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INNOVATIVE IMAGING TECHNIQUES FOR EXAMINATION AND DOCUMENTATION OF MURAL PAINTINGS AND HISTORICAL GRAFFITI IN THE CATACOMBS OF SAN GIOVANNI, SYRACUSE

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Abstract

This paper presents scientific and technical examination of two mural paintings and their historical graffiti located in the catacombs of San Giovanni in Syracuse, Sicily. Reflectance Transformation Imaging (RTI), Infrared Photography, 3D Photomodeling are presented as innovative imaging techniques used to capture significant details of the palimpsest, along with XRF non-invasive point analysis. These methods were performed on the Philadelpheia palimpsest and on the arcosolium of the Madonna. RTI technique was tested as a valid tool to enhance the readability and documentation of the numerous historical graffiti covering some of the murals, which are of high interest to scholars since they are useful to reconstruct the cultural history of the site. The results of the infrared RTI were particularly powerful in their ability to document graffiti on deteriorated surfaces painted with earth pigments. 3D Photomodeling also proved to be a successful and handy tool to document the position of paintings and graffiti in context with one another. The examination of the two paintings was integrated with an analytical study of the palette realized with non-invasive XRF.

Keywords: *Reflectance Transformation Imaging; Infrared photography; 3D Photomodeling; XRF; frescoes; catacombs; graffiti.*

Introduction

This paper presents the technical and scientific examination of two mural paintings and some of their historical graffiti in the catacombs of San Giovanni (St. John the Evangelist) in Syracuse, Sicily. RTI (Reflectance Transformation Imaging) was tested and applied in order to enhance the readability and documentation of some of the historical graffiti covering one of the paintings. Scholars have a keen interest in the study of historical graffiti [1, 2] since they provide unique information on the uses and frequentations of the site over the centuries, and thus they become documentation used to reconstruct the cultural history of these catacombs. Some of the graffiti of the catacombs of San Giovanni are contemporary with the epoch of the paintings that bear them. They mainly comprise funerary or devotional texts and symbols that

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date back to the age of late antiquity, while others have been incised by pilgrims in the Early Middle Ages [3]. Graffiti provide insights into the religious cults and practices inside the catacombs, as well as, information regarding the language, onomastics, and the origin of the pilgrims. The contributions to paleographic studies are also of importance, such as the evolution of the shape of the letters and their execution methods. They were often made by free hand, and sometimes, specific attributions can be reached. The graffiti constitute significant documentation of the late-antiquity and mediaeval Christian history of the catacombs and the use of innovative technologies in order to enhance their readability is highly encouraged, since they are often difficult to interpret due to the dim lighting conditions in the catacombs, and the relatively poor state of conservation of the surface. Particularly innovative methods are also required to document them before the degradation of the pictorial layer on which they are incised occurs. RTI was successfully coupled with Infrared (IR) Photography to enhance its efficacy, and 3D Photomodeling served as a handy means to document the location of the paintings and their graffiti and to rapidly and economically create 3D models. This study integrates the above-mentioned imaging examinations with the XRF analytical study of the palette of pigments [4].

The Catacombs of San Giovanni [5] are an entirely underground post-Constantine community cemetery that was used from the fourth to the sixth century AD. The construction supposedly started after the *Peace of the Church* and the publication of the Edict of Milan in 313 by the Emperor Constantine. At that time, the Syracuse community was almost entirely Christianized and there was an ecclesiastical hierarchy and sufficient economic resources to make the extensive and monumental architecture of the catacombs possible. They feature a long gallery (*decumanus maximus* dividing the site in two halves. The region at north is crossed by a *decumanus minor* while the other region is characterized by three large spaces, probably prior cisterns [6]. The Eastern part of the *decumanus maximus* preserves the two murals objects of this study: the monumental palimpsest arcosolium of *"Philadelpheia"* (Fig. 1) and the arcosolium of the *Madonna (*Fig. 2), both described extensively elsewhere [4]. In brief, the *Philadelpheia* palimpsest illustrates the departed virgin Philadelpheia crowned by Christ between the alpha and omega while the *Madonna*'s arcosolium shows a seated and veiled mother holding a baby in her arms [7].

Fig. 1. Catacombs of San Giovanni, Philadelpheia arcosolium. 3D model and the 40 camera's positions.

Fig. 2. Catacombs of San Giovanni, Madonna’s arcosolium. 3D model.

