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Something old, something new: the late antique mosaics from the catacomb of San Gennaro (Naples)

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ABSTRACT

Naples assumed an important political and economic role within the region of Campania during the late antique period. LA-ICP-MS data of 285 glass tesserae from the catacomb of San Gennaro in Naples confirm that the surge in building activities in the late fourth and early fifth century CE was accompanied by imports of new materials for the production of mosaic tesserae. Our results from Naples identify a substantial number of Jalame-like Levantine glasses for which there is no parallel within the Italian Peninsula. Only few scattered examples of this type of base glass are found among the published data from Aquileia, Ravenna and the Villa of Faragola, pointing to a link between the supply of glass and the sites' connectivity and economic strength. This seems to have changed after the fifth century. Elemental analyses, combined with SEM-EDS and micro-Raman indicate that the mosaics dating from the fourth to the eighth/ninth century CE in the catacombs of San Gennaro were overwhelmingly made from reused first- to fourth-century Roman base glasses opacified with calcium antimonate. The reuse and recycling of Roman glass and Roman tesserae is a common feature of mosaic assemblages in Italy more generally. The definition of a Roman spectrum tesserae reference group revealed this dependence on old Roman material throughout the first millennium CE.

1. Introduction

Increasingly systematic macroscopic and chemical analyses of glass mosaic tesserae from numerous Italian contexts over the last two decades have significantly broadened our understanding of the different traditions and technologies of early Christian and medieval mosaics (Maltoni et al., 2016; Silvestri et al., 2016, and references therein). Major cities like Rome, Milan and Ravenna are believed to have had their own mosaic schools, meaning workshops producing stylistically and technically distinct mosaics (Bisconti and Mazzoleni, 1994). Judging from the abundance of mosaics in Campania from the late fourth century onwards and their iconographic and stylistic *koine* that seemed independent from the rest of Italy, a mosaic school possibly existed also in Naples (Amodio, 2005, Bisconti, 2015, and references therein, Ebanista, 1998, Ebanista, 2000). Some scholars highlight possible art historical African affiliations, especially after the Vandal invasion of northern Africa that resulted in the influx of migrants to Naples in the second quarter of the fifth century (Amodio, 2005). At around this time, Naples gained a prominent political and economic role in the region. Naples was in charge of the defence of the surrounding territory and maintained trade connections with the wider Mediterranean. The vitality of the city's economy is reflected in the high volume of imports, mostly of African origin (Arthur, 2002; Panella, 1993; Saguì, L., 2001).

Despite the clear historical and archaeological importance of Naples and the distinctiveness of its mosaic art, no analytical study of any of the mosaics in the city has yet been undertaken. The comprehensive investigation of a sizeable collection of glass mosaic tesserae from Naples presented here fills an important gap in the history of Italian mosaic making. The chemical characteristics of glass tesserae testify not only to the base glass and its origins, but also to secondary working traditions and by extension to the economic and cultural transmission of materials and technologies. It is a widely held premise, for example, that the glass cakes from which the tesserae were cut were typically not made on site, but probably imported from secondary glass workshops of

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unknown location (James, 2017). These secondary workshops reworked either collected cullet or raw glass that had been produced in primary glassmaking furnaces in Palestine and/or Egypt. The recipes for the coloration and opacification of mosaic tesserae were accordingly subject to regional and chronological variations (Neri, 2016). Another common form of supply was the direct reuse of ancient tesserae looted from abandoned buildings (e.g. Maltoni et al., 2016; Schibille et al., 2012; Silvestri et al., 2012).

The present study explores the question of a local mosaic making tradition in Naples as well as long-term developments in southern Italy. To this end we studied the chemical composition of 285 tesserae from the catacomb of San Gennaro, located in the northern suburbs of Naples. The catacombs were first established in the third century and were in use through to the ninth century CE. Comparisons with glass tesserae from other Italian sites dating to the fourth to ninth century CE address the critical issue of whether there are regional and/or chronological differences within the Italian Peninsula, which in turn reflects the availability of raw glass and supply networks. By defining a reference group of Roman spectrum tesserae based on published data, our results suggest extensive reuse of Roman tesserae in Naples in line with mosaic making practices in Italy throughout the first millennium CE. At Naples, there is a near complete lack of new post-Roman opacifying techniques that had been introduced in the eastern Mediterranean in the fourth or fifth century. At the same time, a sizeable group of tesserae from the catacombs of San Gennaro are compositionally similar to Levantine glass from Jalame. The systematic use of tesserae made from this type of base glass at Naples is exceptional in the Italian context, where only very few finds of this type of base glass have been reported.

2. Materials and methods

2.1. Archaeological context and samples

The catacombs of San Gennaro preserve numerous in situ mosaics, of which the most important are found on the upper level in the so-called bishops' crypt (A6) (Fig. 1). Four arcosolia were decorated with mosaic portraits of deceased bishops within floral clipea dating to between the first half of the fifth and the first half of the sixth century CE (Amodio, 2005; Bisconti, 2015; Fasola, 1975). The earliest is the portrait of bishop John I († 432) at the rear of the arcosolium, who translated the remains of San Gennaro to the catacomb. A similar arcosolium is on the northern wall of the crypt, the lunette of which is decorated with the portrait of Quodvultdeus, bishop of Carthage, who died in exile in Naples before 25 October 454. He is shown with dark skin, holding a codex embellished with a cross and the four living beings from the Book of Revelation (Fig. 1). The image of an unknown bishop with pale-skin and white-hair occupies the wall on the south, and is believed to represent John II, from the second quarter of the sixth century (Bisconti, 2015; Fasola, 1975). The tonsured figure shown on the upper part of the northern wall of the hypogeum has likewise been identified with John II, however it may alternatively be linked to the restorations of Anastasios and the establishment of a monastic community in the catacombs in the ninth century (849–872) (Fasola, 1975), 219–222).

Mosaic decorations are furthermore found in the arcosolium of a sixth-century burial located near the entrance to the bishops' crypt, on the southern wall of the bishops' basilica (A69). Fragments of a vine branch executed in yellow and blue survives in the extrados and a decorative border of white and dark tesserae in the lunette. Cubiculum A38, located on the northern side of passageway A4, retains portions of its mosaics and traces of *opus sectile*. Mosaics covered the niche at the rear and the upper part of the extrados. In the centre of the vault is a monogrammatic cross with alpha and omega inscribed in a *clipeus* surrounded with a white and red decorative border. A funerary inscription of brownish red tesserae on a white background and overlain by a thin red band runs at the centre of the extrados (Ebanista and Donnarumma, 2016). Other fragments of mosaic inscriptions were retrieved by father Ciavolino in 1977 on the edge of an arcosolium in cubiculum A38 (Amodio, 2005). The vault of cubiculum A49 had likewise been decorated with mosaic. Even though no tesserae remain in situ, the traces of an *imago clipeata* between two chandeliers can still be seen at the centre of the lunette, and plant volutes framed by a wide jewelled band had clearly decorated the intrados (Ebanista, 2015; Fasola, 1986). At the lower level, a phytomorphic mosaic had been created in cubicle B16 for the burial of a child during the first half of the fifth century (Fasola, 1975). Near the arcosolium at the end of cubiculum B61, the vault of the hall was covered with a large mosaic (> 7 m wide), from which a band of green tesserae is still visible, as are the traces of a clipeus in the lunette (Ebanista, 2015, Fasola, 1986). In the early Middle Ages, most probably during the episcopate of Paul II (762–766), the vault of two niches carved in the rear wall of the lower vestibulum (B1) were embellished with a mosaic decoration, of which large traces survive (Fasola, 1975, 204).

For the present study, 285 glass tesserae were selected for analysis from a total of 436 loose tesserae that are stored in the archives of the Pontificia Commissione di Archeologia Sacra at the catacomb of San Gennaro. The tesserae had been recovered during various excavation campaigns promoted by the Pontifical Commission of Sacred Archaeology between 1971 and 2015 (Ebanista, 2016). In particular, a first group of tesserae (Na SG 44) was collected during the excavations directed by father Fasola in 1971–74, investigating in particular the bishops' crypt (A6), cubicula B6 and B7, as well as ambulacra A2 and B8 (Fig. 1). Although we lack precise data, most of these tesserae should belong to the fifth- to sixth-century decorations of the arcosolia in the bishops' crypt (Ebanista, 2016). A second set of tesserae (Na SG A49 55b, NA SG 102, Na SG 103) was retrieved by Ciavolino in 1977 from tombs 5 and 7 in cubiculum A49 in the north-western sector of the upper level of the catacomb, which is the most recent part to be used as a burial site well into the ninth century. A third group (Na SG 100) derives from Ciavolino's excavations in 1994 within the bishops' crypt (Bisconti, 2015; Ebanista, 2016). The tesserae Na SG 192 were unearthed in 2011 in the western sector of passageway A4 during the construction of a new staircase from Capodimonte to the upper level of the catacomb. Since the passageway was dug from the east after the translation of the relics of San Gennaro sometime after 431 CE (*Gesta Episcoporum Neapolitanorum*, ch. 6), the western section of the passageway and the burials date to between the second half of the fifth and the first half of the sixth century. The last group of tesserae was collected in 2015 during an intervention aimed at completing the excavation, suspended in 1994, of loculi 209, 211 and 201 in the bishops' crypt (Na SG 205, 207, 208, respectively). Loculus 201 is a burial located above the arcosolium of Quodvultdeus that must have been dug after the deposition of Quodvultdeus in the middle of the fifth century. Loculi 209 and 211 flank the arcosolium located in the upper part of the northern wall of the hypogeum and can be attributed either to the middle of the sixth or to the middle of ninth century CE.

