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LOOSE GLASS TESSERAE AND LOST DECORATIONS: CHRONOLOGY AND PRODUCTION OF MOSAICS FROM GERASA'S NORTHWEST QUARTER**

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Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of loose glass tesserae from the Northwest Quarter of Gerasa/Jerash has enhanced our understanding of the dynamics regulating the production and circulation of glass tesserae in second- to eighth-centuries CE *Jordan and the diachronic development of mosaics at the site. The identification of Levantine and Egyptian compositions (Roman-Mn, Levantine I, HIMT, Foy 2.1) proves the continuous production of mosaics from the second to the seventh centuries. The Levantine I tesserae were made by the recycling and colouring of glass cullet. The gilded tesserae, in contrast, were all of an Egyptian base glass, likely illustrating the import of finished tesserae.*

KEYWORDS: FOY 2.1, GLASS RECYCLING, HIMT, JORDAN, LEVANTINE I, MOSAICS, ROMAN GLASS TESSERAE AND BYZANTINE GLASS TESSERAE

INTRODUCTION AND AIMS

Since 2011, the Danish–German Jerash Northwest Quarter Project (DGJNWQP) has been investigating the longue durée development of a 4-hectare area in Gerasa situated within the Roman walls at the highest point of the city (Lichtenberger and Raja 2018a) (Figure 1). Gerasa belonged to the Decapolis and flourished at least from the early Roman period until the mid-eighth century

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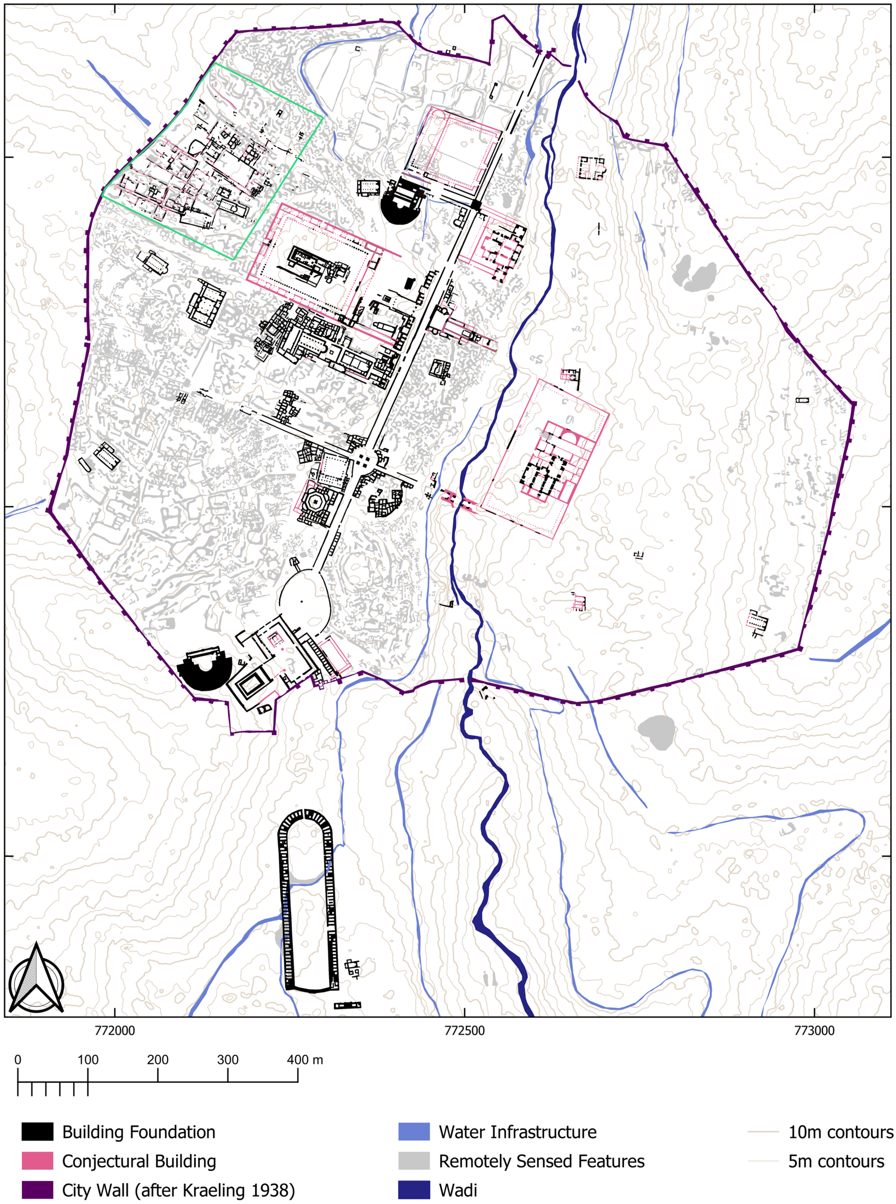


Figure 1 *Scaled plan of Gerasa, with the North Western Quarter outlined in green at top left. Source: Elaboration of plan from Lichtenberger et al. (2019).*

CE when it was devastated by an earthquake that interrupted the settlement activity in this part of the site (Lichtenberger and Raja 2019b). During the Roman period it was a city of approximately 80 ha with residential quarters and public buildings, as well as some outstanding monuments (Lichtenberger and Raja 2015), and one of the largest sanctuaries ever constructed in the Roman world: the Artemision (Brizzi 2018). From the fifth century onwards, numerous churches were built, seven during the reign of Justinian I alone (527–65 CE), testifying to Gerasa's continuous integration into the Byzantine Empire (Crowfoot 1931, 1938; Michel 2011, 224–76).

