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Research Article

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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)

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Abstract: Pliny the Elder testifies that roman workshops used volcanic glass (obsidian), but also produced and used a dark glass (obsidian-like glass) quite similar to the natural one. In the context of the study on medieval mosaics, the use of the obsidian and obsidian-like tesserae is a challenging research topic. In this paper, we present the results of a multidisciplinary study carried out on the *Dedication* wall mosaic, realized by a byzantine workshop in the 12th century in the Church of St. Mary of the Admiral in Palermo, and where numerous black-appearing tesserae, supposed to be composed of obsidian by naked-eyes observation, are present. Historical documents, multispectral imaging of the wall mosaic, and some analytical methods (SEM-EDS and XRPD) applied to a sample of black tesserae, concur in identifying here the presence of obsidian and different obsidian-like glass tesserae. This evidence, although related to the apparent tampering and restoration, could open a new scenario in the use of obsidian and obsidian-like glass tesserae during the Byzantine period in Sicily and in the reconstruction of multiple restoration phases carried out between 12th and 20th century AD on the mosaics of St. Mary of the Admiral.

Keywords: byzantine mosaics, St. Mary of the Admiral, obsidian, multispectral imaging, SEM-EDS, XRPD

1 Introduction

The *Dedication* wall mosaic (Figure 1) decorates the eastern wall of a northern baroque chapel, partially demolished in the 19th century, inside the church of St. Mary of the Admiral in Palermo (Figure 2 and Figure 3). The church in 2015 became part of the Unesco's World Heritage. The mosaic represents the Admiral George of Antioch in *proskynesis*, at the foot of the Virgin Mary. The Mother of God, *Μητέρα του Θεού* in Greek, as in the abbreviation *ΜΡ ΘΥ*, is praying for her son Jesus Christ, shown in the right upper corner of the same scene. The Virgin Mary holds in the left hand a long white sheet reporting the text of her prayer made with glittering dark tesserae. Pointing at George, she asks Jesus Christ for the forgiveness of his sins because he built her this beautiful temple (Kitzinger, 1990, pp. 316–17).

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Figure 1: Palermo, St. Mary of the Admiral, *Dedication* panel, 12th century mosaic wall: *George of Antioch prostrate at the foot of the Virgin Mary* (photo R. Deiana).

The church of St. Mary's of the Admiral, in Italian also named "la Martorana", as reported in some documents, was built during the 12th century and completed in 1143. Many scholars agree in dating the completion of its decoration a few years later (Matranga, 1872, p. 16; Perria, 1981; Lavagnini, 1987, p. 350; Acconcia Longo, 1988, p. 168; Kitzinger, 1990, pp. 15–26), but before the death of the Admiral (1151). The Syrian George of Antioch was a powerful and influential man, speaking both in Greek and Arab: perfect qualities to serve Roger II, the Norman king of Sicily, after three centuries of Islamic rule (De Simone, 2007, pp. 283–308; Kislinger, 2007, pp. 47–63).

Figure 2: Palermo, piazza Bellini, church of St. Mary of the Admiral, northern facade (photo V. Cantone).

George built this church for two primary purposes: first to express his gratitude for the carrier and the military glory in North Africa, and second to guarantee a respectable mausoleum for his family, as confirmed by its iconographical program (Demus, 1949, pp. 78–84; Kitzinger, 1990, pp. 123–221). Unfortunately, the mosaics, which decorated the eastern and the western walls of the church, were lost when the demolition of the presbytery and the atrium occurred between the 16th and the 17th centuries (Comandè, 1948, pp. 12–14; Maniaci, 1994, pp. 69–71). After this event, only two wall mosaics by the western part of the ancient church, even if detached from their original position, were preserved: the *Dedication* and the *Coronation* scenes (Gandolfo, 2010; Torno Ginnasi, 2014; Vagnoni, 2017). Thirty years ago, Kitzinger (Kitzinger, 1990, pp. 106–107) published the results of the radiocarbon dating of a wooden sample of the rear panel of the *Coronation* mosaic, thus tracing back to the 18th century the rearrangement of both decorations inside two chapels (Salinas, 1872). During the 19th century, the church implemented several new demolitions and reconstructions. The architect Giuseppe Patricolo, convinced that it was appropriate to restore the original medieval shape of the building (Andaloro, 1983, p. 106), demolished the baroque chapels (Salinas, 1872), moving the *Dedication* mosaic in the actual position, on the eastern wall of the northern chapel (Figure 3).

