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TITOLO TESI

***Fragile* connections, persistent methodology**

A *tailor-made* archaeometric protocol to investigate technological and cultural issues in the supply of glass tesserae under the Umayyad caliphate

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"*We're all stories, in the end*"

Matt Smith, as Doctor Who

Abstract

In the panorama of ancient glass manufacture, several aspects concerning the glass industry under the Umayyad caliphate still need to be investigated. While our knowledge of Umayyad glassware has been enhanced by recent research thanks to combined typological and archaeometric studies, when considering mosaic glass tesserae even a preliminary scenario is lacking.

A pivotal issue addressed in this research concerns the effective relationship between Umayyad and "Byzantine" mosaic manufacture and technology. On the one hand, several Muslim literary sources claim that Umayyad caliphs got from the Byzantine emperor workmen and materials to construct and decorate religious buildings, like the Prophet's Mosque at Medina, the Dome of the Rock and the Great Mosque of Damascus. On the other hand, the issue of the sent tesserae has arisen several problems primarily due to the reliability of the sources themselves. In addition to that, legacies other than Byzantine stem from other documents like the 8th CE Aphrodito papyri (reporting an official correspondence between the Governor of Egypt and the Prefect of the District of Aphrodito), referring to materials and skilled craftsmen being sent from Egypt to Jerusalem and Damascus, to collaborate on the construction of the al-Aqsa mosque and the Great Mosque.

The research is focused upon an archaeometric characterisation of three assemblages of Umayyad glass tesserae from the sites of Khirbat al-Mafjar (Jerico), the Dome of the Rock (Jerusalem) and the Great Mosque (Damascus). The adoption of a tailor-made multi-analytical approach allowed achieving remarkable outcomes on both the base glass (EPMA, LA-ICP-MS) and the colourants and opacifiers (NCS Index, VIS-RS, SEM-EDS, m-Raman, XRPD). Framing the data in the broaden scenario of mosaic glass tesserae consumption and supply in the eastern Mediterranean basin, preliminary hypotheses on models for the manufacture and trade of glass tesserae under the Umayyad will be discussed and evaluated.

Apart from the archaeological relevance of the assemblages under study and the contribution they can give to the history of mosaic glass tesserae technology and supply, undertaken research will also show how the application of a "best practice" and tailor-made protocol on mosaic glass tesserae can be the starting point for providing outcomes able to further enhance our knowledge of this peculiar (and, to date, still fragmentarily investigated) material category.

Introduction

Nothing can be considered more storytelling than material culture: wisely and carefully framed in its historical and social context, material culture can speak and tell the story of ancient societies by unravelling the relationships between people and their things.

The lives of people and the lives of things cannot be separated: objects are not inert but invested by meanings which change over time.

For this reason, the study of material culture needs to be focused upon objects, their properties, the materials that they are made of, and the ways in which these material facets are central to an understanding of culture and social relations.

As a material, glass is a sophisticated custodian of our material culture.

Playing on words, we could say that the products of glass industry are "looking glasses" of the age in which they were made.

Research into ancient glass production, manufacture and supply has provided fascinating insights into the technology of this multifaceted and captivating material. Especially in the last decades, our knowledge of the distribution of glass across time and space has greatly increased, resulting in an almost "*kaleidoscopically colourful*" scenario. Though several geographical and chronological gaps still exist, the development of a larger picture – focused upon the definition of organisational models of ancient glass industries, the recognition of several major glass families, as well as a better understanding of trade networks – has started being defined.

If, however, a detailed look is given to the plethora of case studies that can be found in the literature, it appears that a specific category of glass-made objects, that is mosaic tesserae, has always been suffering from a somewhat marginal attention compared to glassware. It seems that tesserae have been conceived as a kind of fringe, borderline glass product, unfeasible to be studied according to typological criteria able to define - as it is commonplace for glassware - a distribution of peculiar shapes and decorative features.