The DGJNWQP has been concerned with the diachronic study of the production techniques and materials of mosaics (Lichtenberger and Raja 2017). Considering that the archaeological record for *in situ* mosaics from the Northwest Quarter is extremely scarce and fragmentary, the primary aim of this article is to identify the chronology of the mosaics from the Northwest Quarter during the whole period of life of the site, using as evidence the chemical composition of loose glass tesserae retrieved from well-documented secondary contexts (Kalaitzoglou *et al*. 2013, 2015b). The results of the compositional analysis are discussed in light of their urban and regional context to elucidate the dynamics of glass production and supply to Jordan from the Roman to the Byzantine periods, a time when the composition of glass and its circulation around the Mediterranean underwent some fundamental changes. While the chemistry of Imperial Roman glass is generally homogeneous, showing only minor variations (Silvestri *et al*. 2008; Paynter and Jackson 2018), the fourth century was marked by a certain degree of diversification in ancient glassmaking and the appearance of new Egyptian and Levantine compositions (Brill 1988; Nenna *et al*. 2000; Foy *et al*. 2003; Phelps *et al*. 2016; Freestone *et al*. 2018).

Based on published data of glass assemblages from ancient Jordan, regional trends in the distribution of known compositional groups emerge. Whereas between the fourth and eight centuries Levantine glass is virtually ubiquitous, Egyptian compositions are rare (Schibille *et al*. 2008; Marii and Rehren 2009; Abd-Allah 2010, 2012; Rehren *et al*. 2010; Schibille *et al*. 2012; El-Khouri 2014; Ali and Abd-Allah 2015; Al-Bashaireh *et al*. 2016b , b; Barfod *et al*. 2018). The Egyptian finds are presently limited to one gold-glass tessera from the Petra Church (Marii and Rehren 2009), a few lamps from the sanctuary of Deir ‘Ain ‘Abata (Rehren *et al*. 2010) and vessels from the Petra Great Temple (Schibille *et al*. 2012). The proximity of Gerasa to the Levant, where primary furnaces were active, would suggest easy access to raw glass (Brill 1988, Phelps *et al*. 2016, *passim*). The analytical work conducted on fifth- to sixth-centuries vessels from the Northwest Quarter (Barfod *et al*. 2018) and on fifth- to eighth-centuries vessels from Umm el-Jimal, however, showed the almost exclusive use of recycled glass (Al-Bashaireh *et al*. 2016a, 2016b). This intensive recycling is quite unexpected and is also documented during the third and fourth centuries in vessels from Petra and Khirbet et-Tannur (Schibille *et al*. 2012) and, at the beginning of the fifth century, in the window panes, vessels and mosaic tesserae from Petra (Marii and Rehren 2009; Rehren *et al*. 2010). The latter are presently the only references available for the chemical composition of glass tesserae in Byzantine Jordan. This article expands the current data set, thereby improving our understanding of the regional dynamics of glass production and consumption in the region.

