heritage

MDPI

*Article*

# The Medieval Glass Mosaic of *S. Agnese fuori le mura* in Rome: Multispectral Imaging for Preliminary Identification of Original Tesserae

**Rita Deiana [1], Alberta Silvestri [2,*], Manuela Gianandrea [3], Sarah Maltoni [4] and Chiara Croci [4]**

[1] Department of Cultural Heritage, University of Padua, Piazza Capitaniato 7, 35139 Padua, Italy
[2] Department of Geosciences, University of Padua, Via G. Gradenigo 6, 35131 Padua, Italy
[3] Department of History, Antropology, Religions, Art History, Media and Performing Arts, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy
[4] Faculty of Arts, Section of Art History, University of Lausanne, Anthropole 4143, 1015 Lausanne, Switzerland
* Correspondence: alberta.silvestri@unipd.it

**Abstract:** The mosaic in the apse of the Church of *S. Agnese fuori le mura* in Rome represents one of the most important examples of the wall mosaics of the Roman Middle Ages. Although it is associated with Byzantine figurative culture, no scientific study has addressed this important piece of Italian art history. One factor that has probably limited and created difficulties for its analysis is the poor legibility of the original parts, which are compromised by heavy restorations affecting the gold background, the faces of the two male side figures, and the lower band of the mosaic. The present work describes how multispectral imaging provided significant guidance in the preliminary identification of possible original areas in this ancient wall mosaic. Through an interdisciplinary approach, the art historical background and historical graphic documentation of known restorations supported the use of multispectral imaging to recognize original parts. The initial results of the lab analyses (SEM-EDS and EMPA) of supposed original tesserae validated the hypothesis made a priori thanks to multispectral acquisition, opening up new application possibilities for use of this noninvasive technique in the preliminary in situ identification of original parts in restored glass wall mosaics.

**Keywords:** wall mosaic; Roman middle ages; glass tesserae; multispectral imaging; SEM-EDS; EMPA



**Citation:** Deiana, R.; Silvestri, A.; Gianandrea, M.; Maltoni, S.; Croci, C. The Medieval Glass Mosaic of *S. Agnese fuori le mura* in Rome: Multispectral Imaging for Preliminary Identification of Original Tesserae. *Heritage* **2023**, *6*, 2851–2862. https://doi.org/10.3390/heritage6030152

Academic Editors: Elena Tesser, Chiara Coletti, Luigi Germinario, Claudio Mazzoli and Rebecca Piovesan

Received: 30 January 2023
Revised: 3 March 2023
Accepted: 6 March 2023
Published: 9 March 2023



## 1. Introduction

Commissioned by Pope Honorius I (625–638), the apsidal mosaic of *S. Agnese fuori le mura* is one of the most outstanding early medieval works in existence (Figure 1). As stated in the *Liber Pontificalis* [1], the basilica was founded by the patron over the burial place of the significant Roman female martyr Agnese on Via Nomentana, which had been a focus of attention since Constantine's time.

The synthetic and hieratical composition, compared to the more common five- or seven-figure apsidal groups, the gold background, the frontality, and the linearity of the figures make this mosaic a breakpoint in the Roman artistic production of the early Middle Ages, interpreted as a mirror of a Byzantine taste of the imperial administration during these times [2–6]. The use of stone tesserae to realize the martyr's face, never observed in earlier Roman glass mosaics but widespread in the East, confirms the "Byzantinity" of the *S. Agnese* mosaic [6,7] (Figure 2). However, more recent studies have laid the groundwork for addressing the work not only from a purely stylistic perspective but within the Honorius architectural project, in which the mosaic represents the centerpiece of a theatrical stage orchestrated for the liturgical performance [8–10].

The synthetic iconography could indeed be explained by the decision, relatively new for the time, to place the martyr saint in the center of the apse, namely at the focal point of the basilica, most commonly occupied by the figure of Christ or the Virgin [8,11].

**Figure 1.** The wall mosaic in the apse of *S. Agnese fuori le mura* (photo by Domenico Ventura).

**Figure 2.** Detail of the figure of *S. Agnese* (photo by Domenico Ventura).

Precious marbles enhance the overall piece, as does the titulus below the mosaic, the style of which denotes the antiquarian vein evident in Honorius, a pontiff firmly rooted in the Roman senatorial aristocracy [9,12,13]. These developments offer the possibility of understanding the mosaic's formal—"stylistic"—outcomes in terms of specific rhetorical choices [8,10,14]. Even the material used to make the mosaic could reflect iconological orientations, not just local or foreign technological and craft practices. The marble tesserae in *S. Agnese* are used in a very different way than those in the later mosaics in *Santo Stefano Rotondo* (642–649) and especially in the Oratory of John VII (705–707); the latter was most likely created by an Eastern-trained workshop.

This material and technical choices may indeed result from a strategy adopted to convey the peculiar essence of the martyr, an "icon" presented simultaneously in the same space as the viewer but in a different realm [8].

The wall mosaics of *S. Agnese fuori le mura* and *S. Venanzio* were, until 2021, the only 6th–7th century mosaics in Rome which had never undergone any archaeometric studies of their glass tesserae [15]. New information about effective practices and the origins of materials

provided by these studies could offer a better understanding of this outstanding mosaic, which is crucial for understanding of the artistic tradition of Rome and the early medieval West. It became immediately evident that the bad preservation of *S. Agnese* mosaic would create great difficulty in tackling the study of its glass tesserae. Significant restorations are attested as early as the 17th century, when Ciampini describes and illustrates the heads of the two pontiffs flanking Agnes as having been replaced by wall paintings [2,16,17] (Figure 3).


**Figure 3.** Graphic representation of the wall mosaic of *S. Agnese fuori le mura* by Ciampini [2].

After World War II, the *Soprintendente ai Monumenti di Roma* Guglielmo Matthiae viewed the mosaic from a scaffold and made a graphic of the restoration (Figure 4), which was published in 1967 [6]. The Matthiae graphic does not, however, coincide in every detail with our initial observations (Figure 3) [18].


**Figure 4.** Identification of restored parts of the mosaic of *S. Agnese fuori le mura* (grey areas) by Matthiae ([6], modified).

