della Scimmia is part of the antique religious arts related with the Etruscan funerary cult. This hypogean monument is located near Chiusi, Italy, eight meters below the ground level. It is decorated with wall paintings realized with hematite, Egyptian blue and charcoal black. During time, some conservation problems occurred, such as wall decohesion, including the painted areas, whitening due to biological development or salts efflorescences. Microenvironmental conditions, building materials characteristics and microbial colonization have been investigated in order to determine the factors inducing deterioration and to propose countermeasures to prevent it. The main objectives of this work were focused on the application of modern technologies and innovative devices for investigating the state of conservation and to control surface and environmental conditions present in this hypogean environment. Data logger and portable measurement devices have been used for monitoring the microclimate of the tomb. A micro-photogrammetric system has been employed for the analysis of the surface patterns, beside the colour change measurements and investigations of pigments by means of non-invasive fibre optic reflectance spectroscopy (FORS) in the visible range. Furthermore, microsamples have been collected for microscopic observations or for examine the biodeteriogens dwelling in this location. An innovative control method based on microwave heating, was tested against white microbiological spots present in this tomb. The advantages of the proposed techniques and their prospects to be used for similar conservation situations are discussed in this paper.

Keywords: hypogean monument, microclimate, microwave heating, micro-photogrammetry, VIS reflectance spectroscopy

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1. Introduction

The *Tomb of the Monkey (Tomba della Scimmia*, 480-470 b.C), is one of the most important visitable Etruscan tombs of the Poggio Renzo Necropolis [1, 2]. This tomb, discovered in 1846 by Alexandre François, is located in Tuscany, 4 km near Chiusi. It has a cross shape, with three rooms around the atrium (Figure 1a), and was realized into a lithological complex made by Pliocene sands (quartz, feldspars and lesser calcite amount) with clay cement, 8 m below the ground level. Its name comes from a polychrome painting in the atrium, which depicts a monkey on a tree. Some murals inside this tomb feature old Etruscan sports [3] such as wrestling and boxing (Figure1b and c). The paintings, realized with hematite, Egyptian blue and charcoal black, were made on a thin clay layer [4].

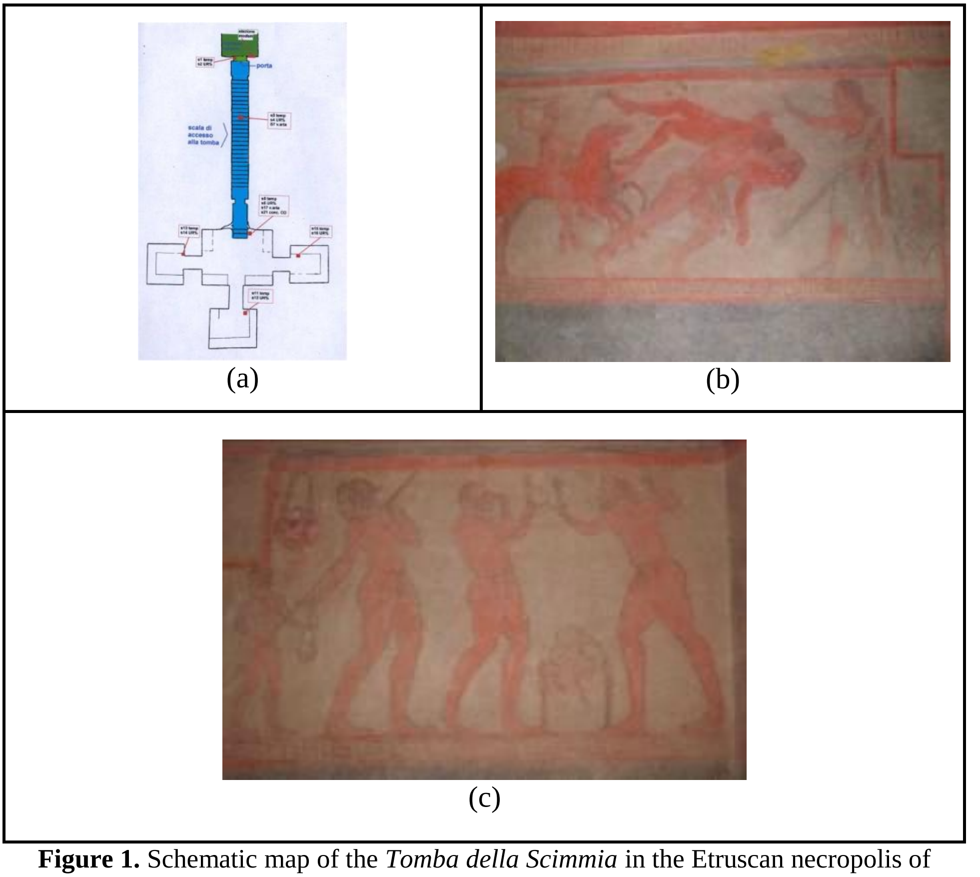


Figure 1. Schematic map of the *Tomba della Scimmia* in the Etruscan necropolis of Chiusi (a) and details of mural paintings (b, c)