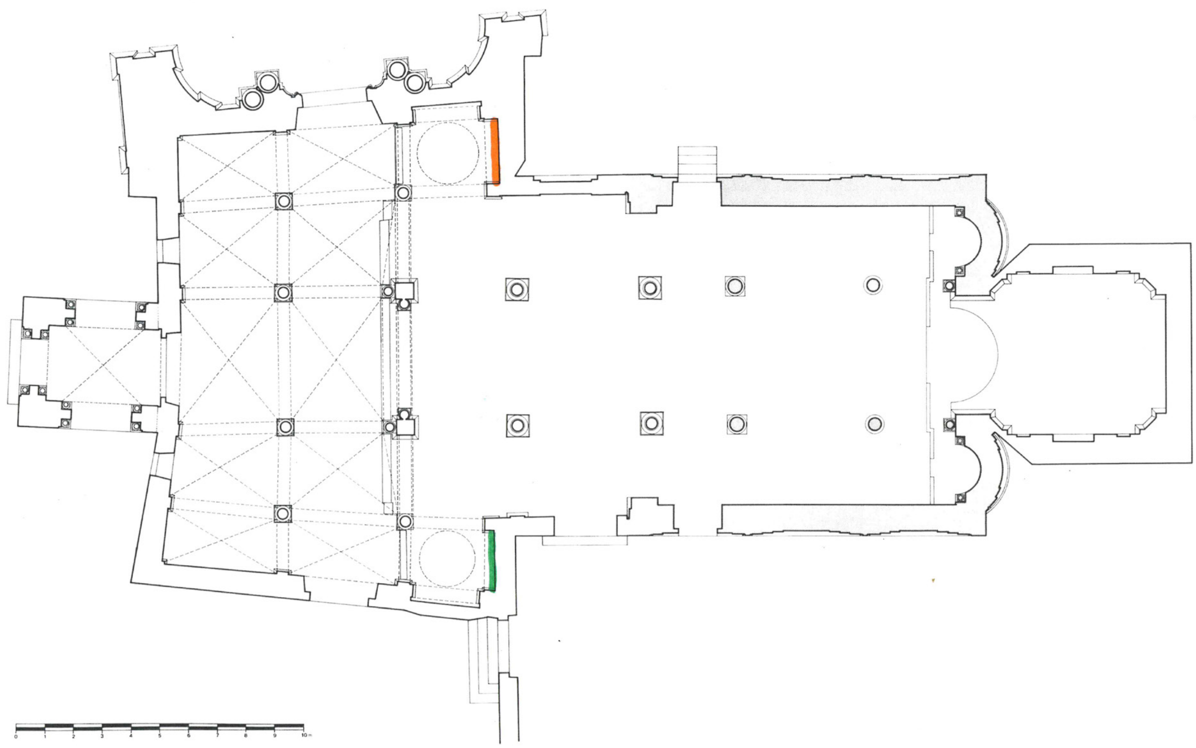

Figure 3: Palermo, St. Mary of the Admiral, plan of the actualchurch. Green line: position of the *Coronation* panel; orange line: position of the *Dedication* panel (authors modified after Ćurčić in Kitzinger, 1990, Pl. A III).

The complex story of the building and the incomplete documentation of the rearrangements in the *Dedication* and *Coronation* mosaics well describe the uncertainty around the classification and the percentage of the original materials, including obsidian and obsidian like-glass tesserae, with respect to the restoration/substitution samples. Therefore, the possibility of collecting new data, offered by a combination of visual and archive researches with analytical in-situ non-invasive and laboratory methods to distinguish modern and medieval materials, could be a crucial issue to understand the techniques here adopted in the Byzantine age compared to the roman ones (Cagno et al., 2014) and will allow the authors, in perspective, to map/quantify the byzantine materials and to reconstruct the multiple restoration phases carried out between 12th and 20th century on the mosaics of St. Mary of the Admiral.

2 Materials and Methods

2.1 Visual Analysis and Archive Research

The first tool to identify the distribution and possible material differences in black tesserae is visual analysis. The *Dedication* wall mosaic shows a coherent use of black tesserae, considering the byzantine practice in this kind of realization. A black line contours the figures, also remarking the boundary of the faces, as usual in byzantine art, to highlight these over the gilded background, where the light reflected by the golden tesserae can excessively soften light colors. Black tesserae also underline the eyes and design the pupils (Figure 4), taking advantage of the reflection of light in the dark chapel, producing an apparent motion, considering the effect of the light of the candles.

Figure 4: Palermo, St. Mary of the Admiral, *Dedication* panel, detail of the text in the white sheet, characters in black glittering tesserae (photo V. Cantone).

Finally, the extensive use of black tesserae is evident in the texts, both over white and gold background (Figure 5).

On the other hand, as confirmed by archive research, the *Dedication* mosaic was removed from its original location in the 16th century. In the 18th century, the mosaic was replaced in the baroque chapel of St. Benedic, using a wooden support, after both its boundaries and the original scene had been modified. After the restoration of the church made by the architects Giuseppe Patricolo and Francesco Valentin, before 1916, the *Dedication* mosaic was also restored (Kitzinger, 1990, p. 316). In this respect, a photo by the Alinari archive, taken at the beginning of the 19th century (Figure 6), and previously cited by Ernst Kitzinger, must be reconsidered.

Figure 5: Palermo, St. Mary of the Admiral, *Dedication* panel, *The Virgin Mary*, face's detail, glittering eyes (photo V. Cantone).

Figure 6: Palermo, St. Mary of the Admiral, *Dedication* panel, 12th century mosaic wall: *George of Antioch prostrate at the foot of the Virgin*, Brogi, 1900 ca. (© Archivi Alinari, Firenze, BGA-F-011371-0000).