The mosaics of Gerasa and the use of glass tesserae

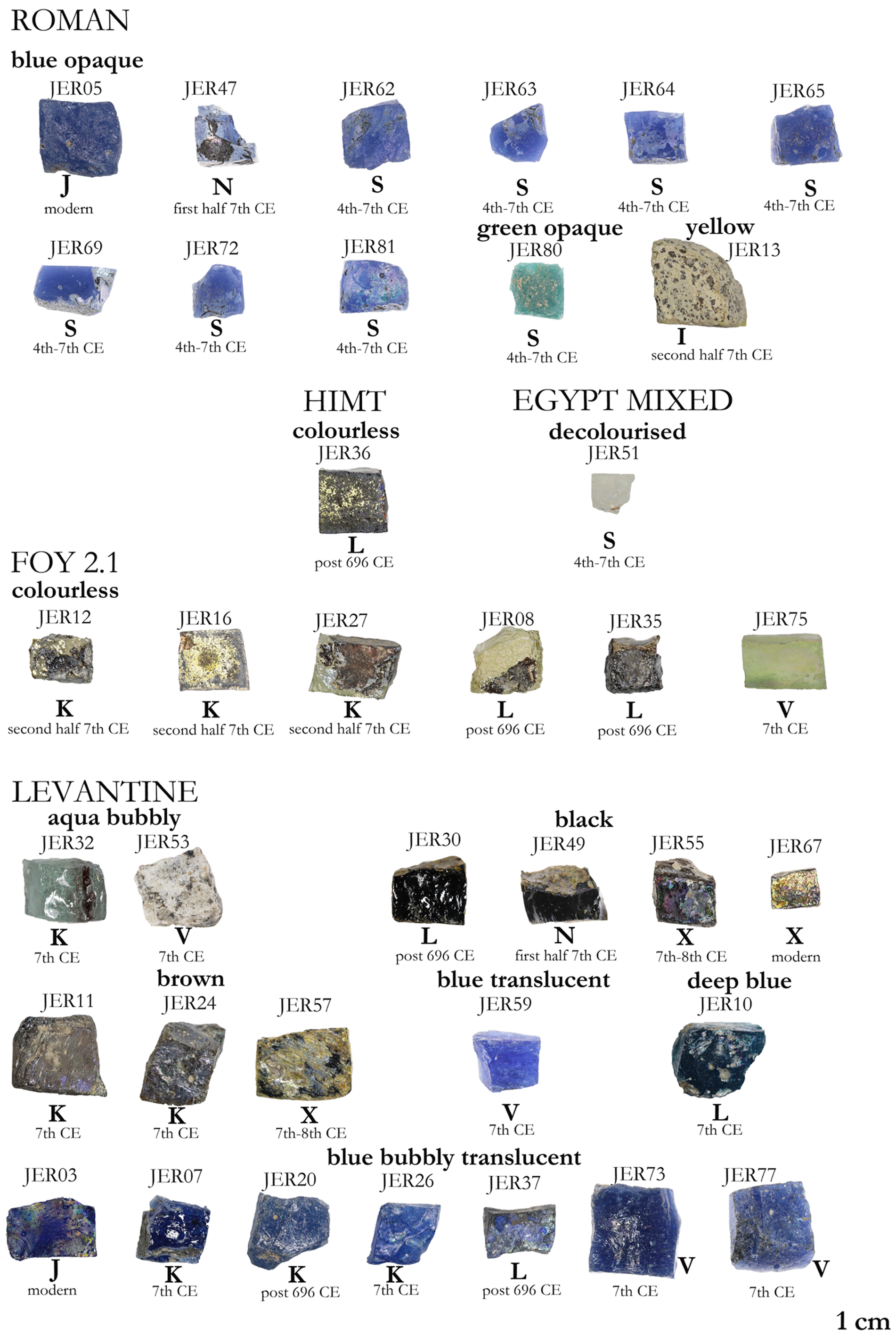
Glass tesserae were used in both floor and wall mosaics of Roman and Byzantine date. Roman mosaics have only sporadically been uncovered because most of the Roman residential quarter likely remains buried under the modern town. An exception is a high-quality figurative mosaic floor (Talgam 2014, *passim*) and some recently discovered fragments (Lichtenberger and Raja 2017, 29). Late Roman and Early Byzantine mosaics have been preserved in the Synagogue (Piccirillo 1993, 280; Dvorjetski 2005; Haensch *et al*. 2016) and the so-called Cathedral and Glass Court (Biebel 1938, 309–11; Browning 1982, 94–5; Piccirillo 1993, 283). Byzantine Gerasa is famed for its churches richly decorated with floor and wall mosaics, starting in the later fifth century (Burdajewicz 2020, *passim*). The numbers of mosaics increased significantly in the sixth century, but declined again in the early seventh (Piccirillo 1993, 270–98; March 2009, 118–19; Talgam 2014, 130–1). A large proportion of the mosaics are floors in religious spaces, but approximately one-third of those with decorated pavements had wall mosaics, too. Mosaics are also known from civic structures (Piccirillo 1993, 283) and what may be private houses (e.g., Talgam 2014, 372–3, *passim*). To this corpus, the DGJNWQP has added the late sixth-century Mosaic Hall, which connects with the Synagogue Church (Haensch *et al*. 2016; Lichtenberger and Raja 2017; Lichtenberger and Raja 2018a, 62–4), and an early Islamic house destroyed in the earthquake of 749 CE (Lichtenberger and Raja 2017).

The materials and colours of these mosaics have not been systematically investigated. Existing publications show that in the Roman period, green and blue tesserae in particular were made of glass, identified, for example, in the fragments of the Mosaic of the Muses and Poets in Berlin (Kriseleit 2000, 35). Glass tesserae were also found in the floor of the Church of Bishop Genesios, one of the latest churches known at Gerasa, built in 558–59 CE (Harmaneh and Abu-Jaber 2017, 29). A few churches from the second half of the sixth century have glass tesserae in both their floors and walls: the Church of Bishop Isaiah (Clark 1986, 307–11), the *diakonia* of the Propylaea Church (Talgam 2014, 179) and the Cross Church (Arinat *et al*. 2014, 44–5). There is also evidence for the embellishment of the naves and apses from the mid-fifth to the mid-sixth centuries in the Church of the Prophets, Apostles and Martyrs (Talgam 2014, 179), the Church of St Theodore (Crowfoot 1938, 196; Browning 1982, 95–6), the Church of St George (Talgam 2014, 179), the Church of St John the Baptist (Crowfoot 1938, 243–4), and the Church of SS Cosmas and Damianos (Crowfoot 1938, 196).