To identify the non-original parts according to the relief made by Matthiae (Figure 4), we decided to analyze the surface of the wall mosaic using non-invasive methods in search of the same evidence traces, which are apparently not clear to the naked eye from the

ground without a scaffold. By considering the image of the mosaic shown in Figure 1, it is difficult to recognize the same pattern identified by Matthiae, shown in Figure 4, probably due to the effect of light on the tesserae and to the restorations, but perhaps also partly due to the different "days of work" involved in making the mosaic. Considering the type of surface and the impossibility of conducting a close visual survey from a scaffold at this stage of the research, we then decided to use a non-invasive and no-contact technique, namely multispectral imaging, that would allow the possible identification of original areas of the mosaic, even from the ground, using different bands (e.g., IR). Studies of detachments, moisture, and structural inhomogeneities in wall mosaics using non-invasive methods are documented in the scientific literature, including contact and no-contact techniques [19–23]. Less well known and more recent among these non-invasive, no-contact methods, but very promising in this field, is multispectral imaging [24,25]. This technique, well known as a diagnostic tool in the field of paintings, especially in the identification of preparatory drawings, pentimenti, and traces of restoration and remaking, has only recently shown its great potential to support the finding of inhomogeneities affecting decorated surfaces [26] and specifically wall mosaics [25]. In particular, the use of multispectral imaging to combine and process the VIS (visible) and IR (infrared) bands is extremely useful in the preliminary identification of possible different materials and traces of restorations, reuses, or replacement of mosaic parts. This possibility is fundamental to selecting areas of interest within which to carry out targeted sampling and, therefore offers considerable time savings and the benefit of reduced invasiveness. In the specific case of the *S. Agnese fuori le mura* wall mosaic, in order to validate the hypothesis made a priori by means of multispectral imaging regarding the supposed original areas, some tesserae were sampled and investigated using laboratory analyses such as scanning electron microscopy coupled with energy-dispersive spectrometry (SEM-EDS) and an electron microprobe (EMPA). The results obtained open up new possibilities for the use of multispectral imaging for the study and analysis of restored wall glass mosaics, as in the case of *S. Agnese fuori le mura*, because this non-invasive technique was revealed to be an essential tool to support and orient the sampling towards the original parts of the mosaic, and, therefore, to reduce the total number of samples needed and to save time and costs during sampling.

## 2. Materials and Methods

### *2.1. Multispectral Imaging*

A PROFILOCOLORE system consisting of a Nikon D-800 FR (Full Range) Reflex camera and two modified Nikon sb-910 speed lights (system modified and commercialized by Profilocolore company, Rome, Italy) was used to acquire the multispectral data (Figure 5). Optical cut-band filters placed in front of the lens before image acquisition were used to select the wavelengths of actual interest.

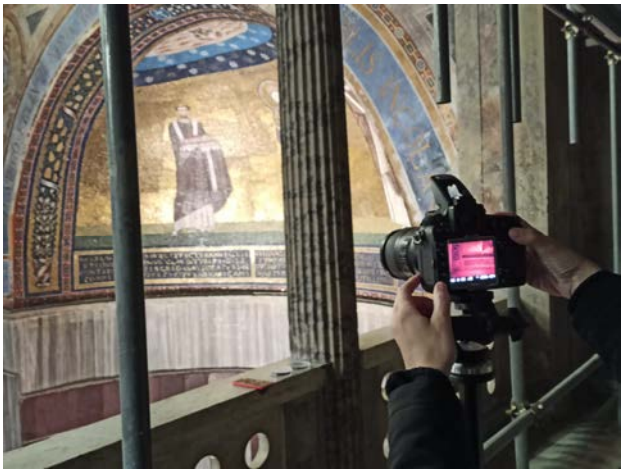

**Figure 5.** Multispectral image acquisition at *S. Agnese fuori le mura*.

The complex logistics of the area around the apse required unconventional positioning of the lights relative to the camera and framing that was not always frontal. Images were acquired from the ground and from the galleries (*matronei*) over the side aisles and on the opposite side of the apse. In particular, the outcomes of images taken in the visible and infrared IR 720 nm ranges are reported and discussed here.

Environmental conditions (non-darkening windows) prevented the correct acquisition of UV data.

### *2.2. Sampling and Archaeometric Lab Analysis*

The information from stylistic, archival, graphic, photographic, and multispectral data allowed us to identify the supposed original parts of the *S. Agnese fuori le mura* mosaic, in which the sampling was focused. In particular, we selected tesserae considering their color and state of conservation, avoiding areas where tampering, although temporary, could potentially have caused modifications to the integrity and originality of the decoration itself. Glass tesserae were identified in the following colors: gold (Au), white (Bi), grey (Gr), blue (B), turquoise (Tu), purple (P), orange (A), red (R), green (VCh—pale green and VS—dark green), and yellow (G). To ensure a better and more complete characterization of the mosaic, at least two tesserae were selected for each color, except for orange, which was identified in minimal areas. Where possible, the tesserae were taken from different points of the mosaic, carefully characterizing the three figures as much as possible and avoiding the disturbed parts (Figures 6 and 7). In total, 34 in situ tesserae were sampled. The sampling was composed of various steps. After photographic documentation of the position and orientation of each chosen tessera, the mortar was removed and detached carefully with a stylet. A layer about 1 mm in thickness was cut with a diamond-coated micro-saw from the back of each tessera. The remaining tessera was then replaced in its original position and orientation, compensating for the loss of thickness with mortar. It should be underlined that, in the case of the apsidal mosaic of *S. Agnese fuori le Mura*, the detachment and repositioning of the tesserae were carried out with the agreement of the local Superintendency, whom we thank for their collaboration. In the laboratories of the Department of Geosciences in Padua, each layer cut in situ was further subdivided into two parts using a micro-saw. One part was stored, and the other one, embedded in a resin block, was polished with a series of diamond pastes down to 1 µm grade and then subjected to laboratory analyses.