Experimental

Visible (VIS) and Infrared (IR) photography were performed with a Nikon D800 camera, DSLR (36 MP, CMOS sensor), modified for full spectrum acquisition (built-in IR filter removed). The imaging equipment and the method are extensively described elsewhere [8] including the description of filters combinations, lighting setup and panoramic multispectral imaging. The Philadelpheia arcosolium was documented with panoramic VIS and IR photography, with a total of 117 photos shot with a 200 mm lens. The arcosolium of the *Madonna* was also documented with VIS and IR photography, however by stitching just 4 images and using a 50 mm lens. For the examination of the pigments palette a handheld Bruker AXS Tracer III-SD® (Kennewick, WA, USA) was used. The portable XRF technique has been widely used specifically for mural paintings [9]. The system features, as well as, the measurement parameters are described extensively elsewhere [4]. The images for the SfM (Structure from Motion) 3D model were shot with the Nikon D800 camera mounting a 20 mm lens for the *Philadelpheia* palimpsest and a 50 mm lens for the arcosolium of the *Madonna*. The dense data clouds were created with Agisoft Photoscan® and subsequently edited in Meshlab. RTI images where shot using the same Nikon D800 and a black sphere of diameter 3 cm. A 75 mm lens was chosen to provide enough distance between the tripod and the graffiti in order to allow the movement of the speed lights around the surface and to provide documentation of an area on the order of half a meter wide.

Results and Discussion

Philadelpheia arcosolium

The 3D model of the Philadelpheia arcosolium is composed of 40 images (Fig. 1). The 3D model represents a very useful tool to document and examine the different painted layers, which compose the palimpsest. This is especially easy to accomplish in Meshlab, which has a feature to control the lighting direction in order to simulate a raking light illumination (Fig. 3). The 3D model is also useful to verify the position of the RTI areas examined bearing graffiti.

Under visual inspection 5 colors were identified: red, yellow, white (plaster), green and black. Fig. 4 shows the points examined with XRF and Table 1 gives their qualitative elemental content, selected spectra are reported in [4]. As expected, the main elements present in all the spectra are calcium and iron, with lesser amounts of silicon, sulfur, and strontium since these are the principle elemental components of the plaster, which was analyzed in point 8, an area where the original paint was missing and the support was revealed. The sulfur and calcium amount is considerable, and it is realistically due to $CaSO_4$, a degradation material of calcite ($CaCO_3$). Additionally, lead was detected in all points and this may be of natural mineral origin, or due to pollution over the centuries, or may suggest that lead white was added to the pigments and that they were applied *a secco*.

Fig. 3. Catacombs of San Giovanni, Philadelpheia arcosolium. 3D model. The manipulation of the lighting direction in Meshlab allows the two layers of the palimpsest to be distinguished.

Fig. 4. Catacombs of San Giovanni, Maps of the points analyzed with XRF and of the areas documented with RTI. Top, Philadelpheia arcosolium. Bottom, Madonna's arcosolium.

Table 1. Philadelpheia arcosolium, XRF point data – qualitative elemental composition.

Point	layer	Color	Major Elements	Minor Elements
1	higher	red	Ca, Fe	Si, S, Sr, Pb
2	higher	red	Ca, Fe	Si, S, Sr, Pb
3	higher	black	Ca, Fe	Si, S, Sr, Pb
4	higher	black	Ca, Fe	Si, S, Sr, Pb
5	higher	yellow	Ca, Fe	Si, S, Sr, Pb
6	higher	yellow	Ca, Fe	Si, S, Sr, Pb
7	higher	red	Ca, Fe	Si, S, Sr, Pb
8	higher	white	Ca, Fe	Si, S, Sr, Pb
9	higher	yellow	Ca, Fe	Si, S, Sr, Pb
10	higher	yellow	Ca, Fe	Si, S, Sr, Pb
11	higher	red	Ca, Fe	Si, S, Sr, Pb
12	higher	black	Ca, Fe	Si, S, Sr, Pb
23(2)	lower	green	Ca, Fe	Cr, Si, S, Sr, Pb
24	lower	blue	Ca, Fe	Cu, Si, S, Sr, Pb
25	higher	green	Ca, Fe	Si, S, Sr, Pb
26	Higher	green	Ca, Fe	Si, S, Sr, Pb
27	higher	black	Ca, Fe	Si, S, Sr, Pb
28	higher	black	Ca, Fe	Si, S, Sr, Pb

Blacks

Points 3, 4, 12 and 28 belong to the dark frame, while point 27 belongs to the letter “I”. They are elementally similar and show a composition of S, Si, Ca, Fe, S, and Sr, identical to that of the plaster. The relatively low iron content dissuades the rationale that iron is a major component of the black pigment, and suggests the use of a carbon black pigment (not able to be detected with XRF) instead. All the historical black pigments absorb infrared light so there is no added information regarding the identification of the black paint. However, the infrared photography becomes useful to recover the black paint areas that have faded, since the infrared image shows more contrast between pigment and plaster (Fig. 5).