The comparison between this old black and white photo and a color photo, first of all, helps in the identification of many discontinuities and some critical particulars, not already discussed by Kitzinger. It is clear that the boundaries of the mosaic have been rearranged (Kitzinger, 1990, p. 316), but apparently, all the inscriptions and the figures appear modified or restored. In particular, the old photo highlights a long, oblique discontinuity in the upper part of the mosaic, crossing the face of the Virgin Mary, and involving the abbreviation *MP*. Other inconsistencies are visible in the white sheet on the left hand of the Virgin Mary and in the right part of the sentence reported below. In this last one, the term “the Admiral” was probably added later to the name George. Kitzinger translates «ΔΟΥΛΟΥ ΔΕΗΣΙΣ ΣΟΥ ΓΕΩΡΓΙΟΥ ΤΟΥ ΑΜΙΡΑ» with “the prayer of your servant George, the Admiral” considering the last capital alpha a metric solution (Kitzinger, 1990, p. 317). At the same time, he agrees with the hypothesis proposed by Salvatore Morso (Morso, 1825; Kitzinger, 1990, p. 198–199), which considers the presence of a little cross at the end of the sentence, as well as at the beginning, as usual in byzantine paleography. Viewing the lower part of the mosaic, many scholars agree to recognize in this one the main modification. Comparing the old and the new photo, it is clear that the lower part of the vest of the Virgin has been modified, probably using the rest of a base (*suppedaneum*) to redesign it. Also, the figure of George appears rearranged, especially in the right part of the mosaic, where there is clearly a discontinuity and the irregularity of the figure.

2.2 Analytical *In Situ* Methods: Multispectral Acquisitions

In February 2016, a series of multispectral acquisitions had been collected with a NIKON Reflex D800 FR camera (Full Range modified by PROFILOCOLORE company) to highlight the presence of non-homogeneous areas in the *Dedication* panel.

The use of the multispectral technique, now known and widespread in the field of non-invasive diagnostics for Cultural Heritage (Del Pozo et al., 2017), is currently not often used for the analysis of mosaic surfaces. However, it represents reliable support in the preliminary identification of possible areas in which restoration work has been carried out using materials other than the original ones (Cantone et al., 2019).

For the analysis of the *Dedication* panel, a series of images has been registered in the range between approximately 300 and 1000 nm, using five different band-cut filters, placed in front of the camera lens. In particular, images have been recorded in the bands: UV (300–400 nm), visible (400–700 nm), and in the IR band in three different areas: IR1 (700–800 nm), IR2 (800–900 nm), and IR3 (900–1000 nm). The light stress of the various bands was possible thanks to the use of a pair of NIKON SB 910-FR modified full range lights, removing two Fresnel lenses. The multispectral images were taken by inserting a reference target whose reflectances, for each colored or white square, were previously accurately measured with a spectral-radiometer. The final result of the calibration obtained through the reference target and of the registration of the images, through the use of the software developed by PROFILOCOLORE (Melis et al., 2013), is a set of seven monochromatic photos corresponding to the reflectance of the subject at the wavelengths of 350, 450, 550, 650, 750, 850 and 950 nm. The un-calibrated images taken in these multispectral bands, adequately filtered, have also allowed highlighting new elements, obtaining further information useful in analyzing the transformation of the mosaic.

2.3 Analytical Laboratory Methods

To verify the hypothesis of the use of obsidian and obsidian-like tesserae in the *Dedication* panel of the church of St. Mary of the Admiral in Palermo, a sampling campaign was carried out in October 2019. In this panel, numerous black-appearing tesserae, supposed, so far, to be composed of obsidian by means of only naked-eye observations, are present. In particular, one black tessera that makes up the first letter of the abbreviation “MP,” which means “Mother” in Greek (Figure 7a), is selected for laboratory analyses. Being the tessera *in situ*, after photographic documentation of the position and orientation of the selected tessera and the removal of mortar, it was detached carefully with a stylet. The selected tessera is 6 x 8 x 8 mm in dimensions (Figure 7b), and a layer, about 1 mm in thickness, was cut with a diamond-coated micro-saw from the back of the tessera (Figure 7c). The remaining tessera was then replaced in its original position and orientation, compensating for the loss of glass, due to sampling, with the addition of mortar. In the laboratories of the Department of Geosciences in Padova, the fragment cut *in situ* was furtherly sub-divided into two parts using a micro-saw. One of these parts was stored, and the other one, embedded in a resin block, was polished with a series of diamond pastes down to 1 µm grade (Figure 7d).