The provenance of the other tesserae is less certain. One has been found in the arcosolium of *Theotecnus* in cubiculum A23 (Na SG T1), located in the western sector of passageway A4, and two tesserae come from the slab tomb 22 in the same ambulacrum (Na SG 224A). Others only bear the number of the burial without any reference to their precise location (e.g. tomb 19, Na SG A49(5)). A substantial number of tesserae belongs to contexts that cannot be identified, since they only have provisional inventory numbers (e.g. Na SG 21, Na SG 29 170, Na SG 29 EN). However, it is likely that the tesserae come from the breakdown of the decorations of the tombs or the arcosolia identified by Ciavolino between 1987 and 1994 in the upper level of the catacomb and from the two early medieval niches (eighth century) at the lower levels (Fasola, 1975; Amodio, 2005). Another series (Na SG 34) may come from the decay of the mosaic in cubiculum B16 dated to the first half of the fifth century. Taken together, our selection of samples should in principle include tesserae from all decoration campaigns and

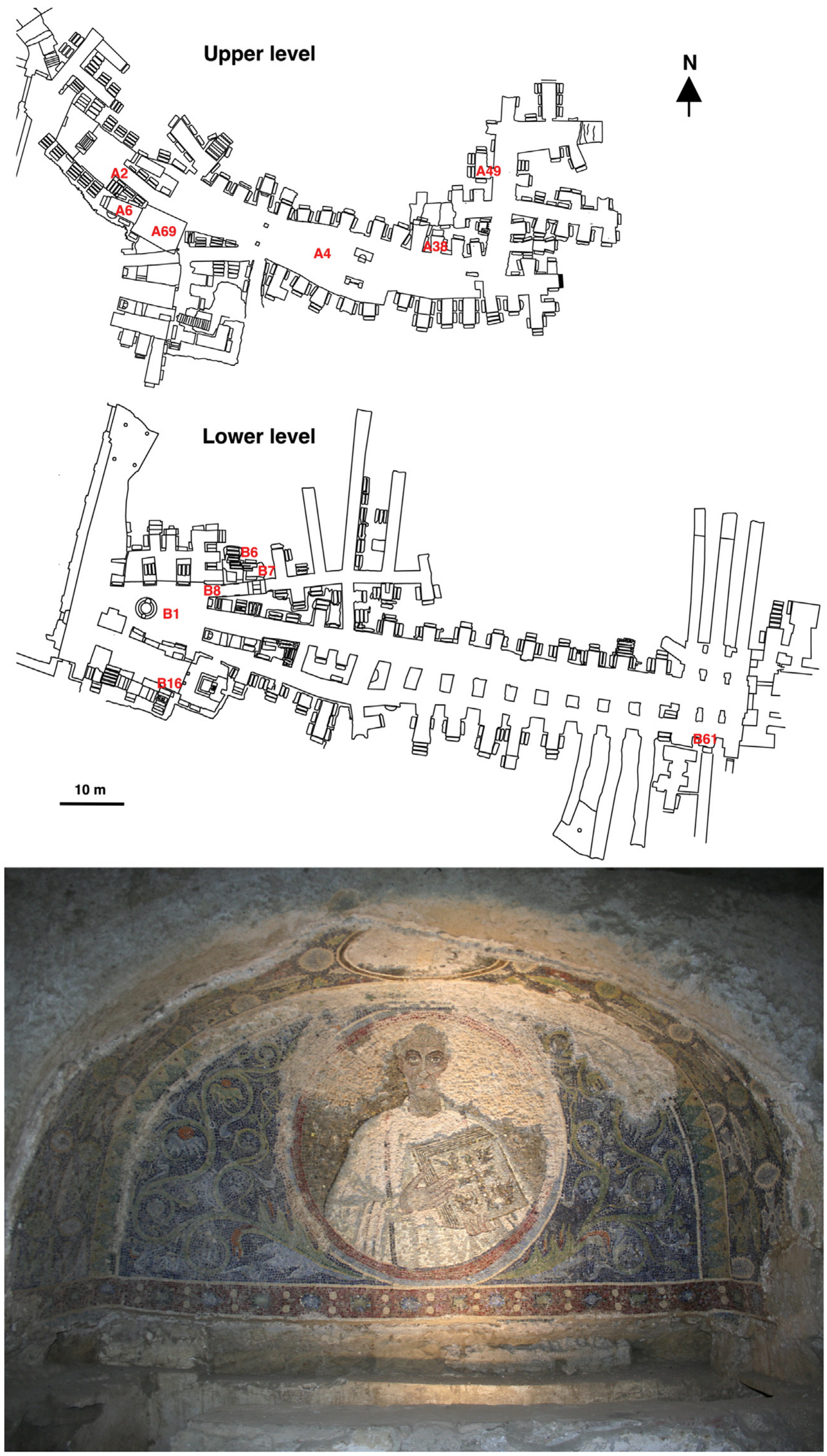


Fig. 1. Catacombs of San Gennaro (Naples). Plan showing the location of the main mosaic decorations mentioned in the text (adopted from (Ebanista, 2010) and portrait of Quodvultdeus († approximately 454 CE) in the bishops' crypt.

contexts were mosaics were found.

2.2. Analytical methods

Chemical analyses were carried out on the unprepared samples by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the Centre Ernest Babelon (CEB) of IRAMAT in Orléans (France), using a Thermofisher Element XR combined with a Resonetic UV laser microprobe (ArF 193 nm). The laser was operated at 5 mJ and with a pulse frequency of 10 Hz. The standard spot size of 100 µm was reduced when saturation caused by manganese, tin or antimony occurred. The 20 s pre-ablation time was occasionally increased to remove any surface alterations. Collection time was set at 30 s during which 58 elements were simultaneously measured. The quantification of the signal intensities has been described in detail by Gratuze (2016). To determine the accuracy and precision of the analyses, standard reference materials Corning A and NIST 612 were measured at regular intervals. The analytical precision was typically better than 5% for most elements, while the accuracy is generally within 5 and 10% for all elements (Table S1).

To characterise the crystalline phases, small fragments from a limited number of samples were embedded in epoxy resin and polished. The polished cross-sections were subsequently carbon-coated and examined in the scanning electron microscope with an energy-dispersive spectrometer (SEM-EDS) at IRAMAT-CEB. Back-scattered images (BSE) were obtained and semi-quantitative analyses of opacifiers and colorants were performed with an acceleration voltage of 20 kV, a beam diameter of 1 µm and a working distance of 10 mm for 300 s (Neri et al., 2017).

The polished blocks were also analysed by Raman spectroscopy to determine both the composition and the structure of the crystalline phases. The experiments were performed in ambient conditions using a Renishaw Invia Qontor spectrometer equipped with a dispersive 3600 L/mm grating and with the UV Nd:YAG Laser at 355 nm wavelength. This wavelength appears to be the most suited for all the analysed materials since they present no (or very limited) fluorescence contribution. The spectra were collected on a Leica DM2500 optical microscope (×40 objective). Very low incident power (~1 mW) was used to avoid heating effects or a possible degradation of the samples. Spectra were processed using Renishaw WiRE software.