Consequently, the present and actual knowledge of production technology, manufacture and supply of mosaic glass tesserae across time and space is extremely scarce and fragmentary, with the result of having more ungiven answers than answered questions.
In the history of ancient mosaic, and, by extension, in the field of study related to glass tesserae manufacturing technology and consumption, a pivotal (as well as extremely debated) issue to be investigated is the current relationship between early Islamic and Byzantine mosaic manufacture and technology, with specific reference to both craftsmen and tesserae supply.
At the dawn of the Umayyad caliphate (661-750), the first Islamic dynasty, the relations with the Byzantines were ruled by both attraction and opposition; besides, it is known that the most noticeable legacy of the Byzantine imperial heritage is the Umayyad policy of erecting imperial religious monuments.
On the one hand, Muslim literary sources claim that Umayyad caliphs requested and got from the Byzantine Emperor both workmen and materials (like glass tesserae) to construct and decorate several religious buildings, like the Prophet's Mosque at Medina, the Dome of the Rock and the Great Mosque of Damascus.
On the other hand, the issue of the sent craftsmen and materials has arisen some problems due to the reliability - as well as the interpretation - of the sources themselves: should these texts be read as propaganda pieces aimed at enlightening the power of the Muslim rulers or, on the contrary, could they imply that the trade between Muslims and Byzantines went on despite their rivalry? Answers to these questions still need to be provided.
"*Fragile* connections, persistent methodology" is the title of this Ph.D. Thesis. The expression "*Fragile* connections" relates to the prime aim of the research: shedding light on the key – and thorny – issue of the connection between Umayyad and Byzantine mosaic manufacture and technology, by means of an in-depth archaeometric characterisation of three assemblages of glass tesserae from the *qasr* of Khirbat al-Mafjar, the Great Mosque of Damascus and the Dome of the Rock.

Since the integration of analytical data into meaningful archaeological research frameworks is an enduring and essential need – and it is a duty, if one does not want to risk obtaining from analyses only numbers –, this thesis has been structured as moving from general frame to detail, and, then, reporting the details back to the general context.

The importance of the role played by material culture in understanding an age of transition, namely the Byzantine-Islamic transition, will be the starting point, followed by an excursus on the state of knowledge about glass (its manufacture, consumption and supply) under the Islamic domain in the East, with a specific focus on the Umayyad period. The ongoing enigma concerning the gathering of glass tesserae for the mosaic decoration of Umayyad religious buildings will be discussed, with the aim of introducing reasons underpinning the choice of the materials selected for this research. Results obtained by scientific analyses will been shown and discussed. Achieved data will be then framed in a broaden scenario and compared to historical sources, with the aim of telling the story of the gathering and supply of tesserae under the Umayyad caliphate. To conclude, further developments of this research will be highlighted.

Back to the title of this thesis, the expression "persistent methodology" refers to what could be defined as a secondary objective of the research, gradually emerged during these three years of work.

Morphologically speaking, mosaic glass tesserae are small cubes/parallelepipeds made of opaque coloured, translucent or transparent glass. Since we cannot benefit from the support of any chrono-typological study, as it happens for glassware, the contribution of archaeometry to the study of mosaic glass tesserae plays an even more fundamental role, and the validation of a "best practice" analytical protocol is needed.

It will be shown, in the following pages, how, together with the paucity of available data, our fragmentary knowledge of manufacturing technology and circulation of glass tesserae is also linked to the lack of a shared analytical approach: tough a number of techniques are utilised to characterise both the base glass and the colourants and opacifiers, the absence of a shared analytical approach often results in the impossibility of punctual data comparisons aimed at outlining a reliable scenario concerning manufacturing processes and supply of glass tesserae.

Moving from this premise, assemblages under study have, thus, also been used as “paradigmatic tests” in the definition of such a “best practice” protocol, starting from an exact and suitable evaluation of the chromatic properties (also working as a preliminary and objective selection criterion), and continuing with an in-depth characterisation of the micro-structure and the base glass.