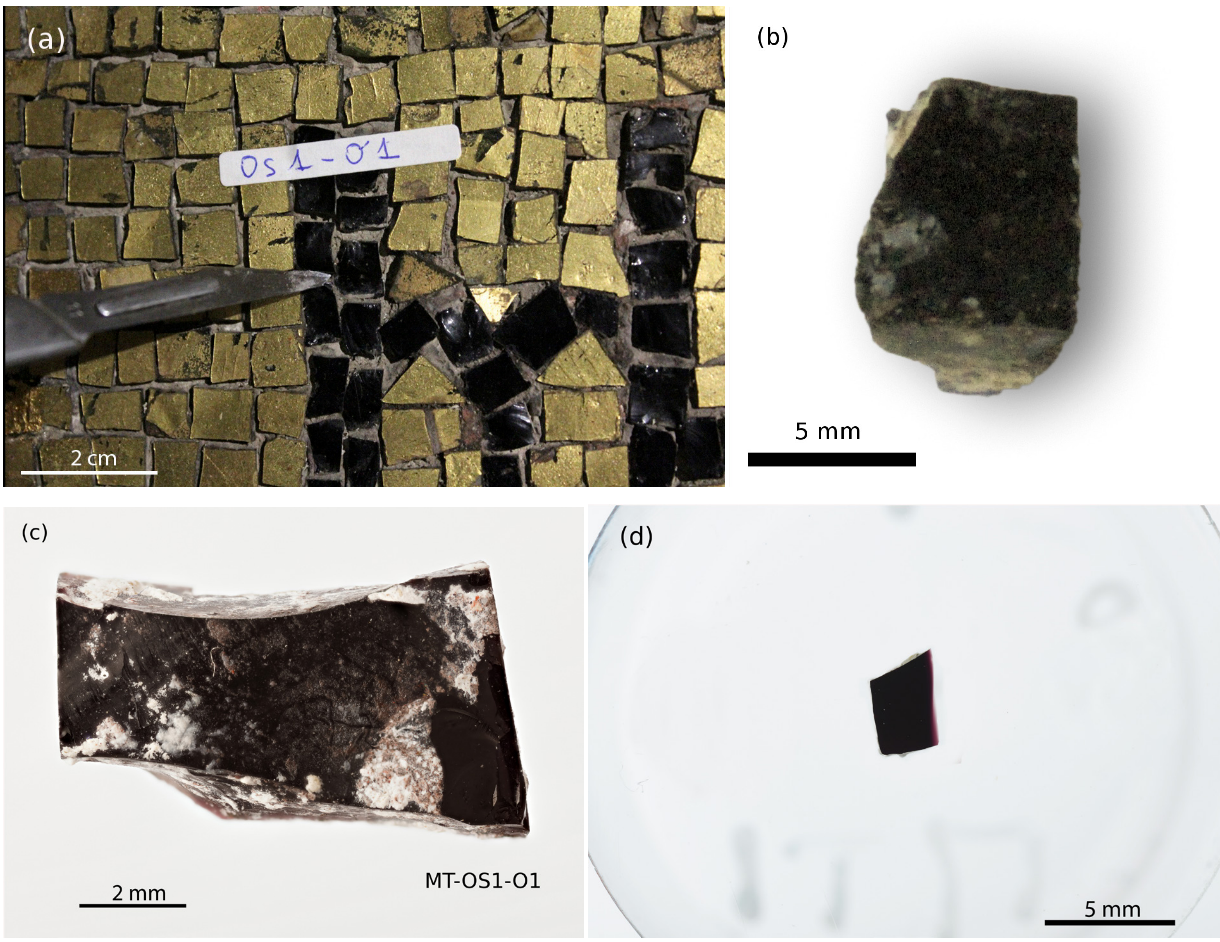

Figure 7: Palermo, St. Mary of the Admiral, *Dedication* panel: (a) Photo of the sampling area, with the position of the black tesseraselected for the archaeometric analyses; (b) photo of the whole black-appearing tessera detached from the panel (a–b: photos V. Cantone); (c) photo of the sampleMT-OS1-O1, cut from the back of the tessera for the archaeometric analyses; (d) photo of the polished resin block including a part of the sample MT-OS1-O1. (c–d: photos S. Castelli).

For the analytical laboratory characterization, we used the scanning electron microscopy coupled with energy-dispersive X-ray spectrometry (SEM-EDS) for high-resolution morphologic inspection of glass and qualitative chemical analyses, and the X-ray powder diffraction (XRPD) to identify possible crystalline phases.

SEM analysis was performed using an FEI Quanta 200 FEG-ESEM instrument, coupled with an EDAX Genesys energy-dispersive X-ray spectrometer (EDS). SEM images were taken by collecting the Backscattered Electron Signal (BSE), operating in a high-vacuum condition (<4 Pa), and with an accelerating voltage of 25 kV and a working distance of about 10 mm. The high voltage conditions assure good image contrast and the possibility of carrying out the EDS chemical analyses without changing microscope conditions. With SEM-EDS, the bulk chemical composition of the tessera was identified by random point microanalyses (about 10 in number) in standardless mode, and the mean and standard deviation were calculated. SEM analyses were carried out on the polished resin block coated with conductive carbon film.

XRPD data were obtained on a computer-controlled Philips X'Pert PRO, with Bragg-Brentano θ-θ geometry. The normal-focus Co X-ray tube (Co $K\alpha_1$ λ=0.17902 nm) operated at 40 kV and 40mA and was coupled with X'Celerator detector. Data were recorded in the 2°–80° 2θ range, in step-scan mode with step width increments of 0.02° and a step counting time of 10 s. Data were processed by the X'Pert HighScore (PANalytical copyright); 2θ and d values were calculated with the second-derivative algorithm of (Savitzky & Golay, 1964). The XRPD diffraction profile was carried out on the whole fragment for conservation purposes.

On the portion of the black tessera unemployed for the chemical and mineralogical investigation, colorimetric analysis has been performed in the laboratory with a wireless digital color reader. The instrument used is an NCS Colourpin II, equipped with a tri-stimulus XYZ sensor, a full-spectrum white LEDs, with a 45°: 0° measuring optics and with a spot size of 4 mm in diameter. The colors are given with NCS notation and also translated to CMYK, RGB, L*a*b*, and lightness values. The technical specification reports an accuracy of DE<0,1 (average) on 2000 colors.