3. Results

3.1. Glass matrix

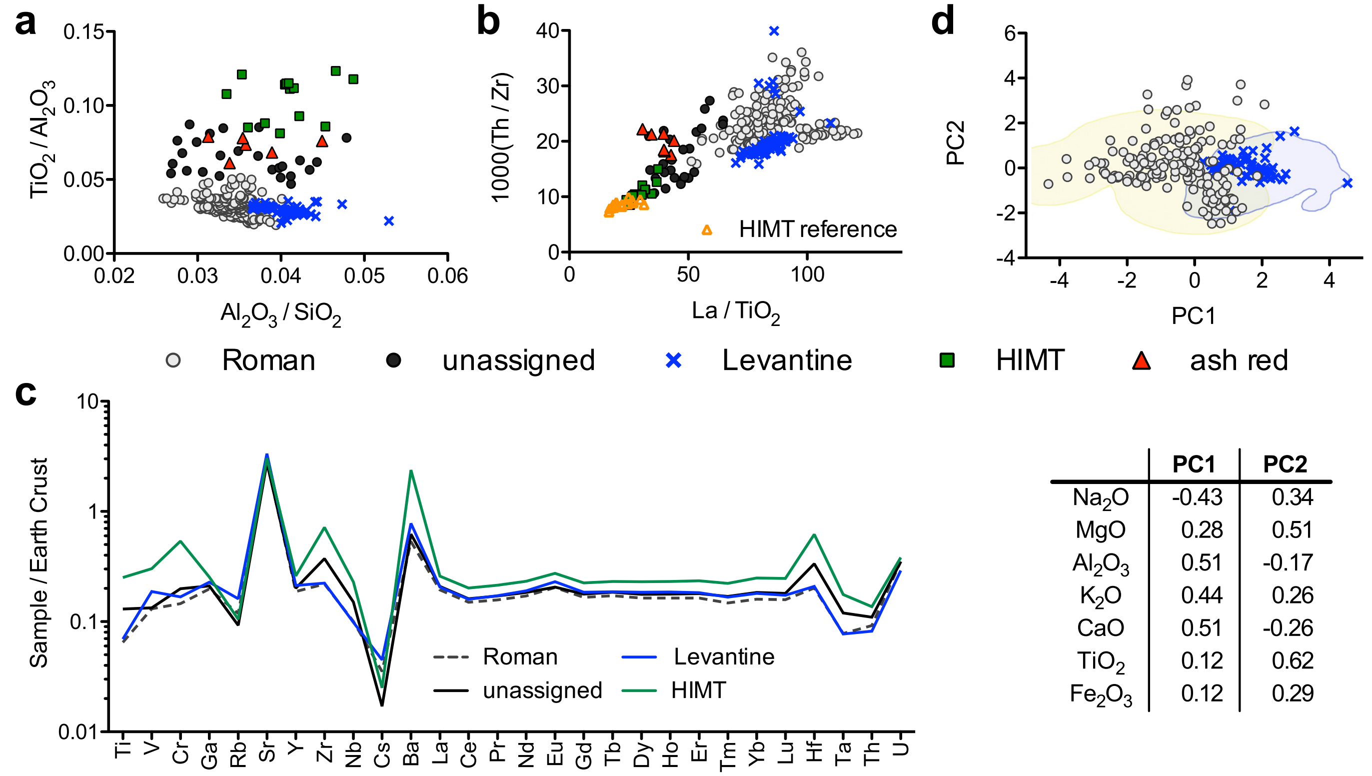
The compositions of the tesserae from San Gennaro are consistent with well-recognised Roman (first to fourth century CE) and late antique (fourth century and later) glass groups (Table 1). They were made from natron-type base glasses with characteristically low magnesium, potassium and phosphorus concentrations. A handful of red ($n = 6$) and one orange sample are exceptional in that they have elevated potassium (> 1.5%), magnesium (> 1.5%) and phosphorus (> 0.7%) oxide contents, indicative of the addition of a plant ash component. The tesserae differ in elements that are related to the silica source. The ratios of TiO_2, Al_2O_3 and SiO_2, for example, clearly separate the natron-type mosaic tesserae into distinct compositional groups (Fig. 2a). These oxides reflect the feldspar, quartz and heavy mineral contents of the silica sources and their ratios have thus proved effective to distinguish different first millennium primary glass groups (Freestone et al., 2018; Schibille et al., 2017). Using ratios also circumvents to a certain extent the problem of potentially distorted base glass compositions due to the different proportions of secondary additives (colorants, opacifiers) usually encountered in mosaic tesserae. Nonetheless, the match between the tesserae and known categories of Roman and late antique primary production groups is only approximate as the compositional spectrum of tesserae tends to be broader than that of colourless and naturally coloured glasses of the same period, which is discussed in more detail later (Section 4.1).

Through an iterative comparative approach, three main groups can be distinguished according to the silica sources, with the cobalt colorant as an additional point of reference for the classification (see Section 3.2). About 60% of the analysed tesserae from San Gennaro have low heavy mineral contents ($TiO_2/Al_2O_3 < 0.05$) and moderate alumina ($0.02 < Al_2O_3/SiO_2 < 0.04$) and thus correspond broadly to Roman glasses, of either the antimony, manganese or mixed antimony and manganese type (Table S2). These Roman glass categories typically date to the first to fourth century CE (Gliozzo et al., 2015; Jackson and Paynter, 2016; Schibille et al., 2017). A set of tesserae with comparatively high titanium to aluminium oxide ratios (Fig. 2a) have been made from a HIMT-like base glass. The absolute concentrations of elements such as titanium, magnesium, manganese and zirconium tend to be lower (Table 1) than those of typical HIMT glass (e.g. Ceglia et al., 2017; Foy et al., 2003; Freestone et al., 2005, 2018; Nenna, 2014). However, the ratios of thorium to zirconium and lanthanum to titanium oxide (Fig. 2b) demonstrate that this subset of tesserae from Naples are related to HIMT glass as commonly understood (Freestone et al., 2018). The trace element levels, most notably vanadium, chromium, barium and hafnium in these samples also exceed those of the other tesserae (Fig. 2c). The small group of HIMT tesserae from Naples may not conform perfectly to HIMT glass in the strict sense, but it is likely that they were made using a HIMT-like glass possibly mixed with another type of base glass. They probably date to the fourth century or later given that HIMT glass was produced and circulated in the fourth and fifth century CE (Freestone et al., 2018).

What we designate as Levantine glass differs from the Roman group in its higher Al_2O_3/SiO_2 ratios (> 0.04) as well as higher potassium, calcium and lower soda levels (Table 1). They furthermore deviate from the Roman group in the elemental signature of the cobalt colorant underlying the blue samples (see section 3.2). Using the cobalt colorant as an additional criterion, several blue samples with Al_2O_3/SiO_2 ratios between 0.037 and 0.04 are attributed to the Levantine group. These Levantine samples form a relatively tight cluster with relatively low standard deviations across the main base glass components (Table 1). A principal component analysis (PCA) of the seven base glass components (Na_2O, MgO, Al_2O_3, K_2O, CaO, TiO_2, Fe_2O_3) separates the Levantine glasses clearly from the Roman samples (Fig. 2d). For comparison, Roman glass from the early third-century Iulia Felix shipwreck (Silvestri, 2008; Silvestri et al., 2008) and fourth-century glass from Jalame (Brill, 1988) were included in the PCA and are represented as outlines of a 95% kernel density estimation (Ramsey et al., 2015). The groups vary mostly along the x-axis (PC1), positively associated with aluminium, potassium and calcium oxides and negatively with soda. The tesserae defined as Roman coincide with the glass from Iulia Felix, while the bulk of the Levantine samples fall within the Jalame perimeter. Statistically it is impossible to prove that two datasets are the same, hence we cannot say for certain that the tesserae from San Gennaro are made from Jalame glass. However, what this graphical representation confirms is that the Levantine tesserae are unlikely a subset of Roman glasses. At the same time they are different to the more narrowly defined Levantine I glass of the sixth- to eighth-century Apollonia type, due to their relatively high concentrations of soda

Table 1
Means and standard deviations (SD) of the glass groups identified among the mosaic tesserae from San Gennaro (Naples). Data [wt%] were reduced to the shown major, minor and trace element oxides and normalised to 100%.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Sr [ppm]	Zr [ppm]
Roman ($n = 168$)	17.1	0.57	2.39	69.9	0.11	1.05	0.59	6.95	0.08	0.49	0.79	420	45
SD	1.45	0.10	0.20	1.14	0.05	0.18	0.11	0.79	0.01	0.27	0.50	42	7.7
Levantine ($n = 72$)	16.6	0.58	2.77	68.4	0.11	0.92	0.82	8.10	0.08	0.75	0.80	479	45
SD	0.49	0.04	0.18	0.54	0.03	0.08	0.09	0.41	0.01	0.10	0.12	18	4.6
HIMT (n = 13)	17.9	0.86	2.75	66.9	0.07	1.04	0.55	6.42	0.29	1.41	1.71	438	144
SD	0.81	0.11	0.23	1.45	0.02	0.11	0.08	0.91	0.05	0.34	1.04	37	25
Unassigned (n = 25)	18.6	0.70	2.42	68.5	0.09	1.30	0.56	6.22	0.16	0.46	1.00	408	77
SD	1.30	0.16	0.36	2.02	0.11	0.23	0.22	1.70	0.03	0.47	0.53	116	18
Red/orange (n = 7)	14.9	2.51	2.72	63.9	0.98	1.06	1.95	9.04	0.21	0.38	2.21	671	76
SD	2.14	0.42	0.96	1.19	0.15	0.12	0.39	0.45	0.09	0.07	1.10	54	18