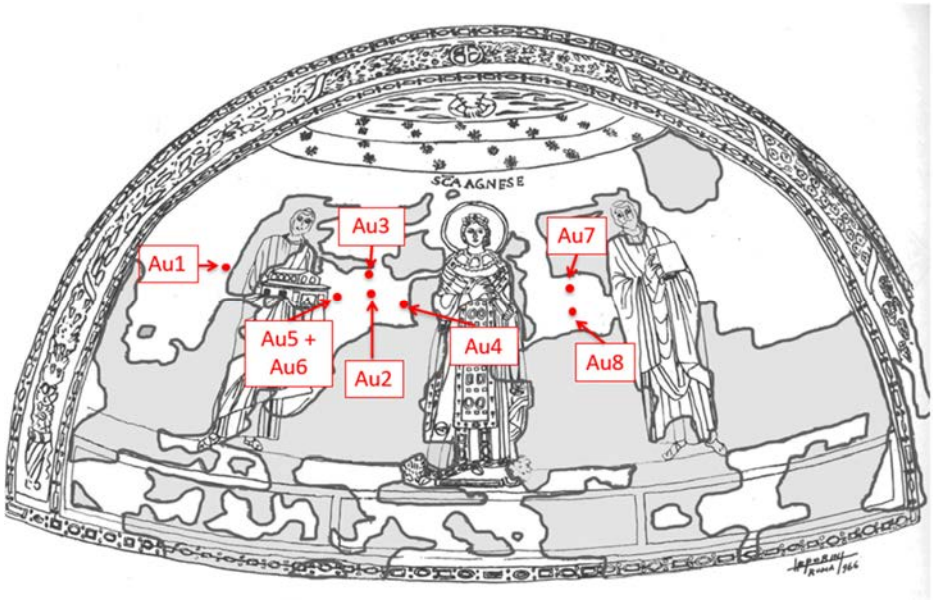


**Figure 6.** Indication of sampling points of gold tesserae.

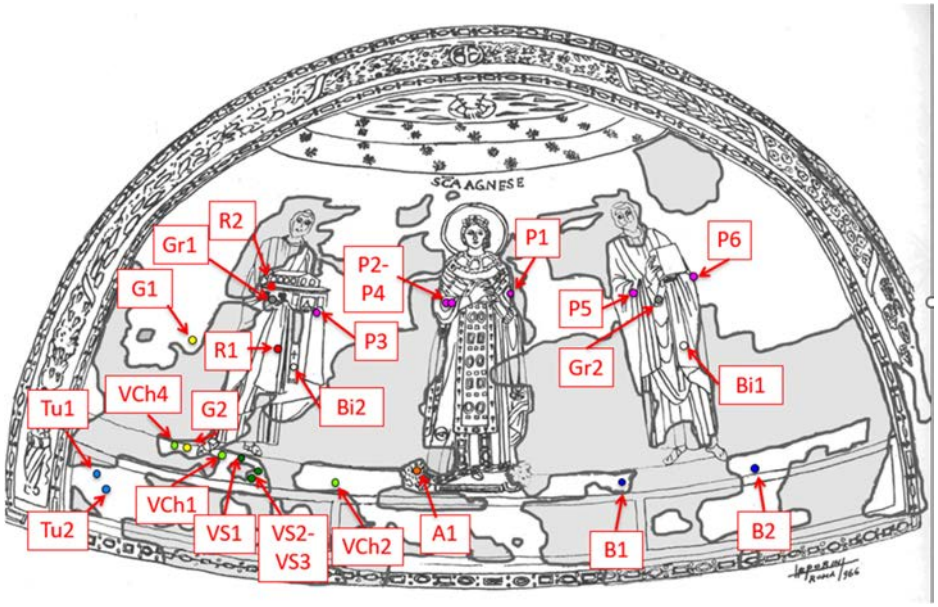


**Figure 7.** Indication of sampling points of colored tesserae.

In particular, the laboratory analyses used to verify whether the selected tesserae from the *S. Agnese fuori le mura* mosaic were original or could be ascribed to previous restorations were scanning electron microscopy coupled with energy-dispersive spectrometry (SEM-EDS) for high-resolution morphological inspection of the glass and qualitative chemical analyses of the glassy matrix and opacifiers/pigments, and an electron microprobe (EMPA) to determine the quantitative chemical composition of the glassy matrix, focusing on major and minor elements, which are particularly useful for distinguishing original from restoration tesserae.

The instrument employed for SEM-EDS analyses was a CamScan MX 2500 microscope (Electron Optic Services Inc., Ottawa, Canada) equipped with a $LaB_6$ cathode. SEM images were taken by collecting the backscattered electron signal (BSE), operating at 20 kV and 160 nA, with a working distance (WD) of about 25 mm. The EMPA employed was a JEOL 8200 Super Probe (JEOL (ITALIA) S.p.A, Basiglio (MI), Italy), equipped with five WDS spectrometers and located at the Department of Earth Sciences of the University of Milan "La Statale". The electron beam was operated at 5 nA and 15 KV, with counting times of 30 s for the peak and 10 s for the background. The standards used for quantitative analyses were grossular for Si, Al, and Ca; omphacite for Na; olivine for Mg; K-feldspar for K; fayalite for Fe; apatite for P; and scapolite for Cl. All certified analyses are available from the Unitech COSPECT of the University of Milan "La Statale".

These analytical techniques, which have been shown to be particularly suitable for the characterization of glass tesserae, were previously applied to other in situ glass mosaics, such as the paleo-Christian mosaic of *S. Maria Mater Domini* in Vicenza and the Byzantine Dedication wall mosaic of St. Mary of the Admiral in Palermo [25,27].

## 3. Results and Discussion

Comparison of the 720 nm IR image of the mosaic with the Matthiae relief (Figure 8a and Figure 8b, respectively) allowed us to find immediate, though not precise, correspondences with the 1967 publication [6].