After all necessary critical revisions and, if needed, integrations, the possible adoption of such a protocol could function as a re-starting point for the analysis of glass tesserae, aimed at achieving result to be turned into highly comparable datasets and working, therefore, as premise for wider debates about production technology and trade networks of glass tesserae across time and space.

I opened this introduction by stressing the intrinsic storytelling nature of material culture.

For every object, there is a story to tell.

And some objects have told me a story that deserves to be shared.

Chapter 1

From Byzantium to Islam

Understanding an age of transition through material culture

"*Whatever term one chooses to apply in a given context – whether it is objects, material culture, things or goods – one needs only look to their immediate surroundings to find examples. It is this endless diversity and ordinariness of subjects for study that makes material culture fascinating and fundamental to understanding culture*."

(Woodward 2007, p.16)

Though the upsurge of Islam, with the Arab conquest of the Near East, has long been the object of extensive studies and debates, it is still, to some extent, a jigsaw puzzle.

Was the shift from Byzantine to Islamic rule bloody and devastating, or was it reasonably peaceful? Did the Near East change rapidly or gradually?

These are among the main questions that remain without clear answers, one of the key reasons being the scarcity of available literary sources: whilst Greek and Syriac chronicles provide only sketchy outlines, the Arabic, though apparently more detailed, are not entirely reliable as they were composed more than a century after the events and often passed through an oral tradition.

This chapter is aimed at outlining how systematic archaeological research has greatly contributed, especially in the last decades, to enhance our understanding of the Byzantine-Islamic transition, providing, through material records, a valuable source of insights into this turbulent period and leading to the emergence of an extraordinary complex scenario.

Placed within its social context, material culture has told (and goes on telling) the story of a society undergoing a gradual transformation in the period of the

Byzantine-Islamic transition, rather than being the victim of violent and destructive invasions.

Evidence underpinned through the remains of urban settlements, coins, pottery and textiles will briefly be considered and summarised in the following paragraphs; glass, being the material this research is focused upon, will be more extensively discussed in chapters 2 and 3.

1.1 A paradigmatic shift: from *thundering hordes* to a smooth metamorphosis

The idiom Byzantine-Islamic transition refers to the period when the shift from Byzantine to Islamic rule in the Near East occurred, the breakdown between the two dominations conventionally being the Arab conquest of Palestine and Jordan between 634 and 640 century[1].

At the beginning of the 7th century, the eastern Mediterranean area was the heart of the Byzantine Empire ruled from Constantinople. Nevertheless, during this century, historical events of crucial importance begun to happen in the eastern Mediterranean provinces of the Byzantine Empire – from Syria through Egypt and across North Africa – having as catalyst the teachings and revelations of Muhammad (c. 570-632 century), prophet of the Islamic faith[2].

Muslim power in Arabia rapidly consolidated and, under the "Rightly Guided" Caliphs, successors to Muhammad, Palestine, Iraq, Syria, Egypt and large parts of Iran were conquered between 674 and 715 century. At the end of the first quarter of the 8th century, the conquest of the Maghrib, North Africa, and al-Andalus, Spain, was also complete (Insoll 1999).

The span from the middle 7th into the end of 9th century was a critical phase of transition and transformation for the Byzantine Empire and its provinces, involving almost all societal aspects (Evans & Ratliff 2012).

However, until the second half of the 20th century, this shifting period has mainly been explored from a historical and literary point of view, since, up to the 1980s, archaeology was almost absent in the debate (Avni 2014; Insoll 1999; Walmsley 2007).

Furthermore, interpretation of the Byzantine-Islamic transition has gradually changed over time. Three basic models, the so-called "shifting paradigms", have been proposed by scholars for describing this shifting period and the transformation of Near Eastern societies rooted in this phenomenon: the

[1] According to the conventions of major textbooks on the historical and archaeological chronology of the Near East, the Byzantine period covers the years 324-638 and the Early Islamic period spans from 638 to 1099 (see Gil 1992).