	PC1	PC2
Na_2O	-0.43	0.34
MgO	0.28	0.51
Al_2O_3	0.51	-0.17
K_2O	0.44	0.26
CaO	0.51	-0.26
TiO_2	0.12	0.62
Fe_2O_3	0.12	0.29

Fig. 2. Base glass compositions of the tesserae from San Gennaro. (a) TiO_2/Al_2O_3 and Al_2O_3/SiO_2 ratios discriminate between three main groups in addition to a set of unassigned samples and the red/orange tesserae with a plant ash component; (b) ratios of Th to Zr [ppm] and La [ppm] to TiO_2 [wt%] of the Naples tesserae in comparison with reference material show that the HIMT tesserae from Naples are largely consistent with HIMT as defined by Freestone et al. (2018); (c) trace element patterns of the glass groups; averages were normalised to the mean values in the upper continental crust (Kamber et al., 2005); (d) principal component analysis of the Roman and Levantine tesserae from San Gennaro with data from the Iulia Felix shipwreck (Silvestri, 2008; Silvestri et al., 2008) and Jalame (Brill, 1988). The outlines show the 95% contour of a kernel density estimation from the Iulia Felix data (yellow) and Jalame (blue) generated using the open-access RESET statistical tools (https://c14.arch.ox.ac.uk/resetdb/db.php); the PCA coefficients for principal components 1 and 2 are given below. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(16.5%) and manganese oxide (0.5%–1%) (Freestone et al., 2000; Freestone et al., 2008; Phelps et al., 2016; Schibille et al., 2017).

The remaining samples are not easily assigned, due to their intermediate characteristics. They are compositionally situated along the periphery of the Roman glass group. These tentatively unassigned samples have on average higher sodium, magnesium, titanium and zirconium levels and concurrently lower calcium and aluminium contents compared to the Roman and Levantine groups (Table 1). A sub-set of seven samples with high Al_2O_3/SiO_2 (> 0.04) and elevated TiO_2/Al_2O_3 (> 0.05) ratios has base glass features similar to série 2.1 (Foy et al., 2003) but for its lower magnesia (< 0.8%) concentrations (e.g. Bonnerot et al., 2016; Ceglia et al., 2015; Ceglia et al., 2017). Similarly, a subset of green and turquoise tesserae with low alumina ($Al_2O_3 \leq 2\%$) and Al_2O_3/SiO_2 ratios (< 0.03) and somewhat higher TiO_2/Al_2O_3 ratios (> 0.05) fall outside the typical range of Roman base glasses. It thus seems likely that the unassigned tesserae were for the most part made from Roman glass, adulterated by the addition of other base glasses, contaminations from the crucible or as the result of prolonged or repeated secondary working on a small scale (Jackson and Paynter, 2016). The addition of secondary additives such as colouring and/or opacifying agents further smudges the base glass fingerprints of mosaic tesserae. Hence, the differentiation of mosaic tesserae into categories of primary glass is often blurred due to the extensive use of recycled and mixed material as well as additives. The compositional characteristics of the mosaic tesserae from Naples nonetheless coincide with the prevalent groups of colourless and naturally coloured glasses known during the Roman and late antique period. Several of the new base glass compositions that were introduced in the fourth century such as HIMT, Jalame-like Levantine and possibly Foy 2.1 have left their mark on the compositional make-up of the assemblage from San Gennaro even though Roman base glasses greatly outweigh later compositions.

3.2. Colouring and opacification

The colorants and opacifiers in the majority of the tesserae from San Gennaro represent Roman traditions, too. The use of new opacifiers such as cassiterite, lead stannate or calcium phosphate that were introduced in the fourth or fifth century remain scarce. In contrast, the cobalt colorant and its associated elements (iron, copper, and nickel) identify two different pigments responsible for the deep blue colour (Fig. 3). In all the cobalt coloured tesserae (Co > 100 ppm) iron (Fig. 3a) and copper (Fig. 3b) tend to be elevated to a varying degree as is typical of cobalt pigments used during the first millennium CE (Gratuze et al., 2018; Gratuze et al., 1992). Unfused particles of cobalt pigments detected by SEM/EDS confirmed the association with copper and iron. A darker shade of blue appears to be linked to higher iron concentrations (Fe_2O_3 > 1%). Two different correlations exist between nickel and cobalt (Fig. 3c). Recent analyses of numerous first millennium cobalt blue glasses conducted in our laboratory have revealed a change in cobalt colorants from high CoO/NiO ratios to lower ratios after the end of the fourth century CE (Gratuze et al., 2018). In light of these observations, the lower cobalt to nickel ratios of the Levantine and HIMT tesserae from San Gennaro compared to the Roman cobalt blue tesserae is noteworthy. There is again a parallel with Jalame, where two blue samples (3601, 3611) have likewise been coloured by a cobalt colorant with low CoO/NiO ratios (Brill, 1988). What is more, the tesserae that have higher cobalt to nickel ratios contain significant amounts of antimony oxide (Sb_2O_3 > 0.5%), while the tesserae with low cobalt to nickel ratios have either no or very low antimony contents (Sb < 350 ppm) (Table S2). These findings suggest that the change in the cobalt source and the cessation of the use of antimony as opacifier may have occurred at roughly the same time.

Copper alloys of various compositions were responsible for the colours green, red and turquoise, and copper is also elevated in the black tesserae (Fig. 4). The turquoise tesserae are coloured by a combination of copper oxide and calcium antimonate as opacifier moderately correlated (Fig. 4a). Copper correlates also with tin (Fig. 4b), implying that a tin bronze was the most probable source of copper with the exception of two samples (Na SG 34 383 026, Na SG 102 005) that have elevated levels of zinc suggesting the use of a brass instead (Bayley and Butcher, 2004). Most of the turquoise tesserae were made from Roman mixed antimony and manganese glass, a few samples from the 'unassigned group' show high ratios of sodium to calcium oxide with no or little manganese, suggesting that Roman antimony decoloured glass was used as the main base material (Table S2).

The green tesserae have on average lower copper and antimony (Fig. 4a), but higher lead contents than the turquoise tesserae (Table S2). The majority was made from glasses containing both manganese and antimony, indicating the mixing of different base glasses. Seven out of the nine green tesserae made of Levantine type base glass have high zinc concentrations, indicative of the use of brass (Zn > 4 × Sn) or gunmetal (2 × Sn < Zn < 4 × Sn) according to the classification proposed by Bayley and Butcher (2004). Five green and one white tesserae have tin to copper ratios above the range typically encountered in tin bronzes (SnO_2/CuO > 0.8), suggesting that tin in these instances was a deliberate additive, possibly as an opacifier in the form of lead stannate (Fig. 4b). These samples do not contain significant levels of antimony (Table S2). Although lead stannate progressively replaced lead antimonate during the late antique period, their concurrent use has been identified as early as the second century CE (Basso et al., 2014; Verità et al., 2013).

The red and orange tesserae (n = 15) owe their opacity and colour to the presence of metallic copper or cuprite (Cu_2O). They differ both in terms of the matrix as well as the composition of the additives. About half can be attributed to either Roman mixed manganese and antimony or HIMT glass, the other half has elevated levels of potassium, magnesium and phosphorus (Table 1) as a result of a plant ash component. The relatively low soda contents of most of these samples and the notable phosphorus levels point to the contamination of the glass by fuel ash during the secondary working stage, rather than the addition of a soda-rich plant ash during primary production (Schibille et al., 2012). A natron-type base glass containing manganese and antimony and elevated heavy elements (Fig. 2a) is thus likely. Similar characteristics have been observed with respect to red and orange glass from other Roman and late antique contexts (Barber et al., 2009; Freestone et al., 2003; Maltoni et al., 2016; Paynter et al., 2015; Silvestri et al., 2014). An unambiguous chronological attribution of these tesserae is not possible at this point. They all have a broad range of lead oxide contents (3% < PbO < 10.5%), low to medium copper (1% < CuO < 3%) and relatively high iron (1.7% < Fe_2O_3 < 3.4%), and copper and iron are negatively correlated (Fig. 4c). It has previously been observed that metallic copper nanoparticles precipitate in low copper environments in the presence of a reducing agent such as iron, while high levels of copper and lead favour the formation of cuprite (Cu_2O) (Barber et al., 2009). No Raman signals were detected in any of the red samples analysed, confirming the presence of metallic particles rather than cuprous oxide (Table S2).