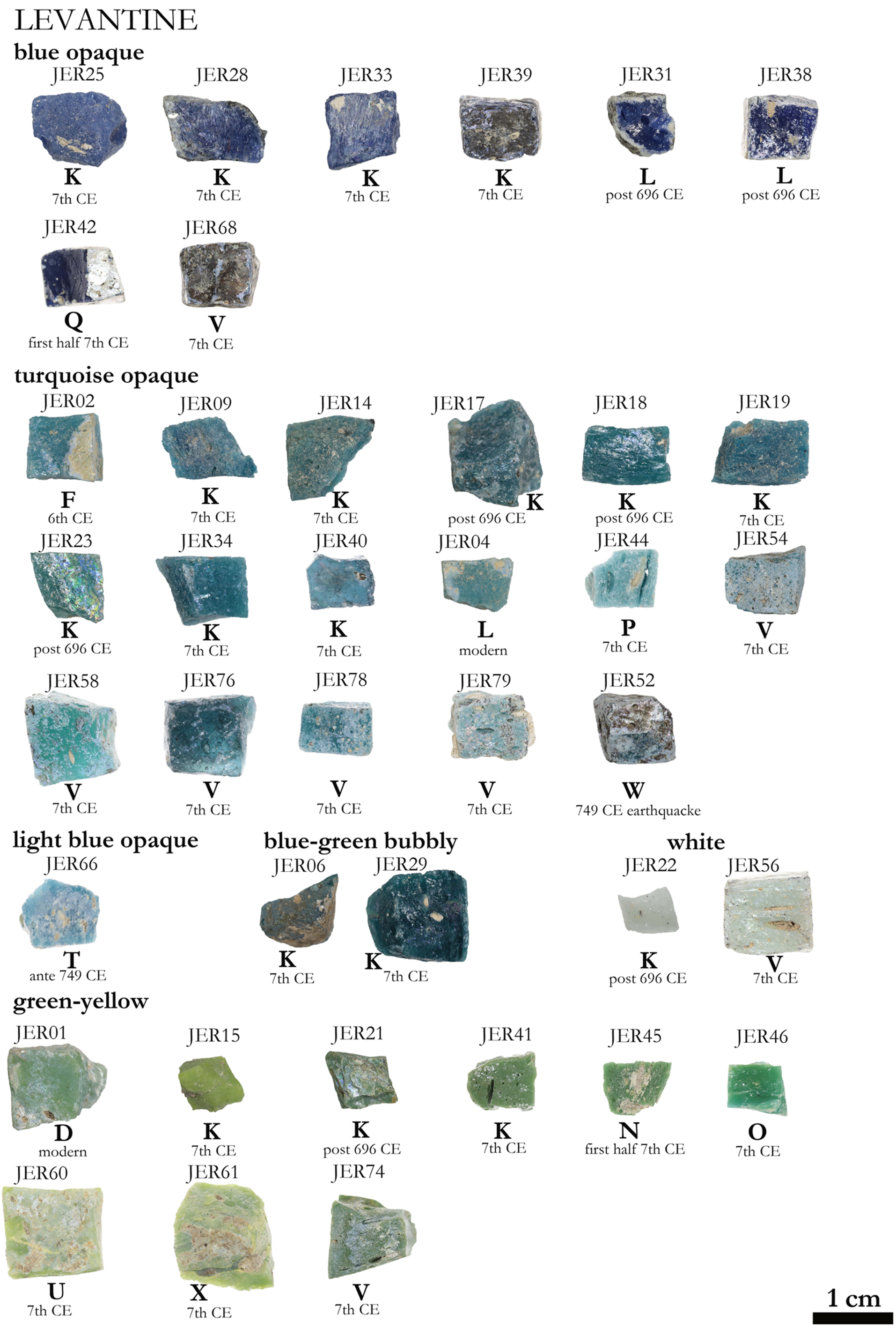
Beyond the primary evidence of tesserae and mosaic fragments *in situ*, abundant material survives that relates to their making, including two important deposits in the cathedral complex, one of which includes the famous 'cakes' from the Glass Court (Biebel 1938, 517–18). Primary and secondary uses of these buildings are significant. Many continued to function until at least the mid-eighth century CE with their fabric, including the decorative materials, often spoliated and reused (Baldoni 2018).

MATERIALS AND METHODS

A group of 76 glass tesserae was selected for analysis. These tesserae had been excavated between 2013 and 2016 in the Northwest Quarter from backfills dating from the early fourth and eighth centuries (Kalaitzoglou *et al*. 2013, 2014, 2015a, 2015b, 2016). The tesserae considered in this study include all the colour variants documented at the site, and were collected from 15 different trenches, covering the entire excavated areas (see Figures 2 and 3 and Table S1 in the additional supporting information). The samples were cleaned and analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at IRAMAT-CEB in Orleans, France, without further preparation. The instrumental set-up consists of a Resonetics M50E excimer 193 nm laser and a Thermo Fisher Scientific ELEMENT XR mass spectrometer. The standard working conditions are a 5 mJ energy, 10 Hz pulse frequency and a beam diameter ranging from 30 to 100 μm (Gratuze 2013). Only one spot analysis was performed for each sample, while the standard reference material was analysed at regular intervals to allow for the calculation of the response coefficient (k) for each element. Accuracy and precision data for the reference material Corning A–D and NIST612 are given in Table S2 in the additional supporting information. For major and minor elements, both accuracy and precision are typically within 5% and within 10% for trace elements, with few exceptions, notably lime and alumina in Corning A and C (see Table S2).