As many other Etruscan and Roman tombs, this hypogean monument is included in a tourism net that brings thousands of visitors per year. Areas receiving visits are exposed to temporarily microclimatic modifications due to the presence of the people for short periods of time, and correlated disturbances of the usual steady state climate (i.e., switch on/off of the lights, ventilation, openings of the door), which may introduce risk factors for the conservation of mural paintings, with possible development of microbiological growth and transportation of new microorganisms from other sites [5]. Beside this, hypogean environments often suffer from characteristic and specific damages such as infiltrations of ground waters and salts with high level of humidity and condensation phenomena. Such phenomena were observed in the case of *Tomba della Scimmia* as well, where the presence of microbiological growth and superficial decohesion of the walls with painting losses.

This study aimed to characterize the tomb features and conditions, proposing innovative diagnostic tools and treatment techniques for its conservation. Microenvironmental conditions, building materials, and microbial colonization have been investigated in order to determine the factors inducing deterioration and to propose countermeasures to prevent deterioration. Specific devices have been used for monitoring the microclimate of the tomb. A micro-photogrammetric system [6], a non invasive FORS analyses and color measurements have been employed for studying painted surfaces, and microsamples have been collected for the study of biodeteriogens dwelling in this location. The microwave heating method was tested to control a biological spot present in the tomb.

3. Experimental

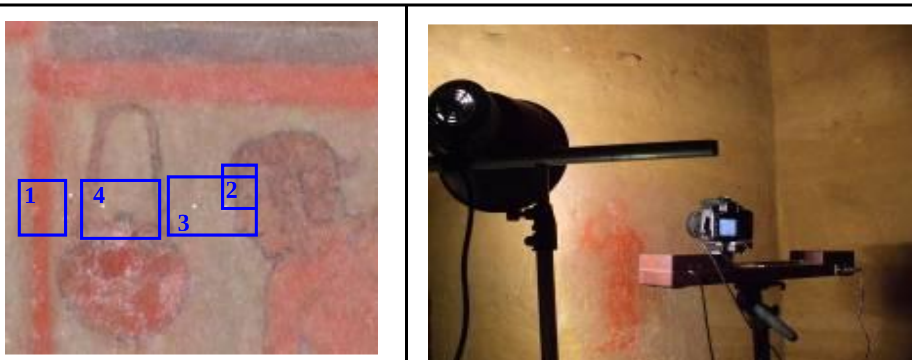
2.1. Monitoring microclimate

The tomb is visited by many tourists during the summer period. The visitors are organized in four small groups of 6 persons each within one day, two groups in the morning and the other 12 persons in the evening. The access to visitors inside the tomb was Tuesday, Friday and Saturday, when the microclimatic measurements were performed. Now, the tomb can be visited on Tuesday, Thursday and Saturday. Temperature and relative humidity variations were monitored using specific sensors (LSI-Lastem s.r.l.) (Figure 2). The characteristics for the temperature transducer range is between -40°C and 60°C, with a precision of +/- 0.1°C. The characteristics for the relative humidity transducer range is between 0% and 100%, with a precision of +/- 0.8% (0%-90%) and +/- 1.5% (RH<10% and RH>90%). They were placed in different areas of the tomb (entrance, stairs near entrance, atrium, room on the right, room on the left and central room). The measuring points are depicted in Figure 1a.

2.2. Surface Pattern Analysis

Four areas (Figure 3a) of the first chamber of the *Tomba della Scimmia* have been selected for monitoring possible changes induced by microclimate variation on the painted surface, using a digital microphotogrametric system (Figure 3b) [7].

Figure 2. Climatic station for controlling temperature and relative humidity, placed in the atrium of the *Tomba della Scimmia*.



(a) (b)

Figure 3. The four selected areas: (a) inside the tomb for analyzing the surface changes in time by the micro-photogrammetry system (b)

Each area is reconstructed by creating a mosaic of many image acquisition areas (40x40mm). The system is composed of a digital camera Canon EOS 400D (10M pixel) equipped with Canon EFS 60mm macro lens, which runs on an automated bar. A dedicated software (Zscan Micro®) automatically estimates the distance between the area of interest and camera sensor, indicating the best step for capturing the images. Using the same software, three shot of the selected surface are acquired and the 3D model is generated. Once the acquisition and 3D model reconstruction have been done, is possible to generate the Digital Elevation Model (DEM), a representation of the quotes of the surface, choosing a suitable reference plane (UCS). A dedicated software allows to extract some dimensional information on the surface pattern such as roughness or quote of particular areas (maximum and minimum values of elevation). DEM is the digital representation of the surface pattern respect to the selected UCS. The Surface Pattern Analysis (SPA) was made confronting two different campaigns - at time zero (T0) and after 8 months (T1). Specific differences DEM were therefore generated for each investigated area, using ZMap® software, by overlapping the data obtained by SPA at T0 and T1.