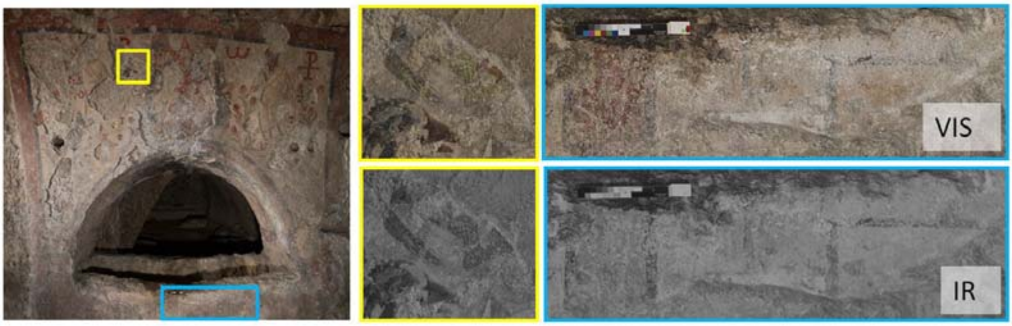

Fig. 5. Catacombs of San Giovanni, Philadelpheia arcosolium. Visible and Infrared images of two details showing that the contrast between some paints (green, yellow and red) and the ground is higher in the infrared photos.

Blues

Point 24 is representative of a very dark blue on the lower layer of the palimpsest and shows significant copper content, in addition to the normal elements of the plaster. The presence of copper in a pigment appearing almost black points to copper sulfide, perhaps in the form of the mineral covellite, which was known to make an indigo blue that could turn to black with time. The formula to manufacture Egyptian blue was lost during late Roman times and covellite, found as a natural mineral, is also known to have been used as a blue pigment in antiquity [10, 11]. Another hypothesis is that the copper content could potentially be due to the degradation of azurite to tenorite, which has been documented to occur in alkaline environments [12]. To conclusively identify the pigment, further tests, beginning with Raman spectroscopy would need to be performed together with X-ray diffraction to confirm the crystal structure of the materials present.

Reds

Points 1 and 2 belong to the upper red frame, while 7 and 11 to the bottom part of the arcosolium. Their spectra indicate the use of red ochre. The ratio Ca/Fe of the integrated peak areas is <10 for these colors, whereas the median Ca/Fe ratio for plaster without an iron based pigment is around 40. The use of red ochre is also confirmed by the infrared imaging where the ochre becomes transparent [13] (Fig. 5).

Yellows

Points 5, 6, 9, and 10 belong to the yellow decorations inside the red frame on the upper layer (points 5 and 6) and the lower one (points 9 and 10) of the palimpsest. They all show very similar spectra and their elevated Fe content points to yellow ochre ($FeO(OH)\cdot nH_2O$), as does the infrared imaging, which shows a transparent pigment (Fig. 5).

Greens

Green points 23(2), 25 and 26 are located on the upper part of the arcosolium, but 23(2) belong to the lower paint layer while 25 and 26 belong to the upper one. A small amount of Cr is observed in point 23(2) along with a small amount of Ti, which may both be of natural mineral origin or otherwise signal a later retouching with modern chrome green. The infrared imaging seems to deny the hypothesis of the use of chrome green or viridian which are infrared transparent. On the other hand, points 25 and 26 do not particularly show any elements that we expect to be associated to a green pigment, but only a small signal related to copper. This would indicate malachite as a reasonable assumption even though the copper content is low, due to the fact that there is also a relatively small portion of the signal coming from the pigment itself. The pigment green earth is generally identified by the K, Fe, and Si elemental content observed with XRF. According to the spectra for points 25 and 26, we can still consider it a possibility, since the abundance of the plaster matrix can obscure these trace components. The infrared image cannot help distinguish between any of these hypotheses since malachite, as well green earth, both absorb infrared. However, the infrared image is useful to detect faded traces of this green thanks to its strong infrared absorbance (Fig. 5).