Figures 2 and 3 *Specimens from the North Western Quarter divided by base glass composition and colour, with an indication of sample number, trench letter and date of the backfill.*



Figures 2 and 3 *Continued*

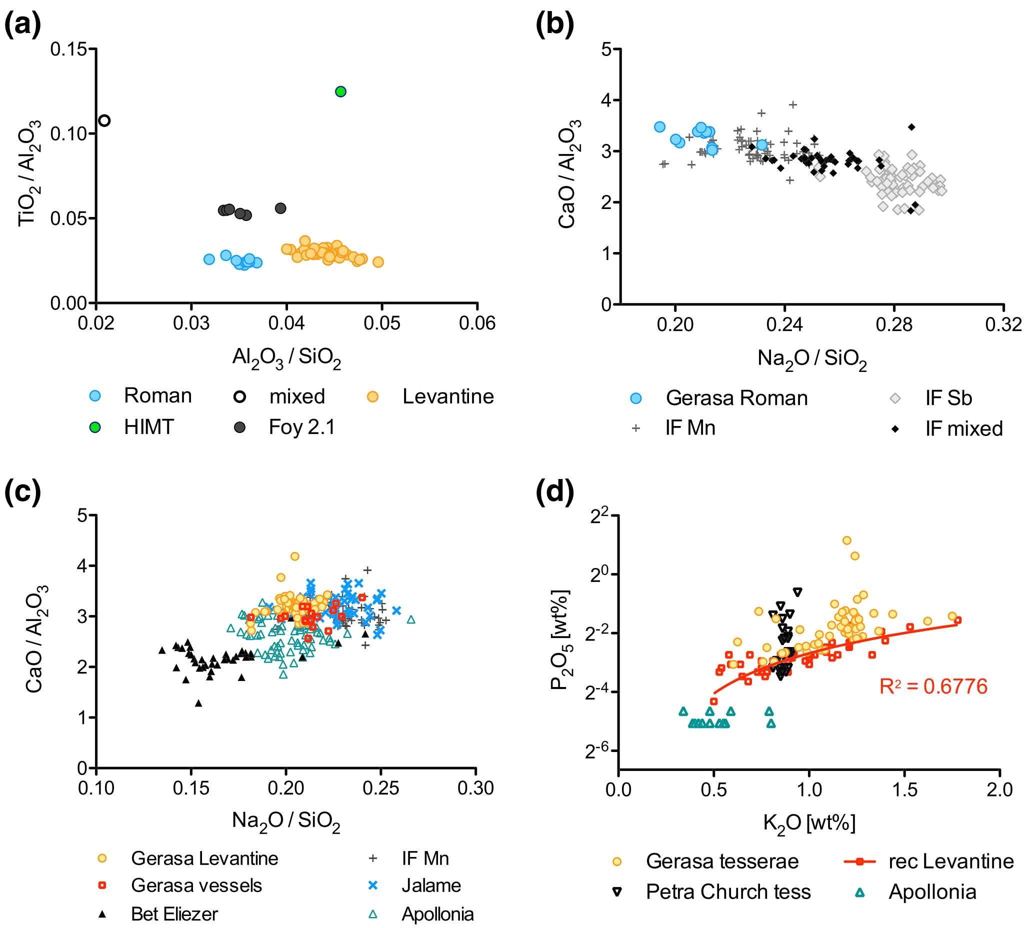


Figure 4 *Base glass characteristics of the Gerasa tesserae divided by compositional groups. (a) The ratios of Al_2O_3/SiO_2 and TiO_2/Al_2O_3 reflect the feldspar and heavy mineral composition of the silica sources and separate the different base glass groups. (b) The Na_2O/SiO_2 and CaO/Al_2O_3 ratios of the Roman tesserae from Gerasa compared with different Roman glass reference groups (Roman Sb, Roman Mn, Roman mixed) based on the glass finds from the Iulia Felix shipwreck (IF). (c) Comparison of the Na_2O/SiO_2 and CaO/Al_2O_3 ratios of the Levantine I tesserae and vessels from Gerasa with primary production groups from the Levantine coast, including Mn glass from the Iulia Felix shipwreck (IF Mn) and glass from Apollonia, Bet Eliezer and Jalame. (d) The K_2O and P_2O_5concentrations of the Gerasa tesserae compared with glass from the primary furnace at Apollonia, recycled Levantine glasses from Jordan and tesserae from the Petra Church in Jordan (y-axis in log_2). Sources: Iulia Felix shipwreck (Silvestri 2008; Silvestri et al. 2008); Jalame (Brill 1999); Apollonia (Brems et al. 2018; Freestone et al. 2008; Phelps et al. 2016); Bet'Eliezer (Freestone et al. 2000); Levantine vessels glass from Gerasa (Barfod et al. 2018) and Umm el-Jimal (Al-Bashaireh et al. 2016a), window panes (Schibille et al. 2008) and Petra Church tesserae (Marii and Rehren 2009).*