(a) (b)

Figure 4. Color measurement of one selected area: (a) using the masks held in place by hand, and (b) a detail of the head of the colorimeter in the acquisition phase.

Figure 5. FORS measurement area.

2.3. Colour measurement

The colorimetric measurements were made using a portable colorimeter (Minolta Chroma Meter CR-200). Three zones were selected and a mask (size 30 cm x 21cm, holes 1.5 cm x 1.5 cm) made of acetate was used (Figure 4) for each one, indicating reference points (outline drawings, lines of demarcation) as well in order to be able to repositioning the mask in the subsequent field surveys. On the mask, each hole corresponding to a measuring area, was then identified by a progressive number (1-20) and each mask was identified by a code (M) and a number (1-3). To calculate the colour parameters was adopted the colour space CIEL*a*b* 1976 [CIELAB 1976, Commission Internationale de l'Eclairage] in which the colour of a surface is described by three parameters: L* (0 to 100) that represents the lightness, a* which is in relation to the stimulus colour red-green and b* which is related to the stimulus colour yellow-blue [EN15886 – Conservation of Cultural Property – Test Method – Colour Measurements of Surfaces, 2010].

The total change in colour ΔE * is calculated according to equation (1) for each point of measurement:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

where ΔL* = (L1-L2), Δa* = (a1-a2), Δb* = (b1-b2).

For each area the measurements were repeated 2 times. This makes it possible to assess the error introduced by the repositioning of the measuring head, this parameter being important in the case where the colour measurements obtained on the surface has to be repeated after time as monitoring test. In this way the colour changes above the threshold defined error can be attributed to real changes and not to the measurement procedure. The measurement was made using diffused illumination (D65 standard source), and the measured area has a diameter of 8 mm. The monitoring campaigns were conducted on May 6th and October 4th, 2010.

2.4. Fibre optic reflectance spectroscopy (FORS)

The spectra were acquired using a tungsten lamp as source, and a spectrometer Ocean Optics (model USB2000) equipped with optical fibers as a detector. The measuring head, in the configuration with a 2x45° illumination and signal collection 0°, allows the acquisition of the reflectance spectrum of an area of about 2 mm^2. Each acquired spectrum is the average of 30 scans. As reference a plate of Spectralon® was used. The chosen area is located on the wall opposite the entrance on the left side at the figures of the wrestlers (Figure 5).

(a) (b) (c)

Fig. 6. Set-up of the microwave treatment (a) with details of microwave applicator (b) and the head of applicator with the soft wet sponge (d)

2.5. Biodeterioration

Several biological samples have been collected from painted walls of *Tomba della Scimmia* using common adhesive tape and sterile swabs, and observed under microscope. A mix of two fluorescent dyes (Plant Cell Viability

Kit, Sigma Co.) has been tested for controlling the microwave treatment efficiency. The staining mix was prepared according to the provided protocol. Fluoresceine stains the viable cells, while the big molecule of propidium iodide dye is able to penetrate only into dead cells. The fluorescence of the samples was observed using the Nikon Eclipse 600 microscope equipped with filter cubes FITC (Ex. 465-495 nm, DM 505 nm, BA 515-535 nm) and UV-2A (Ex. 330-380 nm, DM 400 nm, BA 420 nm), respectively, and the images were collected with a Nikon DXM1200F digital CCD camera.

2.6. Microwave heating treatment

A new methodology for controlling the biodeterioration phenomena on cultural heritage surfaces was applied, after its previously set up in laboratory: This method was tested on a painted figure contaminated by white spots of biological growth on the wall of the central room of the tomb.

The prototype system (Figure 6) employed in this experiment uses a 2.45GHz microwave generator (magnetron) with an adjustable output power up to 1kW [R. Olmi, M. Bini, A. Ignesti, S. Priori, C. Riminesi, D. Pinna and P. Tiano, *Development of Innovative Microwave Applicators for the Treatment of Biodeteriogens and Biotic Agents in Artistic/Archaeological Contexts*, Proc. of 12th Int. Conf. on Microwave and High Frequency Heating AMPERE, Karlsruhe, 2009, on CD]. A wet soft sponge was fixed on applicator in order to maintain a constant humidity of the surface during the treatment. During the microwave heating, the temperature on the test areas was controlled by a fluoroptic thermometer (LUXTRON 1000A/A) which is not sensitive to microwave radiation and by thermography using a thermocamera FLIR 325B, before and after treatment. The possible influence of microwaves on the substrate pattern and pigments has been controlled with the microphotogrammetric system as described at §2.2 . The dose applied was 65°C for 3 minutes and the efficiency of the treatment was evaluated with the Plant Cell Viability Kit (Sigma Co.) on the collected biological samples (before and after treatment) as described at §2.5.

3. Results and discussions

3.1. Monitoring microclimate

The temperature fluctuations measured at the entrance of the tomb, during a summer period (August), were deeply influenced by the outside microclimate, registering a maximum of about 30°C at noon and a minimum of about 21°C early in the morning (Figure 7a). The relative humidity (RH) registered in the same point very near to the outside, was instable during diurnal period, with lowest values in the late noon (about 25%) and the highest values (about 70%) in the morning period (Figure 7b).