Seven of the eight greenish black tesserae are made from HIMT-like glass, one has not been classified, but it has elevated titanium, manganese and iron levels and resembles the other black samples closely. Hence, the greenish black tesserae form a distinct compositional group. Neither the iron concentrations (Fe_2O_3 = 1.2–1.6%), manganese contents (MnO = 1.2–1.6%), nor the elevated copper levels (CuO = 0.5–1.3%) by themselves can explain the greenish black colour. Black HIMT glasses described in the literature tend to have considerably higher iron oxide values (Fe_2O_3 > 8%) (e.g. Cagno et al., 2014). It is likely, that the black colour arises not from a single additive, but from a combination of factors, which includes reducing conditions that facilitate the formation of a ferric-sulphide chromophore (Paynter and Jackson, 2017; Schreurs and Brill, 1984), manganese levels that are too low in relation to the iron contents to act effectively as de-colorant (Silvestri et al., 2005) and the thickness of the sample. The closest compositional match was found in the form of a glass bead from the necropolis of d'Evrecy that is attributed based on typology to the fourth or fifth century CE (Gratuze, forthcoming).

The copper-rich material added to the base glass of the mosaic tesserae from San Gennaro as colorant evidently had different chemical compositions with different ratios of copper, zinc, tin, lead and iron (Fig. 4), but without any direct relationship to the colour. The colouring agents were presumably introduced as mineral or as a metallic by-product, a practice that has been documented in numerous previous studies of strongly coloured glasses (Barber et al., 2009; Freestone et al., 2003; Paynter et al., 2015; Peake and Freestone, 2012; Santagostino Barbone et al., 2008). In fact, the metallic inclusions determined by SEM have various structures and compositions of bronzes (Fig. 5a), brass (Fig. 5b) and lead (Fig. 5c). The compositional features of these inclusions suggest the use of residues of copper alloy objects, rather than slag, because their composition corresponds to that of copper alloy objects of the Roman and Byzantine period (Ashkenazi et al., 2014, 2015; Hook and Craddock, 1996; Ponting, 1999; Unglik, 1991). The exceptionally high levels of zinc in a series of green and red tesserae (Table S2) suggest the use of Roman brass objects or coins produced between the second and third century CE as sources of colorants

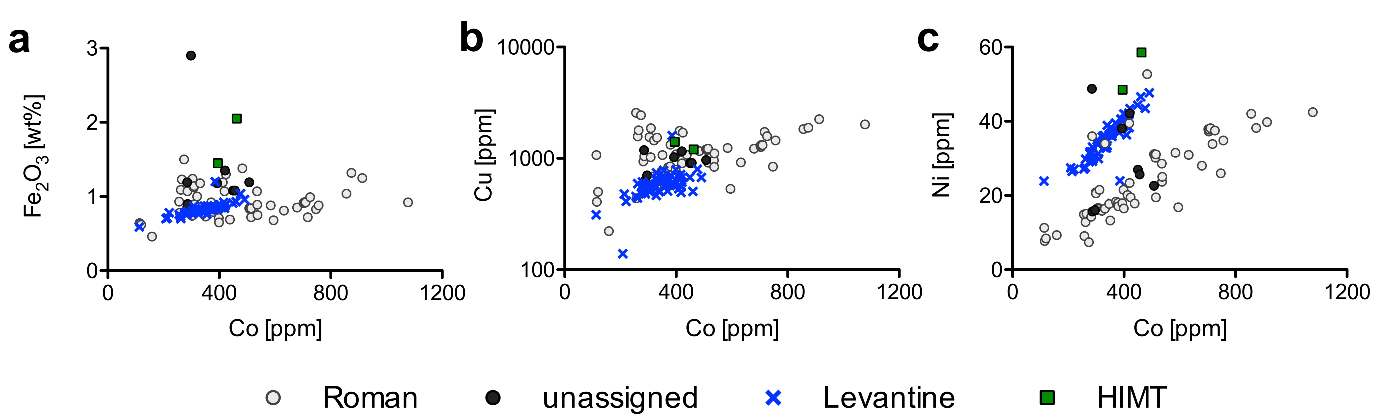


Fig. 3. Compositional characteristics of the cobalt colorant in the blue tesserae. (a) Weak correlation of cobalt and iron oxides; (b) cobalt to copper ratios reveal the addition of copper in some of the Roman-type tesserae; (c) two different correlations of cobalt and nickel suggest differences in the cobalt source.

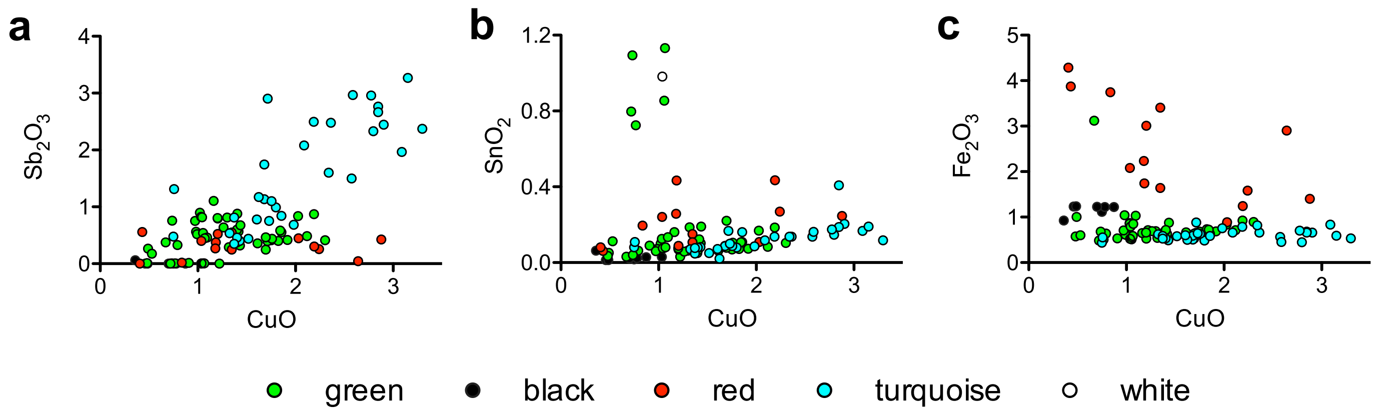


Fig. 4. Elements related to the copper additives used in the green, red, turquoise and black tesserae. (a) Copper and antimony oxides show a positive correlation in the turquoise samples; (b) copper versus tin oxide are moderately correlated, five green and one white tesserae have elevated tin, suggesting its deliberate addition; (c) copper and iron oxide concentrations are negatively correlated in the red samples, while the iron concentrations are relatively stable across the rest of the tesserae. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