RESULTS

All the tesserae are silica-soda-lime glass, with low Mg and K oxides (< 2 wt%), denoting the use of natron as a fluxing agent (see Table S1 in the additional supporting information). This result is in line with the chronology of the site and follows the dominant trend in glassmaking from the Hellenistic period to the ninth century CE (Sayre and Smith 1961; Gratuze and Barrandon 1990; Shortland *et al*. 2006). Oxide ratios of Al_2O_3/SiO_2 and TiO_2/Al_2O_3 are markers of the feldspars and heavy minerals introduced with the silica source (Freestone *et al*. 2018) and distinguish different base glasses according to their provenance and date (Figure 4, a). A first group (n = 11) with lower TiO_2/Al_2O_3 (< 0.028) and moderate Al_2O_3/SiO_2 ($0.032 < Al_2O_3/SiO_2 < 0.037$) ratios can be identified as Roman glass made from the first to fourth century CE (Paynter and Jackson 2018, *passim*). Specifically, the tesserae are consistent with Roman Mn-decoloured glass produced on the Levantine coast, as judged by their Na_2O/SiO_2 ($0.194 < Na_2O/SiO_2 < 0.213$) and CaO/Al_2O_3 ratios ($3.022 < CaO/Al_2O_3 < 3.38$) in comparison with Roman glass from the Iulia Felix shipwreck, which sunk in the Adriatic Sea in the third century CE (Figure 4, b) (Silvestri 2008; Silvestri *et al*. 2008; Freestone 2015). The absence of mixed Mn-Sb compositions suggests the glass was coloured in secondary workshops handling only Roman Mn-decoloured raw glass and probably located in proximity to the primary workshops on the Levantine coast. The first- to fourth-centuries chronology assigned to the Roman tesserae is confirmed by the use of Sb-based compounds as opacifiers: Ca antimonate for the blues and Pb antimonate for the yellows and greens (see Table S1 in the additional supporting information). These opacifiers are widespread during the Hellenistic and Roman periods, until the third century, when a new technology gradually emerges, replacing the antimonates by stannates (Verità *et al*. 2013, *passim*).The majority of the tesserae (n = 57), with low TiO_2/Al_2O_3 (< 0.05) and slightly higher Al_2O_3/SiO_2 ($0.04 < Al_2O_3/SiO_2 < 0.05$) ratios, as well as higher K, Ca and lower soda levels compared with Roman Mn glass, are consistent with Levantine I glass (Freestone

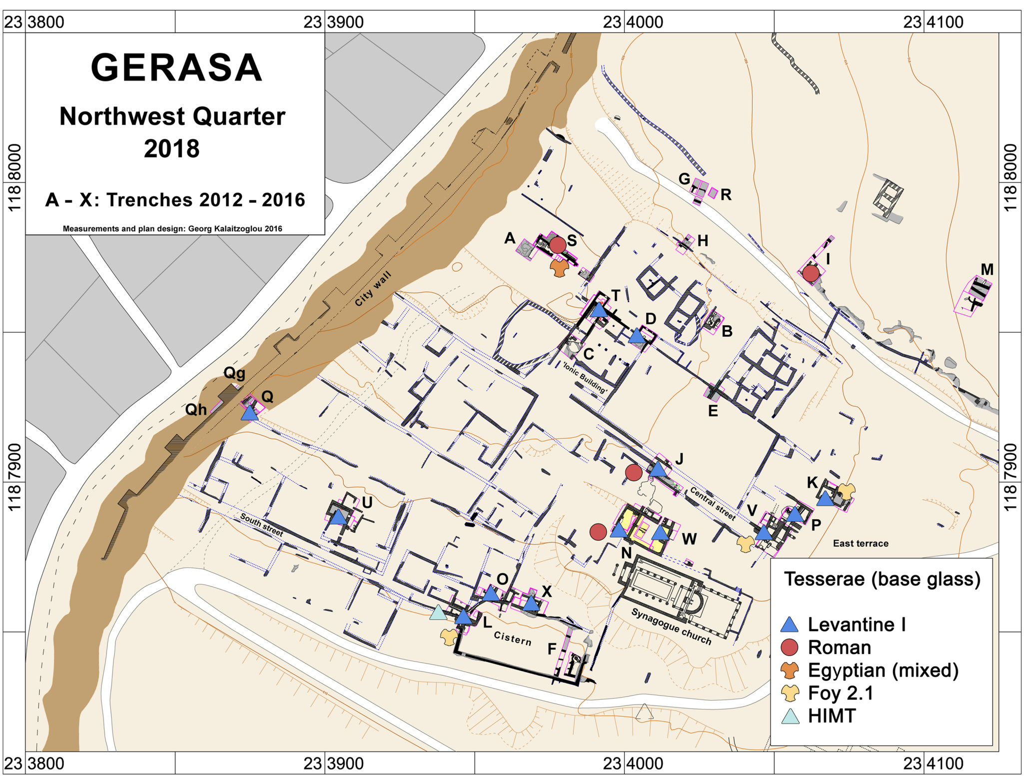


Figure 5 *Distribution of the tesserae, divided by compositional group, in the trenches investigated during the 2011–16 excavation campaigns.*

et al. 2008; Phelps *et al*. 2016; Schibille *et al*. 2017) (Figure 4, a). Levantine I has been defined based on the remains from the primary production site of Apollonia (Arsuf, Israel), dating to the sixth and seventh centuries CE (Phelps *et al*. 2016, *passim*), and is distinct from the fourth-century CE glass from Jalame (Brill 1988). A comparison of Na_2O/SiO_2 and CaO/Al_2O_3 reflects the progressive decrease in both ratios in Levantine productions from the first to the eighth centuries CE (Figure 4, c). Most of the tesserae fall into the overlap zone between the Apollonia-type Levantine I, Roman-Mn and the Jalame glass, while later eighth-century Bet Eli'ezer/Levantine II glass is clearly absent. Thus, it appears probable that the base glass of these tesserae is a mix of Apollonia type Levantine I and earlier Levantine glass types. A similar mix of Apollonia and Roman-Mn glass was observed in the vessels from the Northwest Quarter (Barfod *et al*. 2018). Compared with Levantine I raw glass (Phelps *et al*. 2016), most of the tesserae have higher concentrations of K and P oxides, and lower Cl (see Table S1 in the additional supporting information). The volatilization of Cl, together with the enrichment in P and K is a well-known effect of the repeated exposure of the glass to the fuels of the furnace (Schibille and Freestone 2013).