Once getting down inside the tomb, the temperature decreased while the RH increased with respect to the measurement point of the tomb placed at the entrance (Figure 8). Data recorded showed a stable behavior in the temperature (about 15°C) and relative humidity values (98% in the atrium and 100% in all three rooms) a part the period of opening to public. During the visiting hours (from 11:00-11:30 am 16:00-16:30 pm), it was observed a clearly increasing of the temperatures with about one degree, and a decreasing of the RH with about 3%.

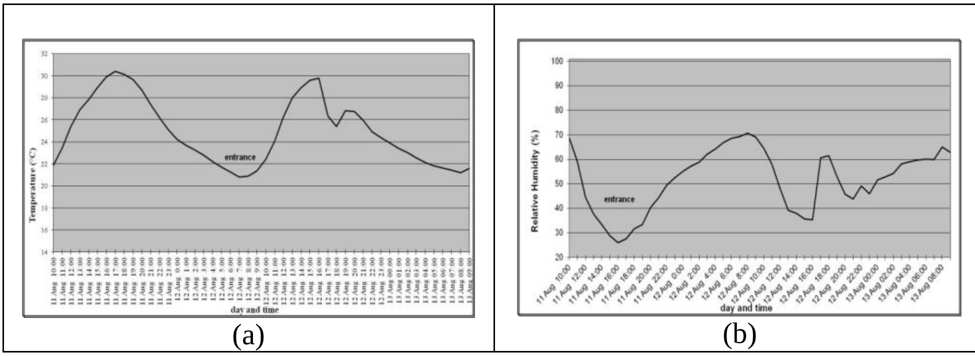


Figure 7. Diurnal variations of: (a) temperature and (b) relative humidity at the entrance of the tomb, expressed as average values registered in one hour.

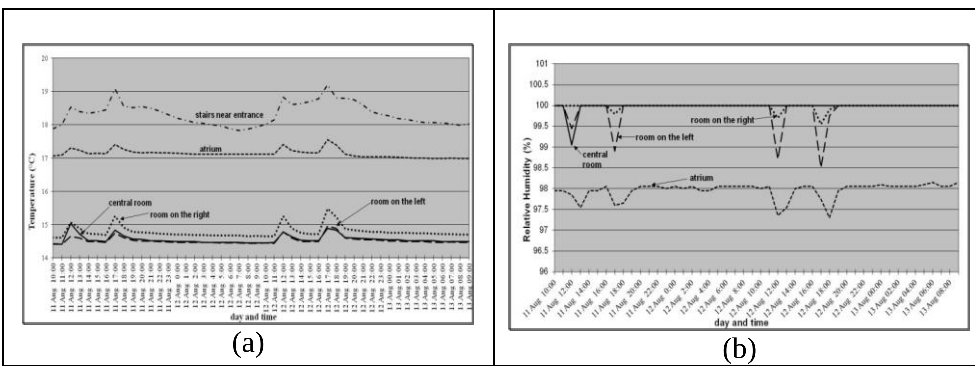


Figure 8. The average values registered for two days of continuous monitoring of the: (a) temperature and (b) relative humidity in different areas of the tomb.

3.2. Surface Pattern Analysis

The difference between the acquired image surfaces at T_0 and T_1 was analyzed for each of the four selected areas (Figure 3a). In order to evaluate the differences between the surfaces, profiles along two directions (A-A' and B-B') were chosen, traced and compared. In Figure 9 is presented the analysis of the test area number 2 (Figure 3a), with the chosen profiles (Figure 9a) and their quotes at T_0 and T_1 (Figure 9b and c). The results showed no meaningful changes in the z axis quotes for all four investigated areas.