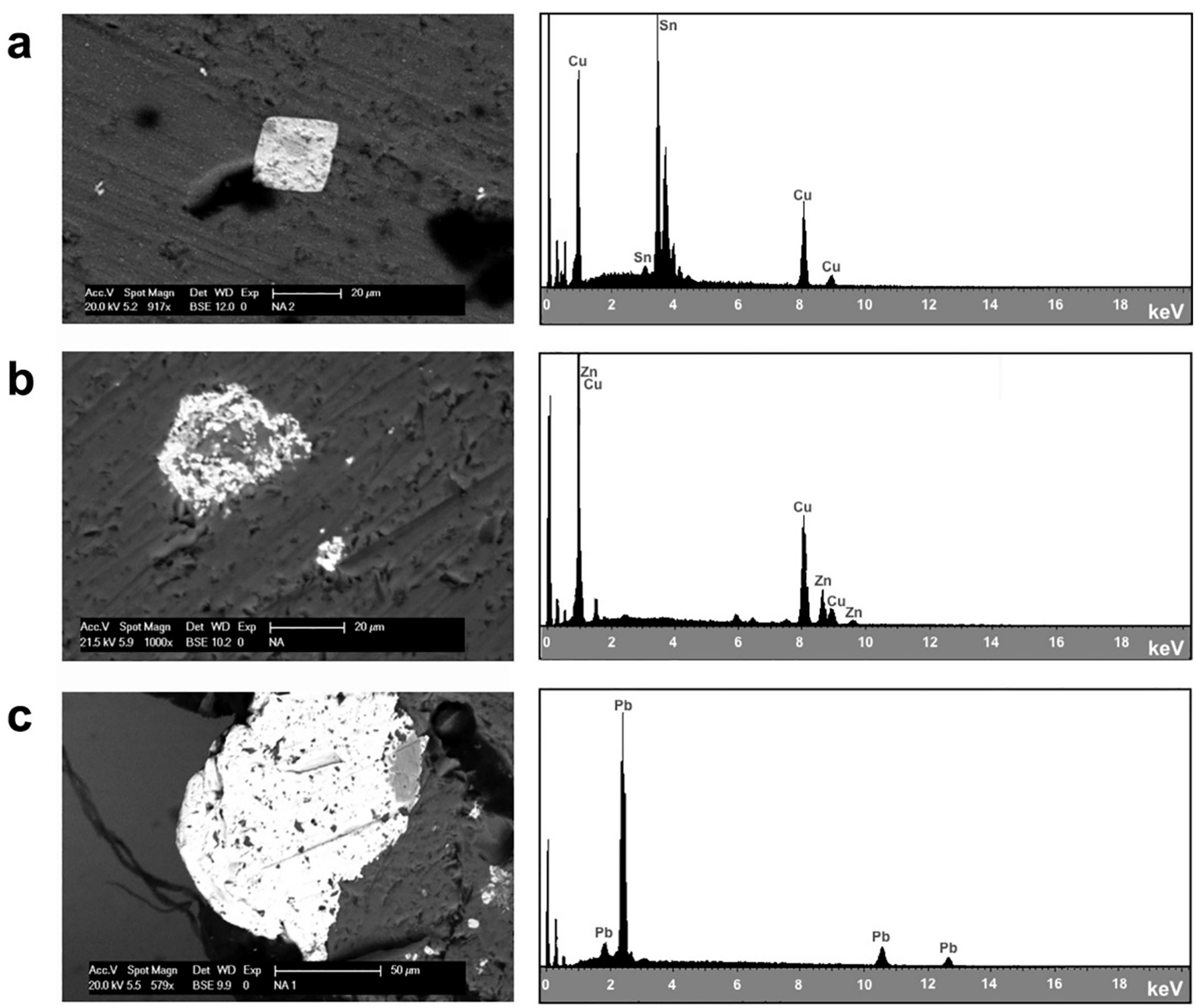


Fig. 5. BSE images of different metallic inclusions in some of the copper-coloured green samples. (a) bronze particle in tessera Na SG T001; (b) brass particles in sample Na SG 103 006; (c) lead particle in tessera Na SG 29 EN7 003.

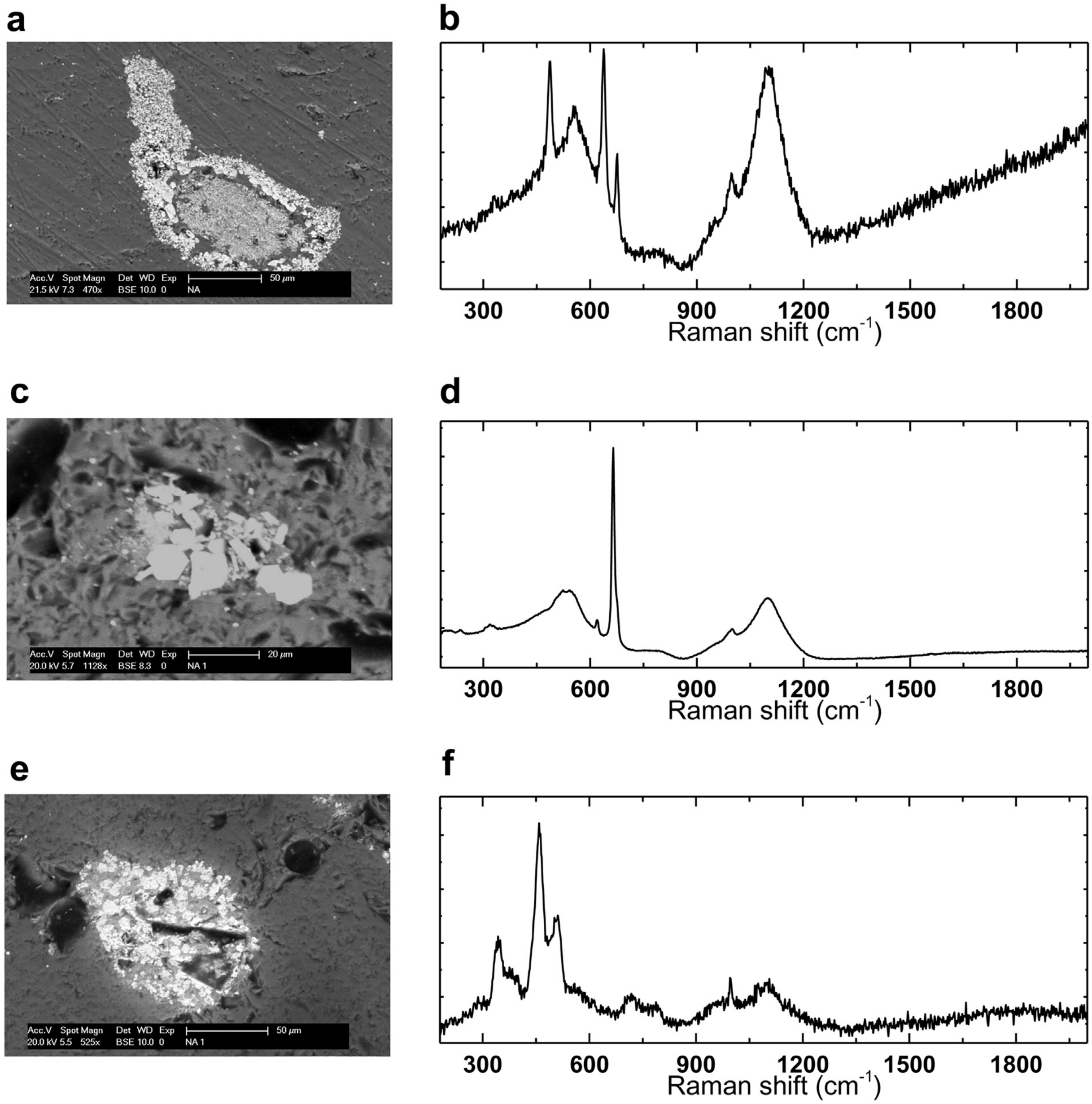


Fig. 6. Characterisation of opacifying agents by SEM-BSE and micro-Raman. (a) SEM-BSE image of green tessera Na SG 29 EN5 004, opacified with calcium antimonate; (b) micro-Raman spectrum of the same sample with peaks for $CaSb_2O_6$ (at 670 cm^{-1}) and $Ca_2Sb_2O_7$ (at 480 and 633 cm^{-1}); (c) SEM-BSE image of flesh-coloured sample NA SG 100 RA21 004 showing newly formed euhedral morphologies of mostly hexagonal crystals of calcium antimonate ($CaSb_2O_6$) and a few orthorhombic structure ($Ca_2Sb_2O_7$); (d) typical Raman bands at 670 cm^{-1} of calcium antimonate $CaSb_2O_6$ and a minor band at 624 cm^{-1} of $Ca_2Sb_2O_7$; (e) yellow sample NA SG 29 EN3 004 with lead antimonate crystals; (f) micro-Raman confirmed the presence of bindheimite ($Pb_2Sb_2O_7$) with bands at 335456 and 507 cm^{-1}, while the peaks at about 972 and 985 cm^{-1} are attributed to the presence of nosean ($Na_8[Al_6Si_6O_{24}]SO_4$). Raman bands in archaeological glasses according to (Basso et al., 2014; Gedzevičiūtė et al., 2009).

(Ashkenazi et al., 2015; Ponting, 1999). Intriguingly, these high levels of zinc are found mostly in the tesserae made of Levantine glass, meaning earlier Roman brasses were recycled as a source of colour during later periods, because the zinc contents of brasses progressively decreased and disappeared in the west entirely by the sixth century CE (Craddock, 1978; Gaffiero et al., 2011; Jackson and Craddock, 1995; Ponting and Segal, 1998).

Calcium antimonate was detected in the white (except one), about half of the blue, most of the turquoise, and a few lead-free green tesserae, as well in the flesh coloured sample (Fig. 6a-d). The flesh tone is the result of a small amount of gold (Au: 12–115 ppm), a technique that is typically associated with high status mosaic decorations in Rome, Ravenna and Milan. The base glass is very similar to that employed in the flesh tones from Rome (Verità and Santopadre, 2010). The calcium antimonate forms both anhedral (Fig. 6a) as well as euhedral morphologies (Fig. 6c), and it crystallises into two distinct structures: hexagonal crystals ($CaSb_2O_6$) as the major phase and orthorhombic crystals ($Ca_2Sb_2O_7$) as the minor variant (Fig. 6 a-d). In Roman and late antique glasses both crystal structures are usually present (Lahlil et al., 2008; Silvestri et al., 2012). Lead stannate was detected in a few green and yellowish samples, occasionally in association with secondary cassiterite (e.g. NA SG 205 209b 001 & 002, NA SG 207 211L 001).