Graffiti

This palimpsest presents a number of graffiti and the RTI [14] documentation was carried out in order to test the capabilities of this method as a tool to enhance their readability. RTI is a natural way to document graffiti, since it overcomes the limitation of requiring raking light photography to adequately read them. In addition to the RGB color, RTI also records the surface normal of each pixel of a scene photographed. These normal are used to render the surface shape of the area. The Specular Enhancement mode can remove the distracting RGB color from each pixel and provide only the reflectivity. This is the obvious enhancement that the RTI method can provide. It is reasonable to argue that RTI in the infrared range can perform an even better documentation. Infrared light provides more informative RTI images because some pigments, such as, in this case, red ochre, become transparent; therefore the photos are not disturbed by the paint which has randomly detached from the mural.

Three areas were documented with RTI in the visible (VIS-RTI) and infrared (IR-RTI) range and they represent 3 different conditions of the graffiti (Fig. 4). Area RTI 1 shows a series of graffiti incised on an area painted with red ochre, which is partially peeled off, thus confusing the readability of the graffiti in visible RGB images. The standard IR photo already provides a better documentation of the incisions (Fig. 6). The comparison of the VIS-RTI and IR-RTI promotes the latter for improved readability. Indeed, while the elimination of the color information can also be attempted using the specular enhancement parameters, this manipulation of the image is less performing than the IR-RTI, where the result is achieved solely from the infrared photo (Fig. 7). In any case, while the color can be eliminated with both modifications, the brightness is still influenced by the paint and so the incisions are more readable in the IR-RTI than in the VIS-RTI, even with the specular enhancement applied. Area RTI 2 was chosen due to the presence of a whitish encrustation, which compromises the reading of the incisions. The IR-RTI is also successful in this case, since the reflectance of the encrustation in the infrared is less intense and therefore is less visually disturbing (Fig. 8). The IR-RTI is also useful when the graffiti have been painted over and they are less readable in visible light, however this effect is most pronounced if the paint used is IR transparent, as for red ochre (Fig. 9).

Fig. 6. Catacombs of San Giovanni, Philadelpheia arcosolium. Area RTI 1. The two images were taken with the same raking light direction. Red ochre becomes transparent in the infrared and reveals the incisions without the noise from the paint losses.

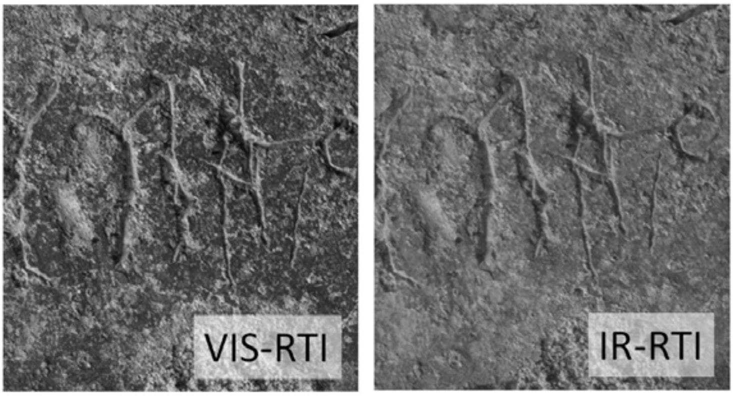

Fig. 7. Catacombs of San Giovanni, Philadelpheia arcosolium. Area RTI 1. Left, VIS-RTI with the specular enhancement applied. Right, IR-RTI.

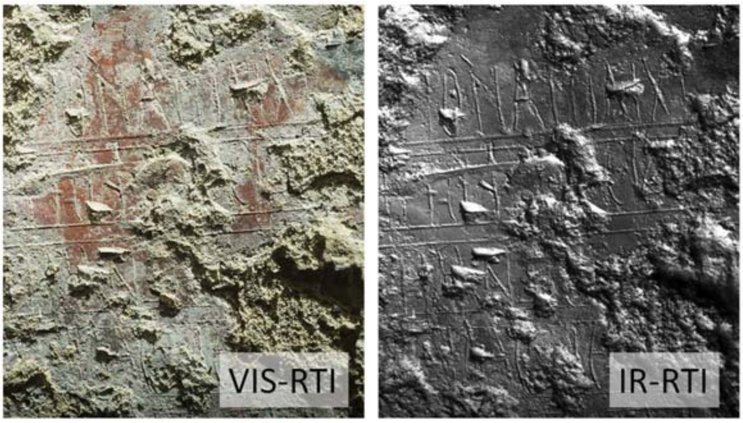

Fig. 8. Catacombs of San Giovanni, Philadelpheia arcosolium. Area RT2. Left, VIS-RTI. Right, IR-RTI.