[2] For an extensive discussion on the origins of Islam, see i.e. Burke & Lapidus 1988; Lapidus 2014; Waines 2003.

"thundering hordes", the "decline and fall" and the "intensification and abatement" (Avni 2014, pp. 11-17).

Born in the bosom of 19th century European scholarship and widely sustained in the 20th century (Walmsley 2007), the "thundering hordes" model contemplated a sudden and destructive Muslim invasion causing the vanishing of the Christian dominion overnight, as well as a prompt abandonment of Byzantine cities and towns. As a result, the Byzantine-Islamic transition was portrayed as a violent and abrupt episode that led to imminent cultural and religious changes in the society (Avi Yonah 1996; Gil 1992; Muir 1898). Several explorers described the empty landscapes of Syria and Palestine dotted with ruins as a result of harmful Arabs' raids, responsible for the demise of Christian Holy Land (i.e. Aharoni 1964; Bell 1907; Macaulay 1953; Merril 1881).

Though, this model started to be questioned in the second half of the 20th century, in the light of new evidence resulting from archaeological surveys. The hypothesis of a smoother transition started to gain ground consequently to information achieved by excavations carried out in the 1930s and 1940s between Palestine and Jordan: at Nessana, in the Negev desert, and at Mount Nebo, near Madaba, convincing evidence of an unbroken use of Christian monuments in the Umayyad period (661-750 century) was found (Kraemer 1958; Saller & Schneider 1941). The prosecution of archaeological projects in the 1960s and 1970s further enhanced this theory of moderate continuity, leading to the belief that the Christian Byzantine presence in the Holy Land did not suddenly disappear, but went on for at least a century following the Arab conquest. As a result, a new scenario emerged, supporting the hypothesis of a non-violent Arab invasion gradually leading to a "decline and fall" of the Byzantine dominion and to the consolidation of the Islamic state (Crone & Cook 1977; Donner 1981; Kennedy 1985a; Kennedy 1999; Wansbrough 1979).

The third and last paradigm, so-called "intensification and abatement" model, emerged at the beginning of the 21st century. This approach mainly stresses the role of internal processes and regional variability in the metamorphosis of urban settlements and societies during the Byzantine-Islamic transition. It also emphasises how the process of change has to be seen as a cyclical pattern of rise and decline, proceeding with regional variability.

"*The Byzantine-Islamic transition* - states Avni - *was a slow process that went on for hundreds of years, gradually transforming the face of settlements and the people who inhabited them, over a long period of time*" (Avni 2014, pp. 300-301). Such a thesis primarily stems from the evaluation of data gained by more than thirty years of archaeological research, conducted on the basis of a precise theoretical and methodological approach adopted at the beginning of the 1980s.

1.2 Archaeological evidence and material culture: kaleidoscopic pictures of a changing process

Before the 1980s, an almost complete lack of interest dominated the field of archaeological research related to the study of the Byzantine-Islamic transition as well as the early Islamic period.

The number of excavated sites was extremely limited, and the finds were scarcely documented, research mainly being subservient to architecture and artistic features of surviving monuments with specific attention to the Umayyad desert castles[3].

In addition to that, studies were either focused upon one aspect of material culture or on specific sites, without considering the wider context (Insoll 1999). Such an extensive lacuna has gradually been filled over the last thirty years, as early Islamic settlements have become the focus of systematic studies. The conspicuous amount of data obtained from excavated sites in modern Israel, Syria, Palestine and Jordan (Bartl & Moaz 2008; Borrut et al. 2011; Foss 1997; Holum & Lappin 2011; Petersan 1995; Schick 1995; Walmsley 2007) has clearly shown that life did not ceased with the Arab invasion, but went on without interruption from Byzantine into early Islamic times[4].

The story that has gradually emerged from large archaeological surveys is a tangible proof of the richness and diversity of settlement, culture and religion that existed in the Near East as Christian dominion gave way to Muslim rule (Avni 2014).

[3] This subject is more extensively discussed in the following paragraph.