3 Results and Discussion

Visual analysis, supported by the research carried out in historical archives and collections, provided the starting points in the analysis of the *Dedication* wall mosaic. The time-lapse analysis of the pictures in a frame of around a hundred years helps in the identification of several significative anomalies. Other restorations of the *Dedication* mosaic, probably not considered before, have been made between the 16th and 20th centuries. However, this first approach cannot help in the identification of new or original tesserae because of their apparent visual similarity. For example, the Virgin face in this mosaic appears similar to this, contemporary, of the Virgin in the *Nativity* scene at the Palatine Chapel (Brenk, 2010, p. 460), but with only this information we cannot have any certainty about this originality. In this sense, visual analysis cannot clarify if the Virgin in the *Dedication* mosaic is a simple but original copy of that one at the Palatine Chapel, or a restored figure made by using different materials mimicking the original ones (e.g., using obsidian or obsidian like-glass tesserae). Several historic documents describe the practice, after 1861 (the new Kingdom of Italy), to restore medieval monuments using the "stylistic completion" (Andaloro, 1983, p. 106), coherent with the research, in this period, of the new national identity (Genovese, 2010). This practice could justify modifications or restorations using new materials to mimic the original ones.

The processed multispectral images, collected on the *Dedication* mosaic, highlight some exciting elements, mostly in the analysis of obsidians and more, in the identification of different materials. In particular, some interesting anomalies in different areas with black tesserae have been highlighted (Figures 8–9), analyzing the IR 850 nm band by histogram equalization processing.

The use of the identified different black tesserae as a comparison to identify other areas made with similar tesserae helped in the identification of four different black tesserae areas in this panel (Figure 10).

This non-invasive preliminary and qualitative analysis represented the starting point to drive the sampling points needed to analyze these apparent different materials.

The micro-textural characterization, carried out by SEM-BSE on a first selected supposed obsidian tessera of the *Dedication* mosaic, revealed a homogenous structure, with sporadic air-bubbles and circular, thin inclusions (Figure 11).

XRPD pattern also confirms the absence of crystalline phases in the black-appearing tessera, where it appears that the sample is entirely amorphous (Figure 12).

Chemical composition, obtained by means of SEM-EDS analyses, described a tessera primarily composed by SiO_2 (63.5±0.6 wt%), Na_2O (15.3±0.5 wt%) and CaO (7.4±0.4 wt%), with potassium, magnesium, aluminum, manganese, iron, and phosphorus as minor elements (Table 1).

A few inclusions were also identified as being composed of silica and zirconium oxide (Figure 11b).

The results of the micro-textural, mineralogical, and chemical analyses then exclude this as an obsidian tessera. Obsidian is, in fact, a volcanic glass, made by rapid solidification of rhyolitic magma and therefore, its chemical composition is highly felsic, usually with 70% or more of SiO_2 (Barca et al., 2019), not matching with the values in our analyzed tessera. Although the oxide percentage of other major and minor chemical elements can vary significantly among the different origins (Barca et al., 2019), their broad ranges appear different from those of the studied sample, as shown in Figure 13.

By making strict comparisons with obsidians from the peri-Tyrrhenian area (e.g. Lipari, Monte Arci, Palmarola, and Pantelleria, raw data from Francaviglia, 1988; Acquafredda et al., 1999; Tykot, 2002; De Francesco et al., 2008; Le

Figure 8: Palermo, St. Mary of the Admiral, *Dedication* panel: some areas with black tesserae in the mosaic wall (yellow areas).