Glass assemblages from Jordan frequently show a strong positive correlation between K and P oxides, which has been attributed to the use of olive stones as fuel (Barfod *et al*. 2018, *passim*). Interestingly, the analysis of tesserae showed no such positive correlation due to the opacifying agent used in these tesserae (Figure 4, d). Compositional evidence points to the use of Ca phosphate obtained from the calcination of bones for the opacification of the white, blue and turquoise tesserae. The use of bone ash as an opacifier is known from the beginning of the fifth century CE in several Mediterranean and Near Eastern sites (Silvestri *et al*. 2016; Neri *et al*. 2017, *passim*; Maltoni and Silvestri 2019). The identification of Ca phosphate is not straightforward, especially in recycled glass that has elevated P due to recycling practices. A comparison with the tesserae from the Petra Church is instructive, where crystals of Ca phosphate were detected by electron microscopy (Marii and Rehren 2009). In the tesserae from Gerasa as well as Petra Church, the elevated P content is independent of the potash, which is in stark contrast to the positive correlation in the vessel glass (Figure 4, d). The latter have $P_2O_5 < 0.2$ wt%, which can therefore be considered to be approximately the limit separating the recycled from the Ca phosphate opacified compositions. The concentration of P_2O_5 in the tesserae above this threshold varies significantly ($0.12 < P_2O_5 < 2.23$) and the texture of the glass ranges accordingly from opaque to bubbly translucent. This chemical and textural variability may reflect the application of an empirical opacification process.

The use of Ca phosphate in the white, blue and turquoise tesserae as well as Pb stannate in the green and yellowish-green tesserae further confirms the chronological separation of the Roman and Levantine samples. Another piece of evidence comes from the Co colourant used to obtain blue (see Figure S1 and Table S1 in the additional supporting information). The blue tesserae assigned to the Roman group have typically low Ni and therefore high Co/Ni ratios, whereas starting in the fourth century, Ni concentrations increase resulting in lower Co/Ni ratios (Gratuze *et al*. 2018).

All the gilded tesserae ($n = 8$) are characterized by their different base glass compositions (Fig. 2 and Table S1, in the additional materials). The glass of these tesserae exhibits a variety of tinges, ranging from perfectly decoloured to green and amber-yellow. This colour variation was a quality intentionally employed to modify slightly the hue of the gold foil (Neri *et al*. 2016). One of these tesserae (JER 38) that has high Ti, Va, Cr, Zr and Hf levels is a so-called HIMT glass (high-Fe, Mn, Ti) that dates to the fourth and fifth centuries CE and is assumed to originate in northern Egypt (Freestone *et al*. 2018, *passim*). A group of six tesserae has a lower TiO_2/Al_2O_3 ratio and can be attributed to the Foy 2.1 group, an Egyptian glass that has turned up in the archaeological record in Europe and across the Mediterranean, dating to the fifth and sixth centuries CE (Foy *et al*. 2003; Ceglia *et al*. 2017; De Juan Ares *et al*. 2019). One sample (JER 075) exhibited elevated transition metals, notably Co, Cu and Fe, most likely due to recycling. The Co/Ni ratio in this tessera is high and may indicate recycling of some older Roman glass. One tessera (JER 051) that has surprisingly low Ca and alumina concentrations and high TiO_2/Al_2O_3 ratios is an outlier that cannot be affiliated with any known primary glass groups at present. It contains significant amounts of Sb and Pb as well as elevated Zr, Eu and Hf (see Table S1 in the additional supporting information). These features suggest that the base glass of this tessera resulted from a mixture of Roman Sb-decoloured glass with a material high in silica-related contaminants. Its close affiliation with HIMT glass allows it to be attributed to an Egyptian origin as well.

DISCUSSION

The chemical composition of the mosaics from the Northwest Quarter of Gerasa outlines a well-defined chronological sequence for glass tesserae (Figure 5). Roman glass from the first to the fourth centuries CE is attested sparingly and concentrated in sectors occupied by Roman complexes from the second century onwards. At this time, Gerasa seems to have entered a long period of prosperity (Lichtenberger and Raja 2015; Lichtenberger and Raja 2018b). Public buildings and houses belonging to high-ranking citizens were probably decorated with mosaics. The absence of mixed and recycled compositions among the early finds indicates the availability and use of first-hand material.