[4] Please note that current geographic names of the cited territories will be used throughout the thesis. For the administrative division of Palestine and Jordan in Byzantine and Early Islamic periods, see Avni 2014, 23-29, and fig. 1.2, 1.3 therein.

1.2.1 Urban settlements in transition

Specific attention has been payed to the study of urban settlements in modern Syria, Israel, Palestine and Jordan, with reference to the transformations they underwent between the Byzantine-Islamic transition and the early Islamic period.

The first radical change of perspective emerged in 1985, thanks to Hugh Kennedy's paper "From *polis* to *Madina*: Urban Change in Late Antique and Early Islamic Syria". His remarkable work greatly impinged upon the state of knowledge, introducing an entirely new perspective on urban transformation in the Near East (Kennedy 1985b).

Starting with the statement that tangible signs of urban changes in ancient Syria and Palestine were already noticeable in the 6th century, Kennedy questions whether these transformations can exclusively be related to the coming of Islam, or should rather be considered as the result of long-term social and economic variations.

Subsequently to the advent of Islam, the traditions of urban life maintained themselves, even if this continuity of social and political function did not result in an endurance of architectural design and urban planning. A different concept of city environment emerged, where the mosque and the market (the *suq*) became the most significant parts, the layout of the streets changed, and the *agorà* lost its role of primary commercial hub of the city.

The transformation from *polis* to *Madina* is, hence, depicted for the first time as a complex process, with several factors impacting on it[5]. As a consequence, this shift started to be seen as an adaptation of the built environment to long-standing social and economic changes, rather than as a decline: "*the coming of Islam – concludes Kennedy – was simply one stage in the long transformation which began in the sixth century or earlier and was probably not complete until the tenth or eleventh*" (Kennedy 1985b, pp. 26-27).

[5] Demographic decline due to the invasion and to the bubonic plague, the occurrence of devastating earthquakes, and the rise of different patterns of government are quoted as the main ones. The main sources on these subjects are reported in Kennedy 1985b.

In the territories corresponding to modern-time Israel, Palestine, Jordan and Syria, the development and change of urban topography can be taken as one of the crucial indicators of the Byzantine-Islamic transition. Archaeological evidence uncovered at several sites has demonstrated how cities were not abandoned after the Arab conquest, but continued to exist and, at times, to burgeon.

At Caesarea Maritima (Israel), no direct evidence of damage to the city seem to have emerged during the Arab conquest[6]. In particular, finds from excavations in the areas of the inner harbour (Arnon 2008; Holum et al. 2008; Raban & Arnon 2007), and the Temple Platform (Levine & Netzer 1986) point towards a continuous prosperity of the city during the 5th and 6th century[7]. A temporary abatement in the second half of the 7th century, characterised by a decline in population and a decrease in the size of urban area and presumably related to administrative changes (Holum 2011), was then followed by a period of prosperity: in the area of the inner harbour, an intensification of settlement and commercial activities took place in the late 8th century, and the city went on flourishing up to the 10th century (Avni 2014).

Amongst the best examples of urban change in Israel during late antiquity, is the transformation of Scythopolis into early Islamic Beth Shean (or Baysan), in Israel (Tsafir & Foerster 1994; Tsafir & Foerster 1997; Tsafir 2009). This long-lasting process of change, started in the 6th century, lead the city to flourish consequently to the Arab conquest, with the establishment of new commercial and industrial activities within the centre and, especially, the installation of the market in the time of the Umayyad caliph Hisham b. 'Abd al-Malik (724-743 century) (Khamis 2001; Tsafir 2009). Beth Shean underwent severe damages when the devastating earthquake of 18 January 749 occurred. However, results achieved thanks to recent excavations have demonstrated

[6] Caesarea has been extensively excavated by a number of expeditions since the 1960. The history of excavations is accurately reported in Raban & Holum 1996.