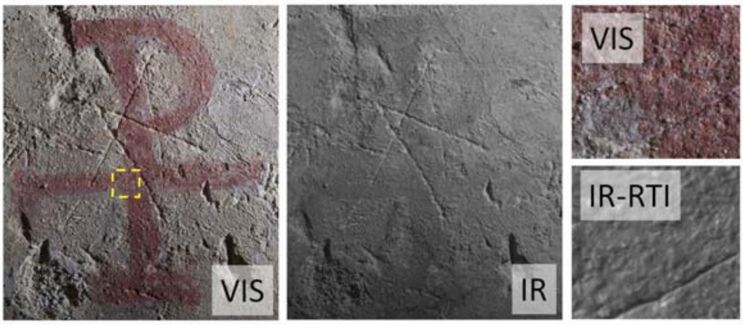

Fig. 9. Catacombs of San Giovanni, Philadelpheia arcosolium. The graffiti in the yellow dashed area was painted over. The incision becomes clearer in the IR-RTI.

Arcosolium of the Madonna

This painting is located on the left side of the *Philadelpheia* palimpsest. Figure 2 shows the 3D model and Figure 4 the location of the XRF points. XRF data is presented in Table 2. The infrared image proved successful to read some previously faded details, such as the hand of the female figure. The ochre and the encrustation become transparent in the infrared and provide the drawing with more contrast (Fig. 10).

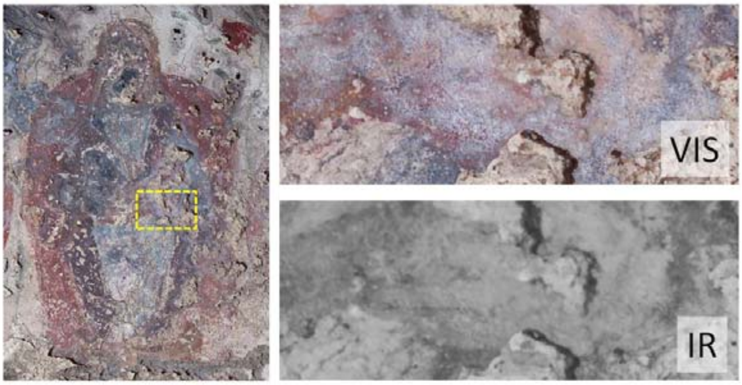

Fig. 10. Catacombs of San Giovanni, Madonna's arcosolium.
The contour of the hand of the female figure becomes visible in the infrared image.

Table 2. The arcosolium of the Madonna, XRF point data – qualitative elemental composition.

Point	Color	Major Elements	Minor Elements
13	green	Pb, Ca, Fe	Si, S, Sr
14	red	Ca, Fe	Si, S, Sr, Pb
15	blue	Ca, Fe	Cu, Si, S, Sr, Pb
16	green	Pb, Ca, Fe	Si, S, Sr, Pb
17	white	Ca, Fe	Si, S, Sr, Pb
18	blue	Ca, Fe	Cu, Si, S, Sr, Pb
19	black	Ca, Fe	Si, S, Sr, Pb
20	green	Pb, Ca, Fe	Si, S, Sr
21	white	Ca, Fe	Si, S, Sr, Pb
22	red	Ca, Fe	Si, S, Sr, Pb
23(1)	white	Ca, Fe	Si, S, Sr, Pb

Blacks

Point 19 belongs to a dark encrustation on the upper part of the mural. The XRF spectrum shows elevated levels of silicon and iron compared to the other spectra and the color could be attributed to a carbon based black pigment, as suggested also by the infrared image, which shows an infrared absorbent paint.