Yellow sample (Na SG 29 EN3 004) contains crystals of lead antimonate both as aggregates (20–50 µm) and as micrometric dispersed crystals (Fig. 6e). The Raman spectra confirmed the presence of bindheimite ($Pb_2Sb_2O_7$) as well as nosean ($Na_8[Al_6Si_6O_{24}]SO_4$) a sodium aluminium silicate sulphate, indicative of the use of sulphide ores of lead or antimony to make the yellow pigment (Paynter et al., 2015). Lead tin antimonate ($Pb_2Sb_{2-X}Sn_XO_{7-X/2}$) was also identified. Antimony-based opacifier were used for most of the Roman imperial period up to the fourth century when it was increasingly replaced by tin-based opacifiers (Tite et al., 2008; Turner and Rooksby, 1959). In the mosaic tesserae from San Gennaro, antimony was used as the opacifier in glasses belonging to the Roman category, and in the cobalt blue samples containing the typical Roman cobalt colorant.

4. Discussion

4.1. Reuse, recycling and new materials

Even though the mosaics from San Gennaro originated in archaeological contexts dated to between the fifth (e.g. bishops' crypt) and the eight centuries (e.g. lower vestibule B1), possibly the ninth century (e.g. tonsured portrait in the hypogeum), at least 60% of the analysed assemblage are consistent with Roman base glass recipes of the first to fourth centuries CE. This suggests the reuse and/or recycling of ancient material on a massive scale. For example, all but three of the gold leaf tesserae ($n = 25$) were made from Roman mixed manganese and antimony glass, and antimony-based compounds were almost exclusively used as opacifying agents in the strongly coloured samples ($Sb_2O_3 > 0.5\%$, $n = 137$). Both findings imply the reuse of Roman tesserae in later contexts, although the recycling of cullet to produce new gold leaf tesserae with an old elemental signature cannot be ruled out. In a study on the gold tesserae from St. Prosdocimus in Padua, Silvestri et al. (2011) concluded that earlier cullet had been used for the manufacture of the gold leaf tesserae in the sixth century. The gold leaf tesserae from San Gennaro do not show signs of extensive recycling, neither the potassium and phosphorus levels nor the trace elements are conspicuous. This points to reuse rather than recycling. However, the available analytical evidence is not conclusive and the attribution of these tesserae to the reuse of objects or to the recycling (re-melting) of cullet of Roman glass must remain provisional. The analysis of the gold leaf sandwiched between the two layers of glass may shed some light on the production history of these samples (Neri and Verità, 2013).

Before discussing the issue of the reuse of Roman material further, it is necessary to consider the compositional spectrum of Roman glass tesserae in itself. Not many analyses of statistically significant numbers of Roman tesserae in the strict sense are available (as an exception see Paynter et al., 2015). The juxtaposition of the collection of tesserae from West Clacton (UK) probably dating to the second century CE (Paynter et al., 2015) and Roman mosaic tesserae from San Vincenzo al Volturno (Schibille and Freestone, 2013) with the vitreous material recovered from the third-century Iulia Felix shipwreck (Silvestri, 2008; Silvestri et al., 2008) provides a good reference point for the compositional nature of Roman mosaic tesserae (Fig. 7a). The colourless and naturally coloured fragments from Iulia Felix are more tightly clustered, with TiO_2 to Al_2O_3 ratios lower (< 0.05) than in the Roman tesserae (up to 0.07). The mosaic tesserae were made from Roman manganese or mixed manganese and antimony glasses, and none match the composition of Roman antimony decolourised glasses (Iulia Felix sub-group on the lower left of Fig. 7a). This interpretation is substantiated by lower ratios of soda to lime and the presence of manganese in the tesserae, albeit at very low levels. The somewhat higher contamination levels in the tesserae are probably related to the secondary working processes involved in the production of strongly coloured glass. Hence, the base glass of mosaic tesserae is evidently made from known primary glass groups, often however, from a mixture of different types, resulting in intermediate compositional characteristics.

Overlaying the data from San Gennaro with a KDE distribution generated on the combined Roman dataset (Iulia Felix, West Clacton, San Vincenzo) makes it clear that all the Roman tesserae from Naples coincide comfortably with the Roman spectrum (Fig. 7b). In fact, they are compositionally similar to the Iulia Felix data as has been shown earlier by means of a PCA (Fig. 2d). A handful of tesserae (lower left on Fig. 7b) may represent Roman antimony decoloured glass. At least half if not more of the previously unassigned samples seem to correspond to Roman tesserae as well, whereas most of the Levantine and HIMT-like samples fall outside or are at the margins of the 95% contour, especially when considering that only very few samples determine the outer limits of the KDE distribution of the Roman reference group (compare Fig. 7a & b). According to the current state of research, HIMT glass emerged in the mid-fourth century (Foster and Jackson, 2009) and the Levantine glass used for the tesserae from San Gennaro resembles the manganese decolourised glass from late fourth-century Jalame (Brill, 1988). The foregoing considerations imply that all the base glasses of the mosaic tesserae from the catacombs of San Gennaro date to between the first and fifth century CE. No new material post-dating the fifth century can be unambiguously identified. The paucity of new opacifying agents such as tin-based opacifiers and calcium phosphate suggest the reuse of old tesserae as opposed to the recycling/re-melting of old cullet for the production of new tesserae with a seemingly older chemical make-up. It has to be acknowledged, however, that the addition of colorants and opacifiers, the mixing of different glasses and prolonged secondary working processes involved in the production of tesserae complicate the detection of recycling in strongly coloured glasses.

Another potential marker to distinguish recycling (i.e. re-melting to produce a new object) from reuse (i.e. the re-employment of old tesserae) and newly made material is the cobalt pigment. As mentioned earlier, the type of cobalt pigment used to produce blue glass undergoes a drastic compositional change sometime between the late fourth and the beginning of the sixth century CE (Gratuze et al., 2018). At San Gennaro, the cobalt blue samples of Roman mixed manganese and antimony glass exhibit the compositional features of the Roman cobalt source, whereas the Levantine and HIMT tesserae were coloured using the new cobalt colorant that is characterised by lower cobalt to nickel ratios. Hence, the elemental signature of the cobalt pigment can help to further separate glass assemblages chronologically, which is particularly significant in light of the substantial overlap and similarities between, for example, Roman (high and low Mn, mixed SbMn) and Jalame-type glasses. Cobalt represents a reliable tool to distinguish different productions, because typically only a limited number of accessory elements are introduced together with the cobalt colorant. The new cobalt pigment may have been introduced at around the same time when the use of antimony both as de-colorant and as opacifier ceased. A mid- to late fourth-century date for these developments seems likely.

4.2. Naples in the Italian context

The comparison of published data of about 500 mosaic tesserae from the Italian Peninsula demonstrates that glass tesserae were systematically reused and/or recycled throughout the first millennium CE (Fig. 7c). Applying the previously defined parameters of Roman spectrum tesserae, the available data show that tesserae dating to the fourth through to the eighth century roughly match Roman glass categories, with few exceptions. In the sixth century, the production of new tesserae appears to have experienced a boost as exhibited by the assemblages from St. Prosdocimus in Padua (Silvestri et al., 2011, 2012, 2014) and San Vitale in Ravenna (Fiori et al., 2004). The degree of reuse and recycling seems to have been dependent to a certain extent on the colours of the glasses. At Padua, for example, the new base glasses and/or opacifiers were found predominantly in relation to gold leaf, green and amber tesserae, while white and different shades of blue corresponded to Roman recipes and represent probably reused material (Silvestri et al., 2014). The increase in the demand for gold leaf tesserae in the sixth century may be linked to artistic changes, because gold leaf tesserae were needed to cover larger surfaces beginning with the fifth century, when gold became the colour of choice for the background of wall mosaics. A surplus of blues and greens may also be indirectly