[7] Amongst these finds, we can quote: the ceramic assemblages analysed by Magness (Magness 2003); a large building entirely paved with mosaics, located in the nearby of the Temple Platform, which has revealed a clear sequence of pottery (Adan-Bayewitz 1986); the elaborate bathouse of a private suburban villa located not far from the Byzantine walls (Horton 1999 and references therein).

that a new town was developed after this catastrophic event, continuing to flourish until the 11th century (Avni 2014).

Tiberias and Jerash are further examples of cities experiencing growth in the early Islamic period.

Founded in the 1st century on the shore of the homonymous lake, in Israel, Tiberias was a major administrative centre in the early Islamic period, after having been peacefully taken by Arabs in 636 century. The city greatly flourished between 8th and 11th century, becoming a multicultural centre dotted with extensive residential areas, site of industrial production (pottery, metal, mats and cottons), and noticeable for its large congregational mosque (Avni 2014; Gil 1992; Lavergne 2004; Walmsley 2007).

Jerash (Jordan) also witnessed a process of urban change after the Arab conquest occurred in 635. Preserving its Christian character and introducing new Islamic elements, the city experienced a vivid economic prosperity, as stated by the construction of a new mosque and its adjacent market (Avni 2014; Walmsley & Dagmaard 2005; Walmsley 2007).

A gradual, long-lasting transformation is also well attested in the urban processes that occurred in the city of Jerusalem.

The Madaba Map[8] and the mosaic of the Church of St Stephen at Umm al-Rasas (Piccirillo & Alliata 1994) provide a picture of the outline of Jerusalem, respectively in the late 6th and 8th century: both representations illustrate a prosperous centre, adorned with numerous churches and several buildings (Fig.1.1).

Archaeological evidence seems to show that, after having conquered the city in 638, Muslims rulers incorporated the new Islamic structures into the existing Christian city, without damaging the areas inhabited by people professing other religions. Therefore, Christian predominance in Jerusalem did not end with the conquest, but went on flourishing for at least three centuries after it (Avni 2014; Walmsley 2007).

[8] The Madaba Map, presumably dated to the second half of the 6th century, is amongst the most important sources for the settlement layout of Palestine and Jordan in the late Byzantine period. Following the main pilgrimage routes in the Holy Land, this document provides detailed representations of the cities, towns and pilgrimage sites (Avi-Yonah 1954; Donner 1992).

a)

b)

Fig.1.1 Depiction of Jerusalem in a) the Madaba Map and b) the mosaic of the Church of St Stephen at Umm al-Rasas

To the outstanding landmarks of the Byzantine Jerusalem, the Church of the Holy Sepulchre and the Nea Church, two equally remarkable constructions corresponded in the Early Islamic period: the Dome of the Rock and the al-Aqsa mosque. Located on the former Temple Mount and its surroundings, these monumental buildings were initiated by the Umayyad caliphs ‘Abd al-Malik and al-Walid in the late 7th and early 8th century, marking a major urban change in the city and conceived as an noteworthy manifestation of the Islamic rule over Jerusalem (Creswell 1969; Elad 1995; Grabar 1959; Grabar 1996; Rosen-Ayalon 1989). Excavations south and south-west of the Temple Mount revealed the remains of four early Islamic structures too, identified as “Umayyad palaces” or administrative centres (Grabar 1996; Rosen-Ayalon 1989).

This eastern part of the city was the only area witnessing such a drastic change; the others were, conversely, interested by a gradual transformation, with the material culture of daily life presenting a picture of great tolerance of the Muslim authorities towards other communities.

Several salvage excavations have attested the occurrence of a continuity of settlements in the outer hinterland of Jerusalem, with a network of farmsteads, agricultural villages, churches and monastic complexes supplying the city with goods[9].

Ancient Syria also underwent a crucial process of transformation between the 6th and the 8th century, as clearly addressed by Clive Foss in his pivotal paper "Syria in Transition, A.D. 550-750: An Archaeological Approach" (Foss 1997).