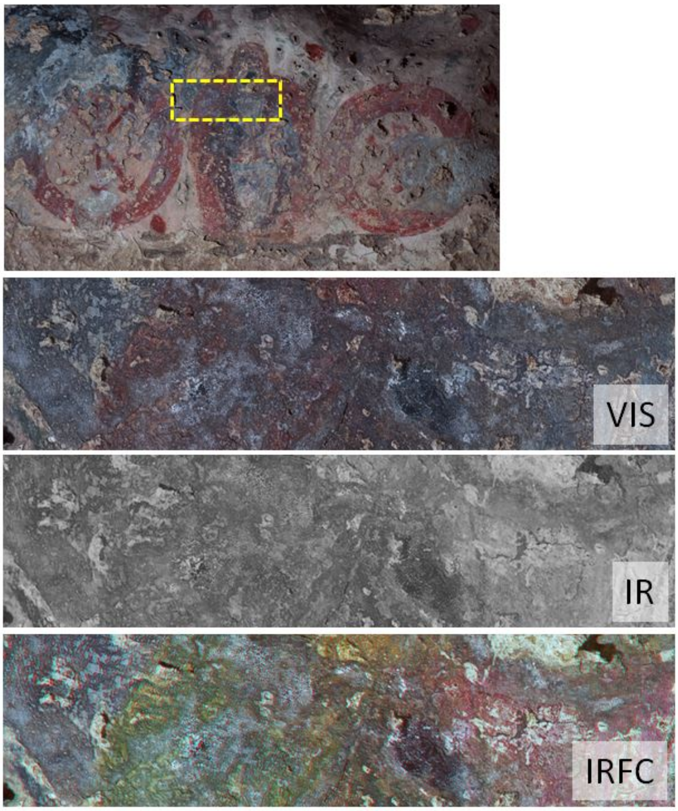

Fig. 11. Catacombs of San Giovanni, Madonna's arcosolium. The infrared false color image reveals the two different blue pigments, the one on the left is characterized by a bluish false color, while the one on the right turns a distinct red.

Blues

Points 15 and 18 belong to the blue paint, which in some areas overlaps the main figures painted with red ochre. Unfortunately the poor condition of the painting does not allow us to discriminate if these blue painted areas represent subjects belonging to the original composition, or if they may have been added later on. These two points were chosen because point 18 is much darker and absorbs infrared, while point 15 has a more distinct blue color and it is transparent to the infrared. Both the spectra of these two points show, in addition to the chemical elements found in plaster, the addition of a significant signal from copper. As for the *Philadelpheia* arcosolium, attributions to copper-based mineral pigments covellite or azurite decayed to tenorite for point 18 are valid. For point 15 the identification is still not clear because it appears distinctly blue and has not degraded, yet it is also transparent to the IR (while azurite is highly infrared absorbent). The difference between these two blues is evident in the infrared false color image (Fig. 11).

Reds

Point 14 belongs to the female figure and its XRF spectrum indicates the use of red ochre (Fe_2O_3), confirmed in the infrared image, where the pigment is transparent. In point 14, a small copper signal is observed, however, this is explained due to the proximity of the point with the blue pigment analyzed in point 15. Point 22 is a very bright red color, as seen in the visible image, and doesn't show signs of degradation, suggesting that it is part of a more recent retouching. Indeed, in the XRF spectrum, we observe a lower amount of sulfur, and a very intense iron peak. This indicates that the $CaSO_4$ degradation product is absent and the pigment concentration, likely ochre (Fe_2O_3), is greatly increased.

Whites

The white plaster was analyzed at points 17, 21, and 23(1) which show the same elemental composition: Si, S, Ca, Fe, and Sr even though with variation in the intensity of the peaks which can be associated to the granularity and inhomogeneity of the sample itself.

Greens

Points 13, 16, and 20, were analyzed, and classified as appearing green. Lead is observed in all their XRF spectra and two of these (16 and 20) show increased amount of Si. Sulfur content is high in all spectra except point 20. The spectra do not overtly indicate a particular element that is associated to a green pigment. Consequently, it may be a mix of yellow and blue pigments, and would require further examination to make conclusive pigment identification.

Conclusions

Two mural paintings and their graffiti in the Catacombs of San Giovanni were studied with innovative imaging methods to test and propose a new technical approach for the examination and documentation of historical graffiti. Reflectance Transformation Imaging proved to be a useful tool and the transparency of red ochre in the infrared imaging modality makes IR-RTI even more effective to enhance their readability. 3D Photomodeling with SfM was also included in this workflow to show that this is a viable, rapid and economical means to creating 3D models of wall paintings. These models are useful for documenting the location of the graffiti and serve to further examine these types of palimpsests. This study integrated three imaging methods with XRF analysis of the palette of pigments in order to provide a comprehensive documentation of the two paintings. XRF results confirmed that these mural paintings are made from the traditional natural pigments, and that there are no consistent retouches or recent executions made with modern pigments. In some cases, such as with the blue and green pigments, hypotheses have been left open and a future study with a more specific examination technique will be necessary.

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