In particular, the gold background around the heads and figures, the band at the base of the mosaic, and the lower parts of the three figures (Figure 8a) confirmed in broad strokes the relief by Matthiae (Figure 8b). However, the comparison of the two images in Figure 8a,b also shows how Matthiae perhaps equalized the mismatches by possibly including zones of apparent but probably not effective diversity (e.g., different days of work in the realization of the mosaic). The analysis of the faces of the two lateral male

figures, which were already indicated in the 17th century relief (Figure 3) as the subject of restoration or replacement, is undoubtedly very interesting [2]. The images shown in Figures 9–11 thus compare the processed images of the bust details of the three figures taken in the VIS (visible) band with modified lights (c) with the indications provided by the 17th century (a) and 1967 (b) graphic reliefs.

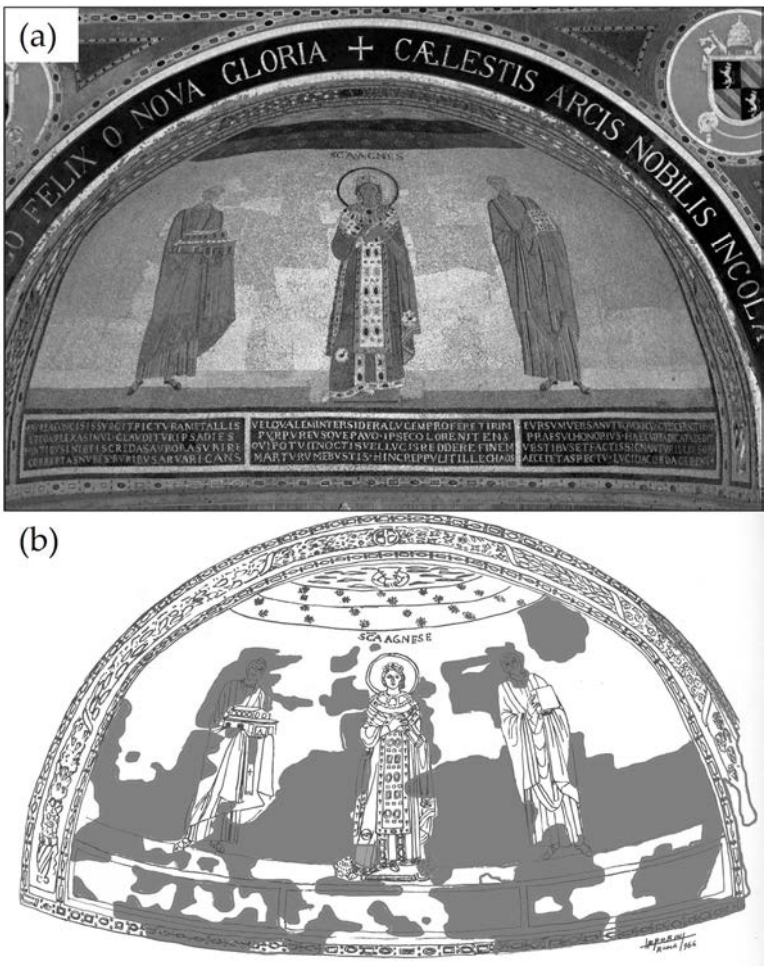


**Figure 8.** Comparison between IR (720 nm) image (**a**) and the graphic relief of restored parts made by Matthiae (1967) (**b**) ([6], modified).

The image related to the sum of the blue and yellow channels, obtained in Adobe Photoshop through the separation of the b channel using the Lab method, clearly showed the inhomogeneities of the gold tesserae in the busts of the three figures (Figures 9–11) and particularly in the heads of the two male figures (Figures 10 and 11). In contrast, the face of *S. Agnese* (Figure 9) showed no traces of obvious reworking.

This essential new evidence obtained by comparing historical reliefs and multispectral images allowed us to find the supposed original parts of the wall mosaic more clearly, driving the micro-sampling of the selected tesserae analyzed in the lab.

Here, SEM-EDS and EMPA results of the supposed original tesserae from the *S. Agnese* mosaic show that all the glass tesserae were made following the Roman/late Antique tradition. The low MgO and $K_2O$ contents (both under 1.5 wt%) of the glassy matrices (EMPA data) indicate, in fact, that natron was used as a flux for all samples (Figure 12).

Natron was used as a flux in glass mosaics and vessels from the Roman to early Medieval times (e.g., [28] and references therein).

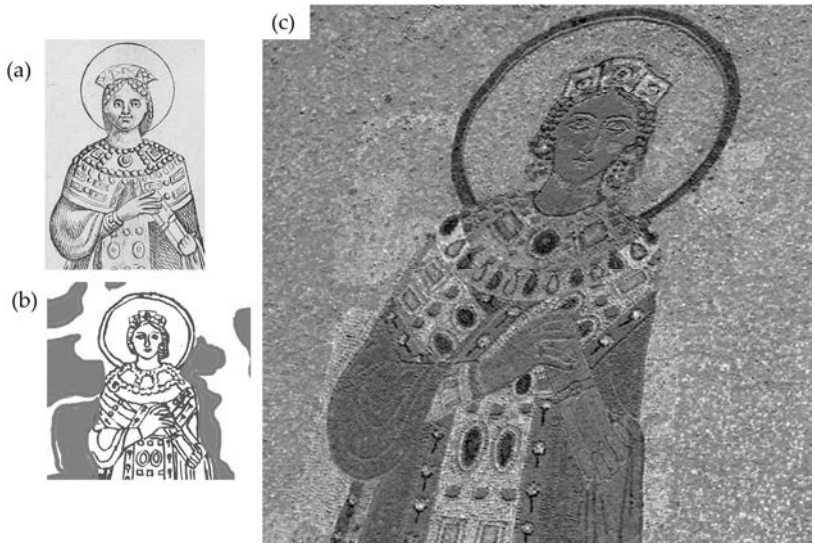


**Figure 9.** Graphic reliefs of *S. Agnese* made by Ciampini (**a**) and Matthiae (**b**) compared to a multispectral elaborated image (**c**).