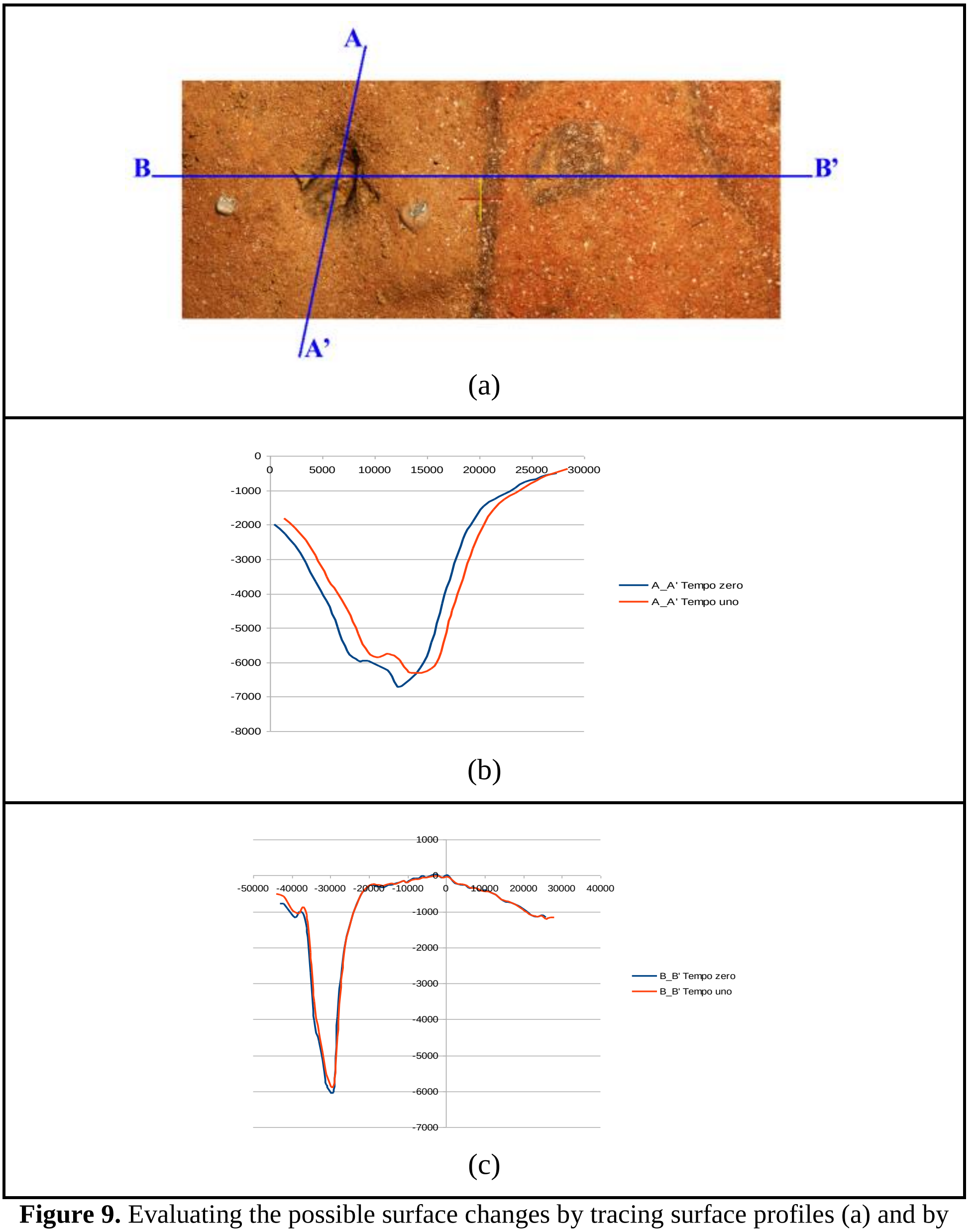


Figure 9. Evaluating the possible surface changes by tracing surface profiles (a) and by comparing their Z profiles along the chosen A-A'(b) and B-B' (c) directions, where T_0 (blue line) show the data acquired at time zero, and T_1 (red line) the one acquired after 8 months.

3.3. Colour measurements

For all measured areas colour variations of the surface after 5 months are quite low considering the repositioning of the mask. In all cases (except for the point M3-18) the ΔE values are below 3 which is considered the limit for the naked eye and within the variability of the measure confirming the stability of the painted surface (Table 1). In the case of zone 1 (M1 mask) ΔE values (Table 1) are less than 1 with the exception of three points where the difference is between 1 and 1.5. In the case of zone 2 (M2 mask) the main differences are found in the two areas (M2-11, M2-12) that include both the red paint and the beige background. In the case of zone 3 (M3 mask) the highest values are found on M3-15 and M3-18 areas, those that during the first campaign had proved critical for the repositioning of the measuring head.

Therefore the observed variations are within the variability of the measure and are not due to physical or chemical changes of the surfaces. Anyway, the average value of colour change due to repositioning between two measures is quite low (0.77) except for some areas where the variation between the two measures is substantially higher (> 3, e.g. M3-15 and M3-18). This variation is due to the extreme unevenness of the surface and then small differences in positioning reflected in large differences in the measures. These areas must be evaluated with particular consideration for the analysis of monitoring data.

Table 1. Values of total colour variation ΔE in all twenty points of measurements (PM) established for each mask (M1, M2 and M3).