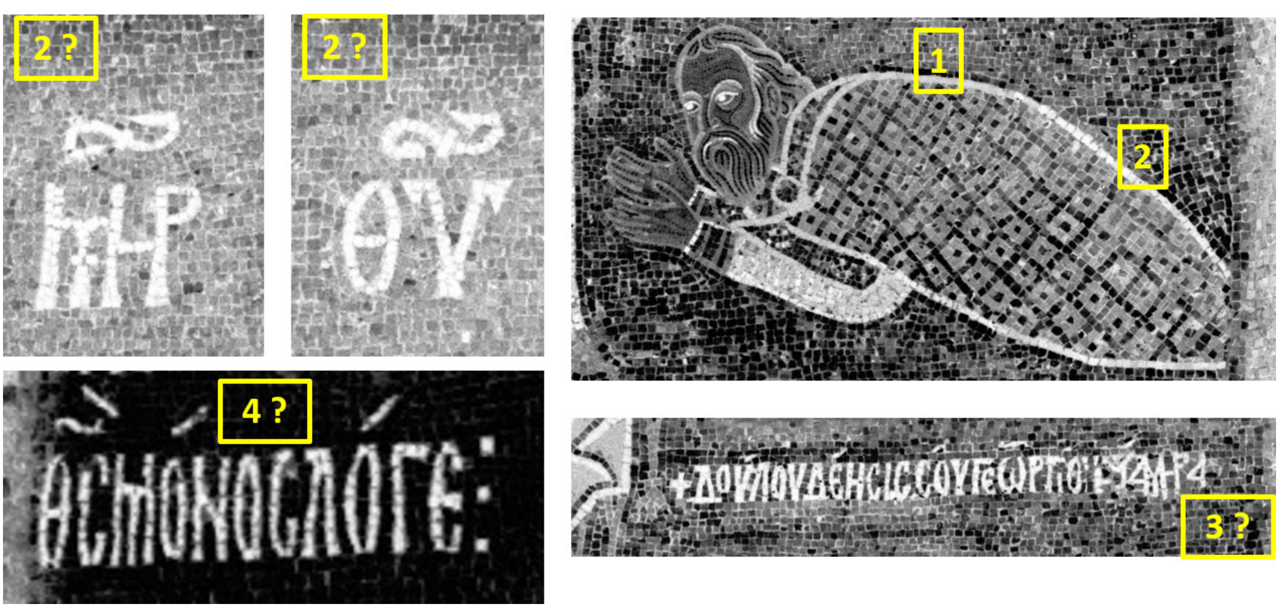

Figure 9: Palermo, St. Mary of the Admiral, *Dedication* panel: three different images of Giorgio a) visible image; b) IR (720 nm) calibrated image; c) IR (850 nm) filtered image with histogram equalization.

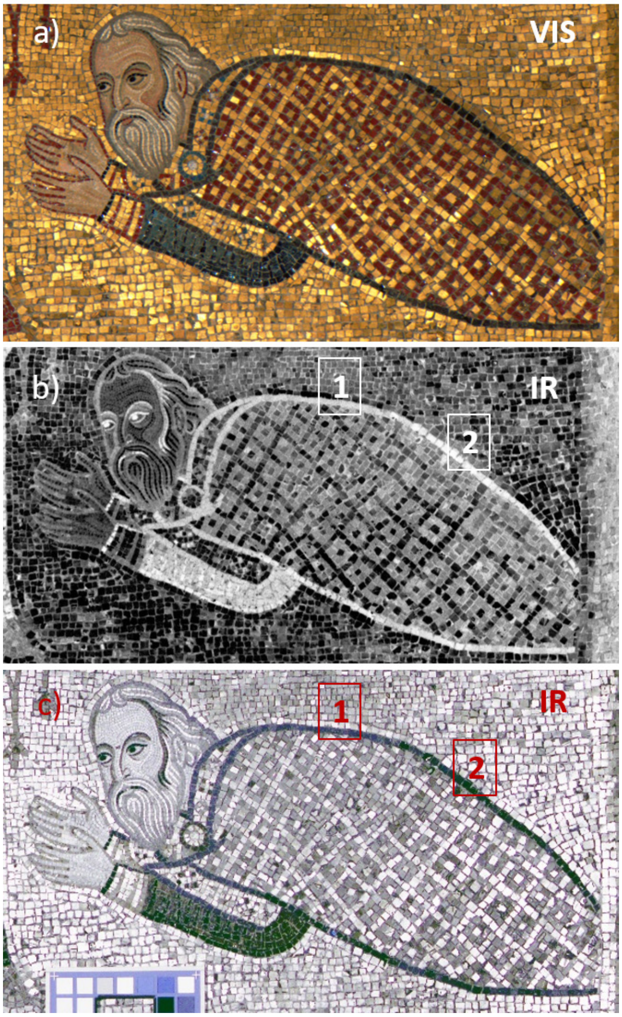

Figure 10: Palermo, St. Mary of the Admiral, *Dedication* panel: identification of similar features in different zones with black tesserae in the wall mosaic using IR images.

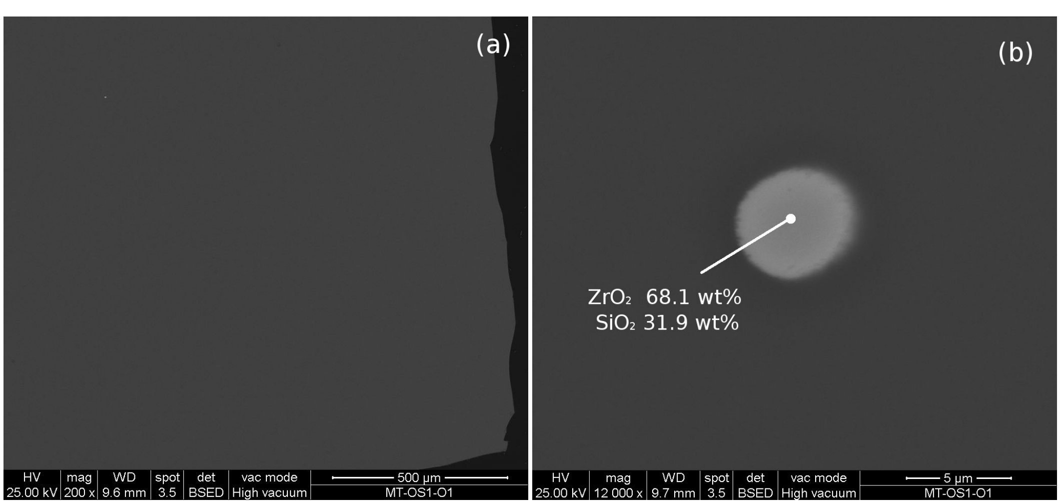

Figure 11: (a) SEM-BSE image of sample MT-OS1-O1. Note the homogeneity of the glass and the absence of air-bubbles and inclusions, except for sporadic ones, circular in shape and very thin in size, shown in (b). SEM-EDS data also reported in (b).