The picture is different for the Levantine I tesserae, which are made from recycled glass and are scattered across the whole site. The Levantine tesserae can be dated from the sixth to the seventh centuries, a period of lively building activity in Gerasa (Lichtenberger and Raja 2019a). In this phase, the use of the Roman sanctuaries ended and numerous churches were erected (Michel 2011, 224–74). The desire to decorate the churches with glass tesserae certainly led to a sudden increase in the local demand for coloured glass. The identification of recycled glass, regularly used for the making of tesserae, offers further insights into the wider context of glass production and consumption. It reinforces a more general pattern of distribution of recycled colourless glass in Byzantine Jordan, suggesting that from the beginning of the sixth century, the availability of raw glass was somewhat limited, and the high demand of glass was met by establishing systematic collection and recycling processes. We cannot exclude a priori that any fresh raw glass was mixed with the cullet, but it is clear that the latter was the main source of glass used in Byzantine Jordan. Colouring is likely to represent the final stage of this practice, probably performed on-site or nearby. The current archaeological evidence of the practice of colouring cullet is very poor and limited to the western Mediterranean, where, at least from the fourth century CE, coloured glass was produced by adding mosaic tesserae to colourless cullet (Boschetti *et al*. 2016). The composition of the recycled tesserae from the Northwest Quarter reflects a different process. The low Co/Ni ratios observed in the blue tesserae and the negligible concentrations of Sb in the white, blue and yellows show that the colour was obtained by adding fresh colourants and opacifiers to glass cullet. With the exception of the HIMT gilded tessera, which dates to the fourth or fifth century, the gold tesserae are roughly contemporary with the Levantine group, and can thus be also associated with the decoration of churches. Gold tesserae with a Levantine base glass composition were realtively common in Byzantine and early Umayyad Palestine, where they might have been manufactured (Gorin-Rosen 2015, Adlington *et al*. 2020). This makes the exclusive import of Egyptian gold-leaf tesserae to Gerasa

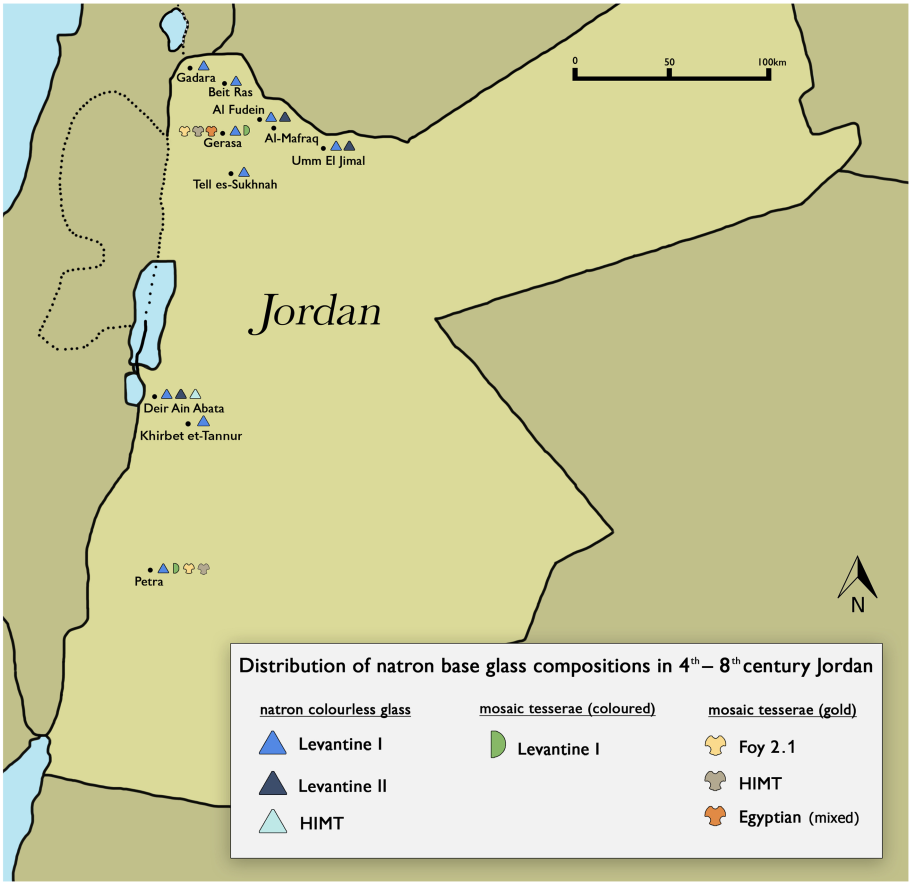


Figure 6 *Base glass compositions thus far identified in fourth- to eight-centuries Jordan. Sources: Schibille et al. (2008, 2012); Marii and Rehren (2009); Abd-Allah (2010, 2012); Rehren et al. (2010); El-Khouri (2014); Ali and Abd-Allah (2015); Al-Bashaireh et al. (2016a, b); Barfod et al. (2018).*

particularly intriguing, especially in view of the general lack of Egyptian primary compositional groups in Jordan at this time (Figure 6).

CONCLUSIONS

The evidence presented here indicates that mosaics with glass tesserae were common at Gerasa at least from the second to seventh centuries CE. While the Roman tesserae were likely manufactured on the Levantine coast, the later Levantine I tesserae were probably produced in the surrounding region, if not on-site. The frequent presence of older tesserae in late Byzantine and Umayyad backfills, and the lack of eighth-century glass compositions, proves the possibility that mosaics were made with reused tesserae during the period immediately before the earthquake of 749 CE, which devastated large parts of the city. It is also possible that tesserae were simply collected for the purposes of recycling. The gold tesserae are among the few Egyptian glasses ever documented in Byzantine Jordan and were probably imported as special products. The reasons for importing gold tesserae from Egypt, and not from the nearby Levantine coast, remains difficult to explain, but the association between Levantine tesserae and Egyptian gold glass at both Gerasa and Petra attests to a broader regional model and, potentially, points to overlooked trading networks, which demand further investigation.

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PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Supporting information.

Data S1. Supporting information.

Table S2. Average laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) data of glass standards compared with published values for Corning glass standards A–D and NIST SRM 612.