	ΔE				**ΔE**		
	M1	**M2**	**M3**		**M1**	**M2**	**M3**
01	0.33	0.49	1.60	**11**	0.75	1.28	0.64
02	0.76	0.64	0.60	**12**	0.50	1.43	0.58
03	0.61	0.13	0.97	**13**	0.92	0.97	0.40
04	0.27	0.30	0.34	**14**	0.72	0.80	1.52
05	0.67	1.03	2.08	**15**	0.68	0.55	2.33
06	0.73	0.23	0.98	**16**	0.57	0.51	0.96
07	1.43	0.85	0.31	**17**	0.59	0.42	0.56
08	0.33	1.32	0.84	**18**	1.12	0.68	3.62
09	0.44	0.24	2.45	**19**	0.70	0.50	0.97
10	1.22	0.79	1.18	**20**	0.33	0.56	1.15

Table 2. FORS spectra and description of the analyzed areas

Area (FORS spectra measured points)	**Results**
Red wrestler (TS01, TS02, TS03)	Iron-based pigment based (Red Ochre)
Red horse (TS04, TS05, TS06)	Iron-based pigment (Red Ochre)
Dark red horse (TS07, TS08, TS09)	Iron-based pigment (Red Ochre) - very similar to TS01÷TS03
Blu monkey, very fragmented (TS10, TS11, TS12)	Very similar to TS16÷TS18, being not uniform it is not possible a univocal identification
Black, below monkey (TS13, TS14, TS15)	Spectral response very low due to dark pigment, no identification
Beige background (TS16, TS17, TS18)	Traces of iron-based materials

3.4. Fibre optic reflectance spectroscopy (FORS)

The FORS measuring points are indicated by reference symbol (TS) and a serial number (1-18) and are listed in Table 2. Measurements were made in 3 areas having similar colour.

FORS spectra (Figure 10) allow the identification of red pigments iron-based (red ochre), particularly evident in the spectra TS04÷TS06 recorded on a vivid red color but also in areas with less intense red color as TS02 (Figure 5).

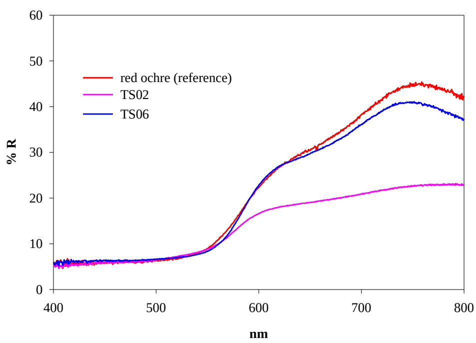
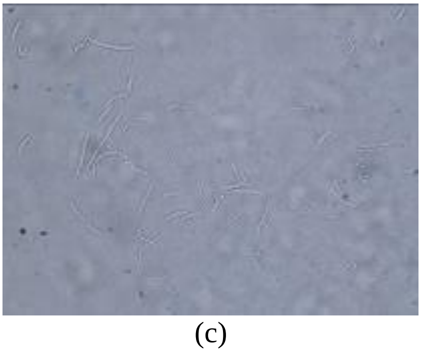


Figure 10. FORS spectra of two red areas (TS02 and TS06) compared with reference spectrum.

(a)

(b)



(c)

Figure 11. General view of microbiological development on a painted wall at *Tomba della Scimmia* (a) and unpainted wall surface (b), and microscopic image of the biodeteriogens (c).

3.5. Biodeterioration

The microenvironmental conditions have favoured the development of several whitish microbiological patches, resembling to salt efflorescences.

Microbial colonization was observed in many areas, both on painted (Figure 11a) and unpainted wall surfaces (Figure 11b). Biological investigation revealed the presence of bacteria (Figure 11c) belonging to Actinobacteria and Firmicutes groups such as *Rhodococcus* sp., *Streptomyces* spp., *Bacillus* spp., *Paenibacillus* sp. (identified by Saiz Jimenez within the bilateral project CNR-CSIC).

3.6. Microwave heating treatment

3.6.1. Temperature control of the treated wall surfaces

The heating variation on the areas treated with microwaves was evaluated by thermal analysis, while the possible induced effects were evaluated both macroscopically and by the micro-photogrammetry. In laboratory experiments several tests on fungal contaminated mortar samples using different dose that raging in temperature from 60°C to 70°C and in treatment time from 1 minute to 6 minutes were performed. The most effective killing dose without over stressing the support has been determined in 65°C for 3 minutes. This dose was applied on a preliminary testing area without paintings checking the temperature variation before and after the microwave heating (data not shown). Thermal investigations showed that the wall completely reverted to the initial temperature after 2 hours (Figure 12a). The same procedure and dose were applied on the selected painted area as well. The thermographs immediately after the microwave treatment are shown in Figures 12b and c.

3.6.2. Control of microwaves efficacy against biodeteriogens

Only one microwave treatment was applied on the painted area where whitish microbiological spot was present (Figure 6a). The mix of fluoresceine diacetate and propidium iodide fluorescent dyes was directly used on adhesive tape containing the samples of biodeteriogens. The results showed different fluorescence of the treated microorganisms with respect to the untreated ones (Figure 13). The untreated biological sample showed only green fluorescence due to the fluoresceine diacetate which stains only the live cells. By contrast, the biological samples collected after the microwave heating treatment showed only red fluorescence in the UV channel and no green fluorescence (Figure 13). This is due to the penetration of the propidium iodide inside dead cells.

3.6.3. Surface pattern of the treated wall surfaces

The SPA of the test area (Figure 14a) before/after microwave treatment and after microbiological sampling, was performed by micro-photogrammetry. This test area is part of the painting showed in Figure 3b. The comparison between Z profiles along AA' and BB' direction showed no significant surface changes after the microwave treatment (Figures 14b and c).