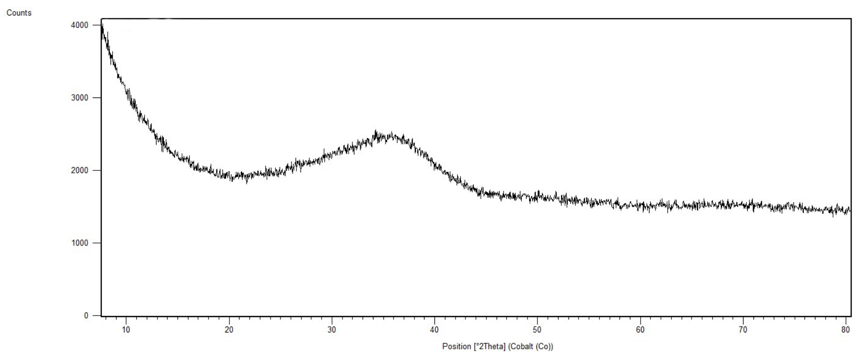

Figure 12: XRPD pattern of sample MT-OS1-01. Note that no peaks, due to crystalline phases, are visible.

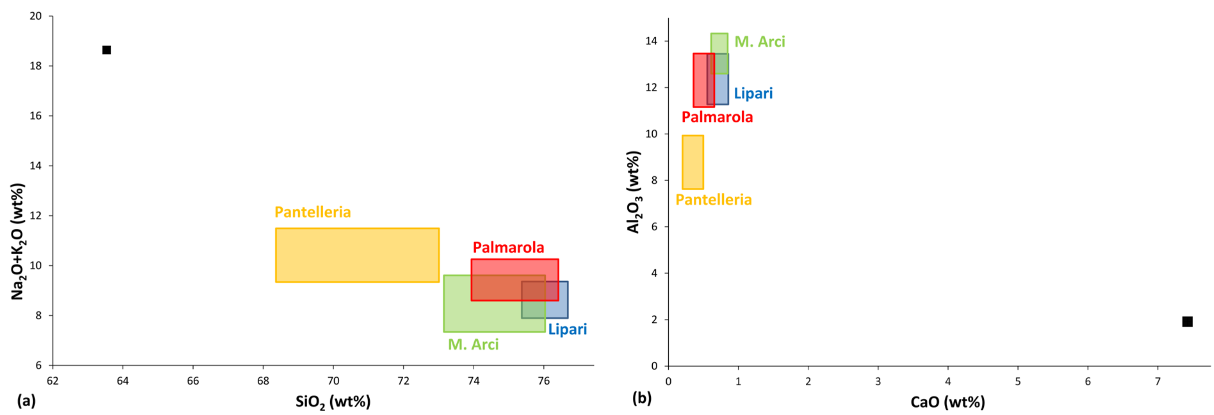

Figure 13: Na_2O+K_2O vs SiO_2 (a), Al_2O_3 vs CaO (b) and MnO vs Fe_2O_3 (c) plots, in which sample MT-OS1-01 (■) is compared with literature compositional areas of obsidians from the pery-Tyrrenian area. SEM-EDS data for sample MT-OS1-01 and chemical data of Lipari, M. Arci, Palmarola, and Pantelleria obisidians from (Acquafredda et al., 1999; De Francesco et al., 2008; Francaviglia, 1988; Le Bourdonnec et al., 2010; Tykot, 2002).

Table 1: Chemical compositions of sample MT-OS1-01 (SEM-EDS data; n = number of analytical points).

	MT-OS1-01 (n=10)	
wt%	MEAN	*ST. Dev.*
Na_2O	15.26	*0.49*
MgO	1.64	*0.27*
Al_2O_3	1.92	*0.20*
SiO_2	63.54	*0.56*
P_2O_5	0.88	*0.25*
Cl	1.25	*0.11*
K_2O	3.38	*0.16*
CaO	7.43	*0.40*
MnO	3.98	*0.34*
Fe_2O_3	1.19	*0.07*
Total	100.45	

Bourdonnec et al., 2010), it is evident that the tessera sample from the *Dedication* mosaic in St. Mary of the Admiral has lower silica, alumina and iron oxide (the last only with respect to Pantelleria) and higher sodium plus potassium oxides, calcium and manganese oxide than obsidians from the peri-Tyrrhenian area. In addition, the present black tessera is characterized by sporadic micro-inclusions of zircon crystals, while obsidians are generally characterized by a high percentage of micro-phenocrystals composed by feldspars, pyroxenes, biotite, and magnetite (Acquafredda et al., 1999; Barca et al., 2019).

The sample here analyzed can be defined as a synthetic glass, silica-soda-lime in composition, and obtained by melting silica sand and soda ash as a flux (Moretti & Hreglich, 2013), as testified by the K_2O, MgO, and P_2O_5 contents and the crystalline inclusions here identified (Table 1 and Figure 11b). The obsidian naturally shows different shades of color varying from grey-green to black due to variable iron contents (Barca et al., 2019). The color of our tessera is due to the very high manganese content, which, when present as Mn^{3+}, imparts hues variable from pink to purple, until to the black-appearing one in the function of its increasing concentration and thickness (Bamford, 1977; Cagno et al., 2014; Bidegaray et al., 2019, 2020). The chemical and micro-textural characteristics of the analyzed sample allow us to hypothesize a substitution of original tesserae with obsidian-like ones during restoration in place of damaged or lost "natural" obsidian tesserae, and to confirm results of the archive research on the discontinuity involving the abbreviation "MP", where the black tessera sampled in this study was located.