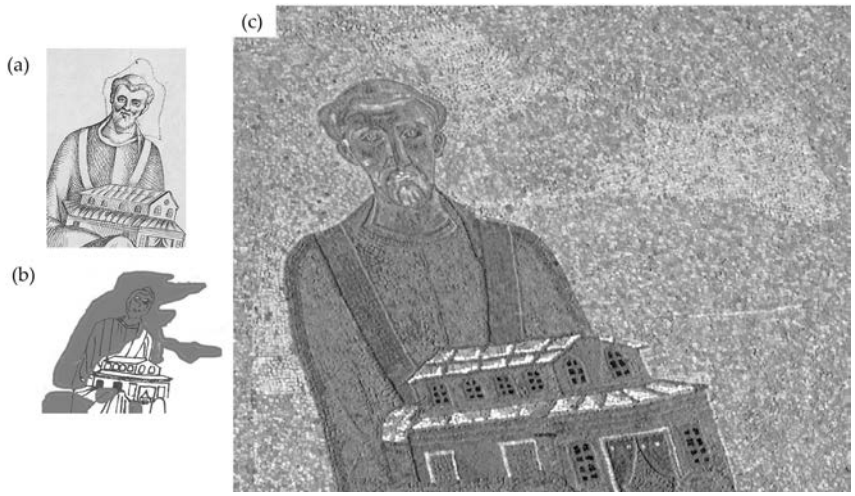


**Figure 10.** Graphic reliefs of the male figure on the left made by Ciampini (**a**) and Matthiae (**b**) compared to a multispectral elaborated image (**c**).

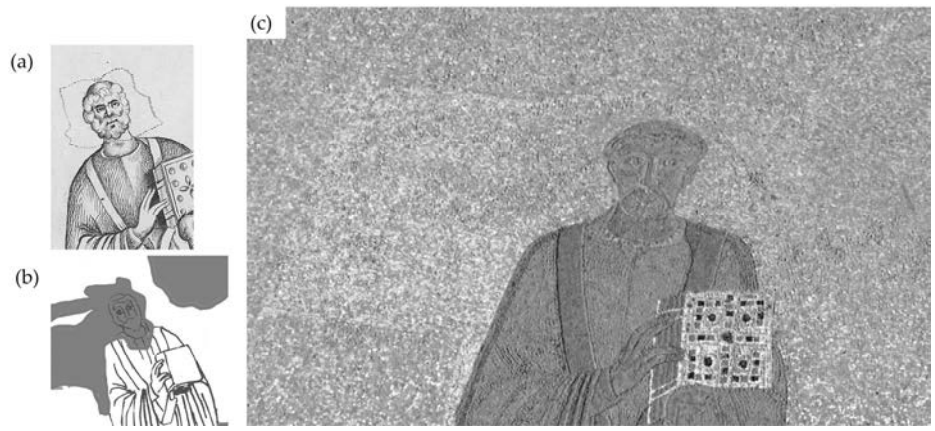


**Figure 11.** Graphic reliefs of the male figure on the right made by Ciampini (**a**) and Matthiae (**b**) compared to a multispectral elaborated image (**c**).

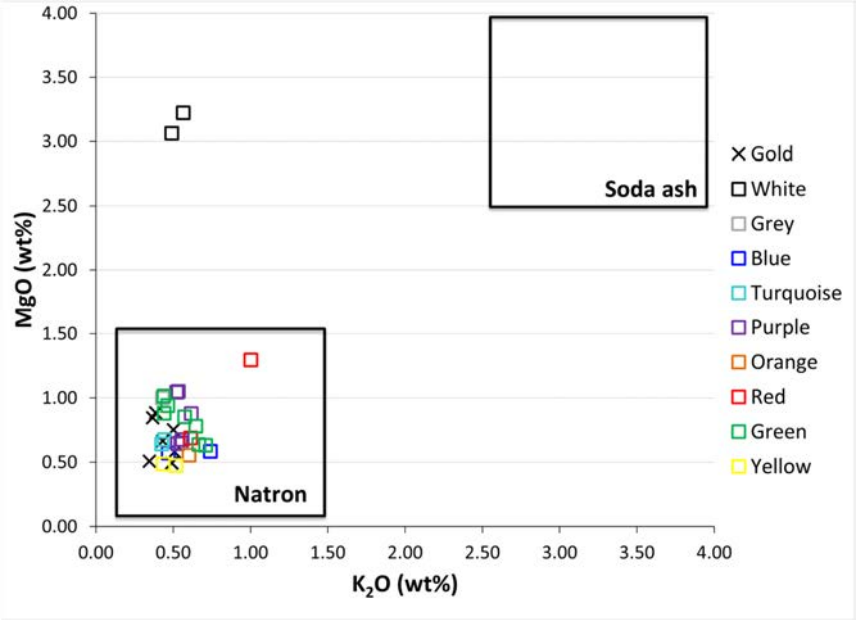


**Figure 12.** Biplot of MgO (wt%) versus $K_2O$ (wt%). Note that all the analyzed tesserae of *S. Agnese fuori le mura* were produced using natron as flux. No soda ash tesserae, typical of the late medieval period, were identified (EMPA data).

The identification of this type of flux is a strong indication that all the selected tesserae from *S. Agnese* came from original areas of the mosaic, as hypothesized based on multispectral imaging and stylistic, archival, and graphic studies. Comparisons among the glassy matrices of *S. Agnese* and those of restoration tesserae from other Roman mosaics (i.e., *S. Sabina*, *S. Pudenziana*, *S. Teodoro*, and *SS. Cosma e Damiano* [15]) further support our hypothesis. The above mosaics, of which the dates range from 5th to 6th century AD, are all characterized by original tesserae produced using natron as flux [15], as in the case of *S. Agnese*. However, similarly to *S. Agnese*, they were subject to heavy restoration operations during the 17th–19th century AD, and the restoration tesserae are characterized by glassy matrix chemical compositions quite different to those of the original ones. The majority of restoration tesserae from *S. Sabina*, *S. Pudenziana*, *S. Teodoro*, and *SS. Cosma e Da-miano* are, in fact, characterized by quite comparable $Na_2O$ and $K_2O$ contents (Figure 13), probably due to the use of mixed alkali plant ash as a flux, and they can be defined as mixed alkali glass. The use of ash as a flux can also be confirmed by relatively high contents of $P_2O_5$ and Cl if compared with those of natron glass, such as the tesserae from *S. Agnese* (Figure 14). Some tesserae rich in soda, similar to those of *S. Agnese*, were also identified among the restoration tesserae from *SS. Cosma e Damiano* mosaics (Figure 13), but they were produced using soda ash or industrial soda and not natron as flux (Figure 14).