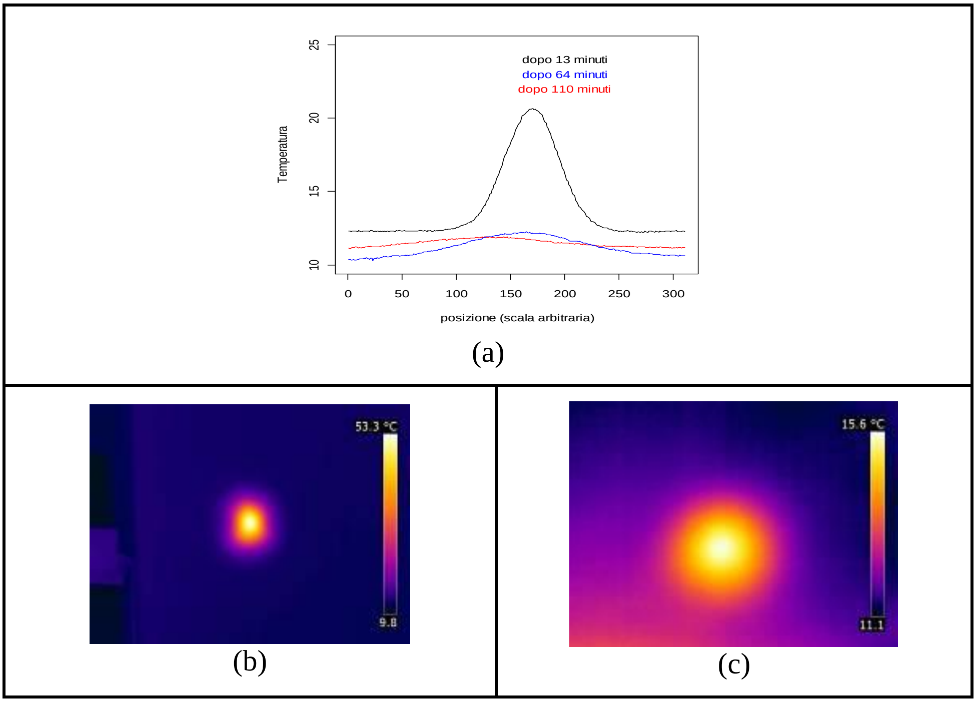


Figure 12. Temperature variation on the unpainted tomb wall after 13, 64 and 110 minutes from microwave treatment remotion (a) and thermographs of the painted area treated by microwave heating method after: (b) 10 seconds and (c) 26 minutes after the applicator removal.

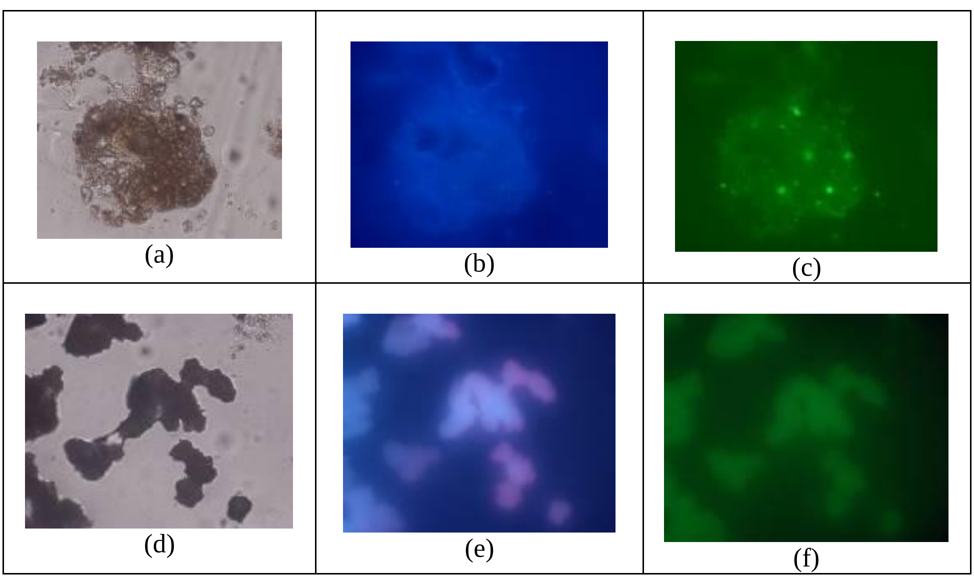
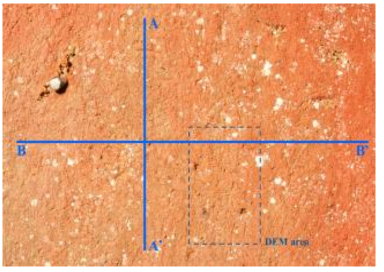
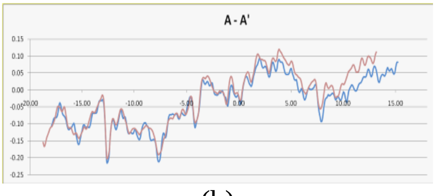


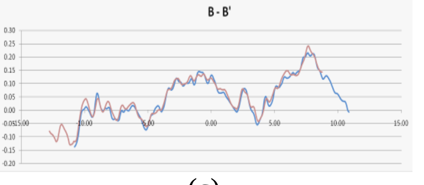
Figure 13. Vitality assessment of microorganisms sampled: (a) before and (d) after the microwave heating treatment, observed in: (a, d) transmitted light, (b, e) UV light and (c, f) green light, using a 40x objective.