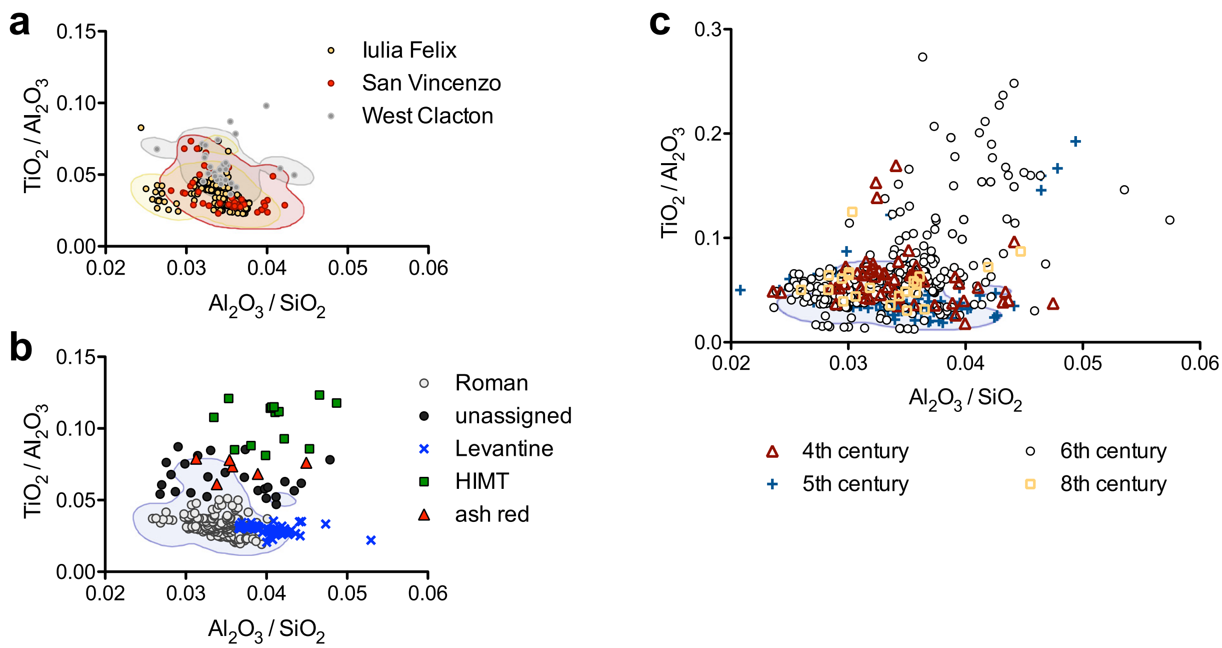


Fig. 7. Compositional spectrum of Roman glass mosaic tesserae. (a) TiO_2/Al_2O_3 and Al_2O_3/SiO_2 ratios of the glass from the Iulia Felix shipwreck (Silvestri, 2008, Silvestri et al., 2008), the mosaic tesserae from West Clacton (Paynter et al., 2015) and San Vincenzo al Volturno (Schibille and Freestone, 2013), including the 95% KDE outlines of the three separate groups generated by the open-access RESET statistical tools (https://c14.arch.ox.ac.uk/resetdb/db.php); (b) the data from San Gennaro in terms of their TiO_2/Al_2O_3 and Al_2O_3/SiO_2 ratios, superimposed with the 95% KDE distribution of the combined Roman group (Iulia Felix, West Clacton, San Vincenzo); (c) the Roman spectrum compared to data from major Italian mosaic assemblages (4th-century Aquileia, Classe, Milan: Maltoni et al., 2016, Neri, 2016, Vandini et al., 2014; 5th-century Faragola, Milan, Piazza Armerina, Ravenna: Gliozzo et al., 2010, 2012, Neri, 2016, Verità, 2010, Verità et al., 2017: 6th-century Classe, Milan, Padua, Ravenna: Fiori et al., 2004, Neri et al., 2013, Silvestri et al., 2011, 2012, 2014, Vandini et al., 2014; 8th-century Classe: Vandini et al., 2014).

connected to the introduction of gold backgrounds. Up to and including the first half of the sixth century, monumental mosaics were often set against dark blue backgrounds and green pasture. Replacing these backgrounds with gold would have made significant quantities of coloured tesserae available for reuse in other contexts. Blue tesserae are among those most extensively reused throughout the period from the fourth through to the eighth century CE.

In terms of base glasses being employed in the manufacture of mosaic tesserae in Italy, the most common types are Roman (low Mn, high Mn, Sb/Mn mixed), followed by HIMT, Foy-2.1 and Foy-3.2. In the sixth century, the latter three base glass groups seem to underlie mostly gold leaf, translucent yellow, red, brown and purple tesserae (Silvestri et al., 2011, 2012, 2014). Naples differs from the other centres of southern and northern Italy in that 25% of the analysed tesserae comprising mostly blues and greens (Table S2) were produced from base glasses similar to the glass from the late fourth-century workshops of Jalame. Not many data of mosaic tesserae from the literature match this Jalame-like Levantine category (Fig. 7c) with a few possible exceptions from fourth-century Aquileia (Maltoni et al., 2016), the fifth-century Villa at Faragola (Gliozzo et al., 2010, 2012) and sixth-century Ravenna (Fiori et al., 2004). The import of new material in the late fourth and/or early fifth century may be related to the intense building activities and urban developments in Naples particularly during the episcopate of Severus (363–409 CE) that testify to the city's prosperity (Arthur, 2002). In order to produce new monumental mosaic decorations, it may have become necessary to supplement the reused material with new supplies, facilitated by a stable political and economic situation. Naples evidently had direct trade links to the eastern Mediterranean, and was in this respect comparable with the exarchate of Ravenna.

If the import of new materials is explained by the building programme and Naples' increasing economic and political clout, the lack of any of the new opacifying techniques that had been introduced in northern Italy during the late antique period can be explained on chronological grounds. Calcium phosphate makes a sudden appearance in the fifth century in Ravenna and Milan, and cassiterite has been used in Milan since the sixth century (Neri, 2016). In the south, calcium phosphate has so far been identified in two tesserae from fifth-century Piazza Armerina in Sicily (Verità et al., 2017). None of the base glass categories nor the opacifiers from San Gennaro post-date the fifth century, indicating that the influx of new material and by extension its demand had ceased by the time new glass compositions and new opacifiers were introduced elsewhere in Italy. Up to the late fourth or early fifth century, Naples received its glass supply for the most part from the Levantine coast. The use of a Levantine (Jalame-like) glass group for the production of a substantial number of tesserae sets Naples apart from other Italian sites, as does the type of greenish black samples for which parallels have yet to be found. These idiosyncrasies of the assemblage from San Gennaro suggest that there existed a regional mosaic workshop supplying a Neapolitan mosaic school in line with art historical evidence. No mosaic workshop has been archaeologically confirmed, but the discovery of a glass-blowing furnace in the Piazza Bovio dating to the fifth or sixth century (Febbraro, 2010) provides proof for some glass working activities in Naples itself.

5. Conclusion

The comprehensive analysis of the tesserae from San Gennaro illustrates the massive and systematic reuse of tesserae over the entire life-time of the catacombs (fourth to eighth/ninth century CE) from the dismantling of ancient decorations, which were likely very abundant in this region. The statistical evaluation of a large number of analytical data of fourth- to eighth-century mosaic assemblages from Italy in comparison with a Roman reference group revealed that the reuse and recycling of Roman material was a common phenomenon within the Italian Peninsula and persisted throughout the first millennium CE.

Our results furthermore confirm that the changes in the production of glass on the Levantine coast from the Roman through to the late antique period are gradual, resulting in a substantial compositional overlap. New colouring and opacification techniques may provide additional criteria for the chronological attribution of samples. At San Gennaro, for example, the use of two different cobalt pigments allowed us to separate the Levantine from slightly earlier Roman glass groups in the strict sense, thus giving a higher temporal resolution. However, the materials added to the base glass in the form of colorants and/or opacifiers and the repeated and prolonged working involved in the production of strongly coloured glasses complicate any attempt to define compositional categories of mosaic tesserae. The compositional spectrum of Roman tesserae is much broader than that of colourless and naturally coloured glasses. In particular, heavy elements such as titanium appear to be more variable, and some geographical variations are discernible. Tesserae from Roman Britain have higher heavy element contaminations compared, for instance, to Italian assemblages (San Gennaro, San Vincenzo). This reveals differential supplies and access to material and suggests that coloured glass for mosaic tesserae was made on a smaller and more localised scale than non-coloured vessel and window glass.

The mosaic tesserae from San Gennaro proved exceptional within the Italian context in that a relatively high proportion of the tesserae correspond to a Levantine Jalame-like glass type, for which only very few examples are known from other Italian sites. A small number of Levantine tesserae (both of the Jalame and the Apollonia types) have been identified among the mosaic assemblages from Aquileia and Ravenna in the north and the Villa of Faragola in the south, suggesting that local demand is directly shaped by economic and/or political processes. After a surge in building activities and the increased influx of new glass in the late fourth or early fifth century, the import of new material to Naples appears to have dwindled. These temporal and regional variations, however, require further investigation of larger datasets from well-defined archaeological and chronological contexts. The patterns we see at San Gennaro may well have something to do with the fact that these are underground catacombs not designed for a coherent, large-scale decorative mosaic programme, for which the reuse of material was deemed perfectly adequate.

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