Microtextural and chemical investigations carried out using SEM-EDS showed the prevalence of antimony-based opacifiers (Ca- and Pb-antimonates), typical of Roman and late-antique tradition [29], (Figure 15). This is further analytical evidence of the supposed originality of the *S. Agnese* tesserae sampled with the support of multispectral imaging results.

The interpretation of all the chemical and microtextural data obtained via laboratory analyses is still in progress, and the detailed results will be reported in a further dedicated publication.

In conclusion, because no modern tesserae were identified in the laboratory analyses, it should be stressed here that there is great potential in the use of multispectral investigations as a preliminary tool to guide sampling towards the original parts of a mosaic, including in situ glass mosaics with a complex history, such as that of *S. Agnese fuori le mura* in Rome.

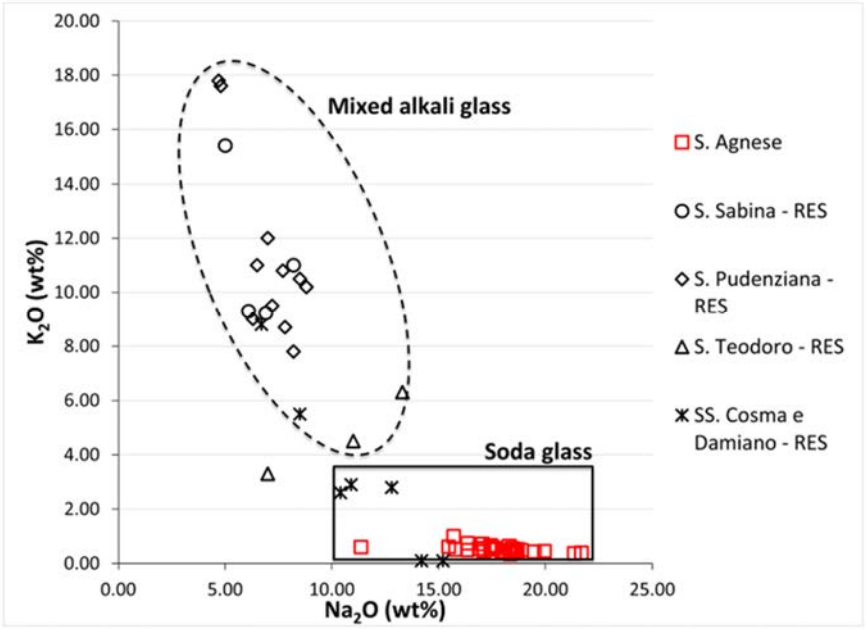


**Figure 13.** Biplot of $K_2O$ (wt%) versus $Na_2O$ (wt%), showing comparisons between the supposed original *S. Agnese* tesserae (EMPA data) and restoration tesserae from the Roman mosaics of *S. Sabina*, *S. Pudenziana*, *S. Teodoro*, and *SS. Cosma e Damiano* (raw data from [15]). Note the difference in glass type between the original (in red) and restored tesserae (in black).

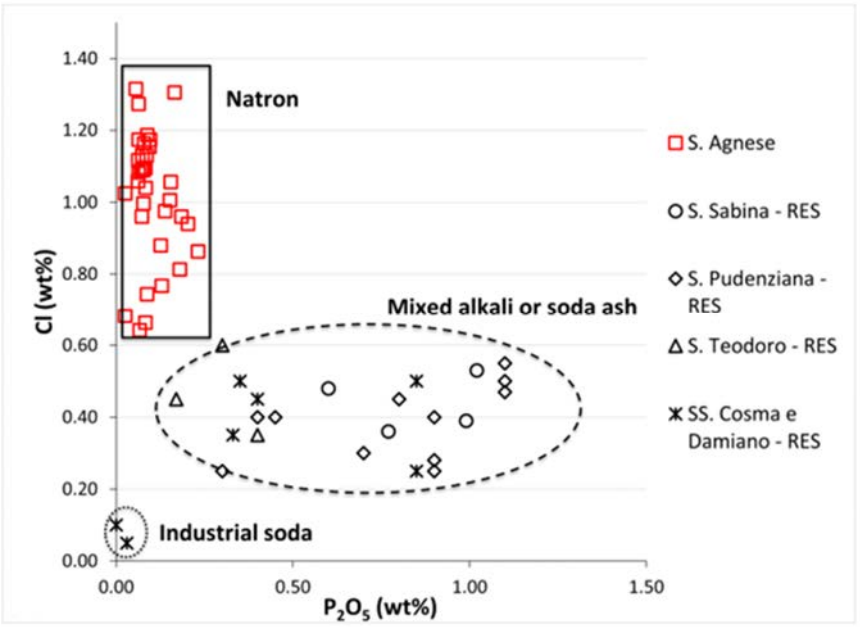


**Figure 14.** Biplot of Cl (wt%) versus $P_2O_5$ (wt%), showing comparisons between the supposed original *S. Agnese* tesserae (EMPA data) and restoration tesserae from the Roman mosaics of *S. Sabina*, *S. Pudenziana*, *S. Teodoro*, and *SS. Cosma e Damiano* (raw data from [15]). Note the different fluxes in the original (in red) and restored tesserae (in black).