(a)

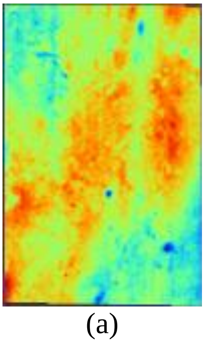


(b)

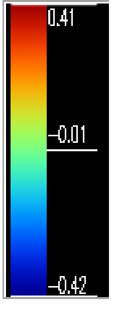


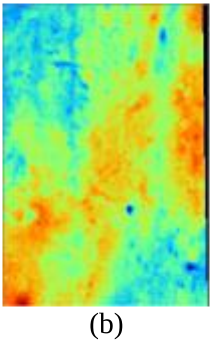
(c)

Figure 14. Detail of the painted area chosen for the microwave treatment test (a) with two chosen Z profiles along the A-A’ (b) and B-B’ axes (c), before (blue line) and after the microwave treatment (red line). Dashed rectangle represents the area chosen for generating a DEM.



(a)





(b)

Figure 15. DEM of the chosen area: (a) before and (b) after the microwave treatment. Units scale are mm.

It was also generated a DEM (Figure 15) of the two shots in order to observe the possible changes on the selected area and not only along the chosen profiles. It was obtained a map of Z-differences which showed no significant changes of the superficial pattern.

4. Conclusions

The causes of the hypogean monuments degradation are related to physical-chemical and biological processes. Variation of the environmental parameters, such as temperature, humidity, CO_2 concentration and the dew point temperature, can accelerate the rate of alterations. For example, the variations of humidity, when high, imply the succession of precipitation and successive solubility of salts inducing the formation of white efflorescence and weakening of the external layer of the stone wall, with possible loss of painted areas. It is therefore required, when some alteration processes occur, to clearly assessed the main cause and to chose the best solution for the conservation, employing affordable devices for acquiring data. In our experience, the main conservation procedures for the hypogean monuments are generally related to monitoring and controlling the microenvironmental parameters.

The Etruscan tomb, *Tomba della Scimmia* was one ideal place for testing a great variety of innovative non-invasive and affordable techniques aimed to easily diagnose and solve possible conservation problems. The diagnostic technique – micro-photogrammetry, FORS, color measurements and micro-sampling – have been used to evaluate the state of conservation of mural paintings and the cohesion of the tomb wall, and to assess the possible alteration processes. To control the biodegradation attack the microwave system has been tentatively used on a white spotted area. The effectiveness of this method on micro-bacteria has been assessed by the vital fluorescent kit (fluoresceine diacetate and propidium iodide) on the samples collected before and after the treatment.

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References

[1] S. Steingraber, Etruscan Studies: Journal of Etruscan Foundation, **2** (1995) 1.

[2] R. Bianchi Bandinelli, *Clusium, I, le pitture delle tombe arcaiche*, in *Monumenti della pittura antica scoperti in Italia: La pittura Etrusca*, Istituto poligrafico dello Stato, Roma, 1939, 1.

[3] K.B. Vellucci, Expedition, **27** (1985) 2.

[4] M.P. Colombini, G. Giachi, P. Pallechi and E. Ribechini, *Tecniche pittoriche utilizzate nelle tombe etrusche di Chiusi e Sarteano*, in *Pittura etrusca. Problemi e Prospettive*, A. Minetti (ed.), Musei Senesi, Siena, 2003, 162.

[5] P. Albertano, C. Urzì and G. Caneva, *Tombs, catacombs, and other hypogean environments*, in *Plant biology for cultural heritage*, G. Caneva, M. P. Nugari & O. Salvadori (eds.), The Getty Conservation Institute, Los Angeles, 2008, 183.

[6] P. Tiano, D. Tapete, M. Matteini and F. Ceccaroni, *The Micro-photogrammetry: a new diagnostic tool for on site monitoring of monumental surfaces*, Proc. of the Int. Workshop SMW08, P. Tiano, C. Pardini (eds), ICVBC-CNR, Florence, 2008, 97-106.

[7] P. Tiano, P. Salvo and F. Ceccaroni, *The Micro-photogrammetry as a Portable Diagnostic Tool for Monumental Surface Monitoring*, Proc. of the DGaO/SIOF Joint Meeting, Deutsche Gesellschaft für angewandte Optik e.V., Brescia, 2009, 85-89.

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