Based on the difficulties in the visual discrimination between obsidian and obsidian-like tesserae that we have encountered in the sample selection, in future campaigns of research we are planning to perform other in situ non-invasive analyses. In order to identify a fast, low cost and easy to apply method able to distinguish between obsidian an obsidian-like glass tesserae, a preliminary test with a digital color-measure device has been performed in the laboratory on the remains of the black tessera sample and on reference obsidians. The digital color reader used, an NCS Colourpin II, is smaller (about 2.7 cm in diameter and 5.5 in high), wireless, and connected to the software by bluetooth therefore it will be easy to use even when the tesserae are located in positions difficult to reach with other instruments. The measure requires only 1 s, therefore a large number of tesserae may be checked and analysed in situ. In our preliminary test, each sample has been measured 3 times on different areas in order to check the variability due to possible heterogeneity of the materials. Three chunks of black obsidian from the beach of Papesca, Lipari (samples Lip-1/Lip-3) and 5 black pieces from Cava dei Turchi, Pantelleria (samples Pant-1/Pant-5) were analysed as reference materials. The remain of the tessera sampled in St. Mary of the Admiral show different colour on the 2 major surfaces: 1) the surface with cutting marks (the sample was removed by means of a rotating micro-saw) appears blackish – very dark grey; 2) whereas the back part of the tessera, after the cleaning of the mortar, is black and presents a very thin opalescent patina (visible only with a stereomicroscope). Three colour measures were done on both the surfaces. The results expressed as L*, a*, b* and RGB values are plotted in 3D diagrams (Figure 14a and 14b).

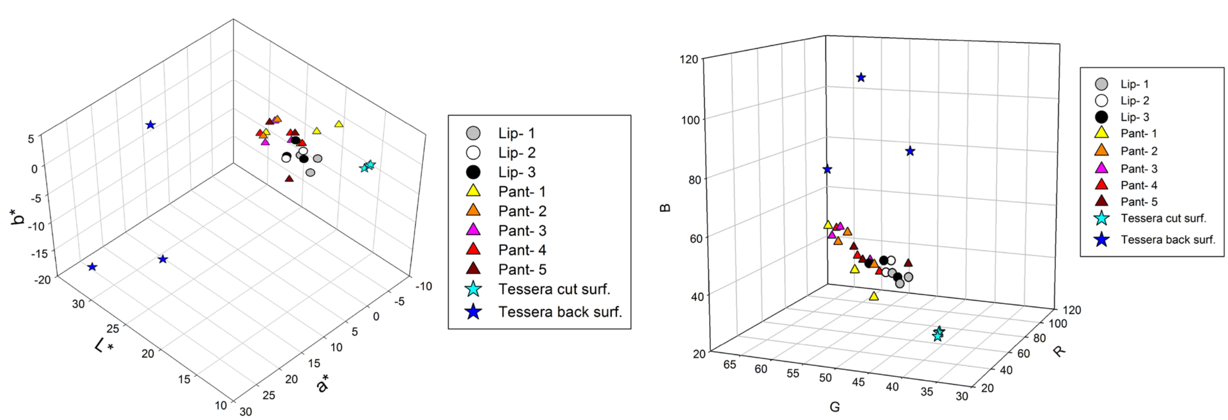

Figure 14: 3D plots of the colorimetric parameters L*, a*, b* (a) and RGB (b) measured on reference obsidian chunks from Lipari (Lip-) and Pantelleria (Pant-). The data are compared with the measures obtained from the surface of the sample MT-OS1-O1 after its cut from the original mosaic tessera, and the back surface of the tessera.

Interestingly, all the obsidian samples fall together in the same volume of the diagrams, even if some variations linked to the different origin are visible. Moreover, both the surfaces of the mosaic tessera in the diagrams are clearly distinguishable from the true obsidian samples.

4 Conclusions

The preliminary results obtained thanks to the multidisciplinary approach adopted to study the *Dedication* wall mosaic of the church of St. Mary of the Admiral in Palermo allow us to make several considerations. In this study, we focused our attention on the analysis of black tesserae, identifying four apparent different kinds of tesserae. The goals of the combined use of visual analysis, archive research, multispectral imaging, and archaeometric lab analyses applied to the mosaic, in the identification of an obsidian-like tessera where the obsidian was expected by only naked-eye observations, suggest an approach for future studies to distinguish the original medieval parts of the mosaic from these restored at the beginning of the 20th century, mimicking the byzantine models.

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Author Contributions: Conceptualization: V.C.; writing of the original draft: all the authors; Art Historical and archival researches: V.C.; Multispectral acquisitions and interpretation: R.D.; Chemical and mineralogical anaysis and interpretation: A.S.; Colourimetric analysis and data treatment: I.A. Conclusions and reviews of paper: all the authors.

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