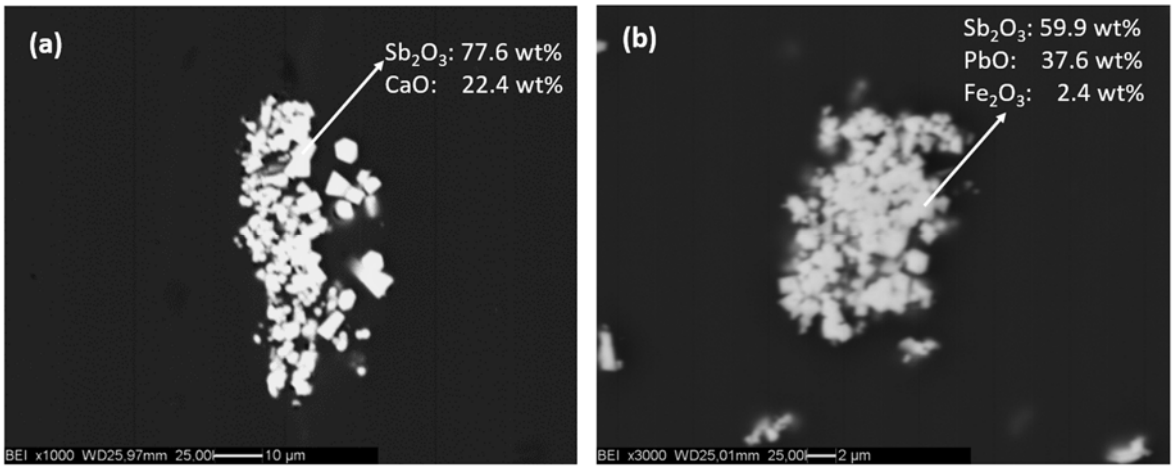


**Figure 15.** SEM-BSE images, showing (**a**) small geometric crystals of Ca-antimonate, used as a white opacifier, identified in a blue tessera; (**b**) an aggregate of Pb-antimonate, used as a yellow opacifier/pigment, identified in a yellow tessera from *S. Agnese fuori le mura*. Crystals (in white in both images) had a mean size of about 5 µm and were dispersed throughout a homogenous glassy matrix (in grey). SEM-EDS data also shown in (**a**,**b**).

**Author Contributions:** Conceptualization, R.D.; methodology, R.D., A.S. and S.M.; software, R.D.; validation, R.D. and A.S.; investigation, R.D., A.S. and S.M.; data curation, R.D. and A.S.; writing—original draft preparation, R.D., C.C., M.G., A.S. and S.M.; writing—review and editing, R.D., C.C. and A.S.; visualization, R.D., A.S. and C.C.; supervision, R.D.; project administration, C.C.; funding acquisition, C.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Swiss National Science Foundation (grant number: 192854).

**Data Availability Statement:** Not applicable—the data are available only by contacting the authors.

**Acknowledgments:** The authors are grateful to Don Mauro Milani (*Parrocchia di Sant'Agnese*), and Daniela Porro, Mariella Nuzzo, and Maria Milazzi (*Soprintendenza Speciale di Roma. Archeologia, Belle Arti, Paesaggio*) for authorizing the present study and supporting the on-site sampling. The staff of the Department of Geosciences of the University of Padua (Leonardo Tauro) and of Unitech COSPECT of Milan (Stefano Poli and Andrea Risplendente) are also thanked for their kind support during the SEM-EDS and EMPA analyses, respectively, carried out on the *S. Agnese fuori le mura* tesserae.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Duchesne, L. *Le Liber Pontificalis*; Tome Premier, Ernest Thorin: Paris, France, 1886; p. 323.
2. Ciampini, G.G. *Vetera Monimenta, in Quibus Prcipue Musiva Opera Sacrarum, Profanarumque Dium Structura, AC Nonnulli Antiqui Ritus, Dissertationibus, Iconinbusque illustrantur, pars secunda*; Komarek: Rome, Italy, 1699; p. 104.
3. De Rossi, G.B. *Musaici Cristiani e Saggi dei Pavimenti Delle Chiese di Roma Anteriori al sec. XV.*; Guglielmo Hass: Rome, Italy, 1899.
4. Toesca, P. *Storia Dell'arte Italiana. I. Il Medioevo*; Utet: Torino, Italy, 1965; (reprint of first edition dated to 1913).
5. Matthiae, G. Riscoperta dei mosaici romani S. Agnese e S. Stefano Rotondo. In *Actes du VIe Congrès International des Études Byzantines; Paris, 1948*; Au Secrètariat du Comitè École des Hautes Études, á la Sorbonne: Paris, France, 1951; Volume II, pp. 273–276.
6. Matthiae, G. *Mosaici Medioevali Delle Chiese di Roma*; Palombi: Rome, Italy, 1967; pp. 171–177.
7. James, L. *Mosaics in the Medieval World. From Late Antiquity to the Fifteenth Century*; Cambridge University Press: Cambridge, UK, 2017.
8. Croci, C.; Gianandrea, M. L'abside di Sant'Agnese fuori le mura: Uno sguardo tra passato e futuro. In *Una Finestra su Roma Altomedievale: Pitture e Mosaici*; Viella: Rome, Italy, 2022; pp. 129–153.
9. Ballardini, A. Habeas corpus: Agnese nella basilica di via Nomentana. In *Di Bisanzio Dirai ciò che è Passato, che Passa e che Sarà; Scritti in onore di Alessandra Guiglia*; Pedone, S., Paribeni, A., Eds.; Bardi Edizioni: Rome, Italy, 2018; Volume 2; pp. 253–279. ISBN 9788894810189.
10. Foletti, I.; Lešák, M.F. Hidden Treasure and Precious Pearl: Sant'Agnese fuori le mura, its Apse Mosaic, and the Experience of Liturgy. In *From Words to Space. Textual Sources for Reconstructing and Understanding Medieval Sacred Spaces. In Proceedings of the workshop, Rome, Italy, 27–28 March 2019*; De Blaauw, S., Scirocco, E., Eds.; Biblioteca Hertziana: Rome, Italy, In press.

11. Gianandrea, M. Il "doppio papa" nelle decorazioni absidali del Medioevo romano. In *Le Plaisir de l'art du Moyen Âge: Commande, Production et Réception de L'œuvre D'art Mélanges en Hommage à Xavier Barral i Altet*; Alcoy, R., Allios, D., Eds.; A&J Picard: Paris, France, 2012; pp. 663–669.
12. Trout, D.E. Pictures with words: Reading the apse mosaic of S. Agnese f.l.m. (Rome). *Stud. Iconogr.* **2019**, *40*, 1–26.
13. Neri, E. Les mosaïques pariétales des églises à la lumière des couleurs: Images et inscriptions (IVe-Vie siècles). In *Rituels Religieux et Sensorialité (Antiquité et Moyen Âge). Parcours de Recherche*; Caseau Chevallier, B., Neri, E., Eds.; Silvana Editoriale: Milan, Italy, 2021; pp. 299–327.
14. Foletti, I.; Lešák, M.F. Zrození pozdně antické avantgardy ve sv. Anežce za hradbami: Factor, kočovníci, liturgie a Max Dvořák (The Birth of the Late Antique Avant-Garde in St. Agnes Beyond the Walls: Factor, nomads, liturgy and Max Dvořák). In *Od Dějin Umění k Uměleckému Dílu*; Galeta, J., Ed.; Masaryk University: Brno, Czech Republic, 2021; pp. 35–46.
15. *Mosaici Medievali a Roma Attraverso il Restauro Dell'ICR (1991–2004*; Andaloro, M.; D'Angelo, C. (Eds.) Gangemi: Rome, Italy, 2017.
16. Delfini, G. Per la storia del restauro musivo nel secolo XIX: L'esempio di Sant'Agnese fuori le Mura. *Stor. Dell'arte* **1989**, *65*, 87–94.
17. Delfini, G. Il mosaico absidale di S. Agnese fuori le Mura: Restauri storici e recenti interventi conservativi. In *Mosaici a S. Vitale e Altri Restauri. Il Restauro in situ di Mosaici Parietali in Proceedings of the Convegno Nazionale sul Restauro in situ di Mosaici Parietali, Ravenna, Italy, 1–3 October 1990*; Iannucci, A.M., Fiori, C., Eds.; Longo: Ravenna, Italy, 1992; pp. 245–249.
18. Maltoni, S.; Silvestri, A.; Deiana, R. L'abside di Sant'Agnese fuori le mura: Approccio interdisciplinare allo studio dei mosaici vitrei: Report preliminare. In *Una Finestra su Roma Altomedievale: Pitture e Mosaici*; Viella: Rome, Italy, 2022; pp. 155–171.
19. Boschetti, C.; Leonelli, C.; Macchiarola, M.; Veronesi, P.; Corradi, A.; Sada, C. Early evidences of vitreous materials in Roman mosaics from Italy: An archaeological and archaeometric integrated study. *J. Cult. Herit.* **2008**, *9*, 21–26. [CrossRef]
20. Ricciardi, P.; Colomban, P.; Tournié, A.; Macchiarola, M.; Ayed, N. A non-invasive study of Roman Age mosaic glass tesserae by means of Raman spectroscopy. *J. Archaeol. Sci.* **2009**, *36*, 2551–2559. [CrossRef]
21. Chaban, A.; Tornari, V.; Andrianakis, M.; Deiana, R. Comparison of induced thermal change to climate chamber simulated environmental change in mosaic model by digital holographic speckle pattern interferometry (DHSPI). In *Proceedings of SPIE "Optics for Arts, Architecture and Archaeology VII"*; Liang, H., Groves, R., Targowski, P., Eds.; SPIE Optical Metrology: Munich, Germany, 2019; Volume 110580I. [CrossRef]
22. Marcaida, I.; Maguregui, M.; Morillas, H.; Prieto-Taboada, N.; Veneranda, M.; de Vallejuelo, S.F.; Martellone, A.; de Nigris, B.; Osanna, M.; Madariaga, J. In situ non-invasive multianalytical methodology to characterize mosaic tesserae from the House of Gilded Cupids, Pompeii. *Herit. Sci.* **2019**, *7*, 3. [CrossRef]
23. Chaban, A.; Deiana, R.; Tornari, V. Wall Mosaics: A Review of On-Site Non-Invasive Methods, Application Challenges and New Frontiers for Their Study and Preservation. *J. Imaging* **2020**, *6*, 108. [CrossRef] [PubMed]
24. Cantone, V.; Deiana, R.; Valenzano, G. *Nuove prospettive di ricerca sul portale centrale dell'atrio: Dalla storia dell'arte alle tecnologie applicate ai beni culturali, in San Marco la Basilica di Venezia Arte, Storia, Conservazione*; Marsilio: Venezia, Italy, 2019; Volume I; pp. 337–350. ISBN 978-88-3174-982-4.
25. Cantone, V.; Deiana, R.; Silvestri, A.; Angelini, I. Obsidian and Obsidian-like Glass Tesserae: A Multidisciplinary Approach to Study the Dedication Wall Mosaic in the Church of St. Mary of the Admiral in Palermo (12th Century). *Open. Archaeol.* **2020**, *6*, 403–416. [CrossRef]
26. Deiana, R. Application of Non-invasive Measurements in the Recent Studies of the Scrovegni Chapel: Results and Considerations. In *Computational Science and Its Applications—ICCSA 2020*; Lecture Notes in Computer Science; Gervasi, O., Murgante, B., Misra, S., Garau, C., Blečić, I., Taniar, D., Apduhan, B.O., Rocha, A.M.A.C., Tarantino, E., Torre, C.M., et al., Eds.; Springer: Cham, Switzerland, 2020; Volume 12255, pp. 960–970. [CrossRef]
27. Silvestri, A.; Tonietto, S.; Molin, G.; Guerriero, P. Multi-methodological study of palaeo-Christian glass mosaic tesserae of St. Maria Mater Domini: (Vicenza, Italy). *E. J. Mineral.* **2015**, *27*, 225–245. [CrossRef]
28. Freestone, I. Glass production in the first millennium CE: A compositional perspective. In *Künstlichen Stein Zum Durchsichtigen Massenprodukt/From Artificial Stone to Translucent Mass-Product*; Berlin Studies of the Ancient World 67; Klimscha, F., Karlsen, H.J., Hansen, S., Renn, J., Eds.; Edition TOPOI: Berlin, Germany, 2021; pp. 245–263.
29. Verità, M. Tecniche di fabbricazione dei materiali musivi vitrei: Indagini chimiche e mineralogiche. In *Medieval Mosaics: Light, Color, Materials*; Borsook, E., Gioffredi-Superbi, F., Pagliarulo, G., Eds.; Silvana Editoriale: Milano, Italy, 2000; pp. 47–64.