Antioch was, for instance, interested by enormous changes. Highly affected by severe natural disasters, as well as by the Persian and Arab invasions (respectively in 540-619 century and 638 century), the city experienced a noticeable reshaping: the great, ancient metropolis, centre of trade and production, was replaced by a much-reduced city, where life continued on a relatively small scale in the Umayyad and Abbasid periods.

Apamea greatly suffered from the Persian sack of 573 century. Although little specific evidence is offered by the remains of the main churches and the private houses, finds seem to show that the elegant Justinian city experienced destructions and demise. It eventually rose from its ruins, but in a less elegant form.

Notably different was the development of Hama and Bostra compared to Antioch and Apamea.

At Hama archaeological evidence, though scarce, seem to suggest that the city flourished until the Arab conquest. Then, urban life continued without interruption, as both religious and private buildings demonstrate[10].

Bostra was also a burgeoning place until the severe earthquake of 749 century, which devastated the city and left little standing. The advent of Islam did not cause the disappearance of Christianity: new mosques and large farmhouses were constructed under the Umayyads but respecting the Christian buildings.

All the above quoted examples emphasise how archaeological research has shed new light on the transformation that urban settlements experienced between the 6th and 11th century in the Near Eastern territories of the Byzantine Empire.

[9] For an exhaustive summary, see: Avni 2014; Bahat 1996; Kloner 2003; Schick 1995; Seligman 2011.

[10] See, for instance, the conversion of the cathedral into the great mosque of the city and the uninterrupted use of the House of the Mosaics (Creswell 1969; Foss 1997).

In particular, evidence shows that the Arab conquest did not result in a catastrophic and dramatic destruction of existing settlements, but in a steady process of change involving the built environment and, gradually, the layout.
These transformations did not only occur in the cities and towns but interested the countryside and rural areas as well. Ongoing archaeological research is outlining quite a complex picture to deal with, highly affected by considerable variability between sites and regions: while in some areas life went on without interruption in the settlements, other sites show a temporary decline followed by a re-flourishing in the 8th and 9th century[11].
The penetration of Islamic institutions was, thus, prolonged but solid, and they gradually made their own marks throughout the territory, respecting Christian religion and its culture. Most of the Byzantine-era settlements continued to prosper, preserving the personality of their populations but with some physical adjustments.
As Walmsley affirmed: "*Two parallel, rather than contradictory, trends can be observed in the urban history of established towns after the Islamic expansion: the maintenance of existing civic traditions inherited from late antiquity and, at the same time, the introduction of new ideas about the essential components of a town*" (Walmsley 2007, p. 124).

[11] See Avni 2014, Chapter 4, for an extensive discussion on settlement patterns and ethnic identities concerning the changing of rural sites and countryside.

1.2.2 "Arab-Byzantine coins" as indicators of cultural continuity before 'Abd al-Malik's reform

In addressing the Byzantine-Islamic transition, coins have held an even greater cultural significance, providing, as contemporary official products, insights that could have rarely been perceived through other sources (Foss 2012).

Research undertaken by Stephen Album and Tony Goodwin (Album & Goodwin 2002), Clive Foss (Foss 2004), and a further study by Goodwin (Goodwin 2005), on a corpus of coins held in the Ashmolean Museum has greatly contributed to enhance our understanding of the numismatic records of the 7th century.

Coinage of Syria-Palestine in the 7th century, before the reform which occurred at the end of 690s (discussed later), is known as "Arab-Byzantine". It consisted of four main types: "imported Byzantine", "pseudo-Byzantine", "Umayyad Imperial Image" and the "Standing Caliph" series (Album & Goodwin 2002; Foss 2004; Walmsley 2007).

For about two decades after the Islamic conquest, Byzantine coins continued to circulate in Syria and Palestine in huge amounts: a Syrian hoard of bronze coins attests, in fact, that gold Byzantine coins circulated until the coinage reform of 696 century, while copper until about 658 century (Phillips & Goodwin 1997).

A first period of importation of Byzantine coppers, spanning from the conquest to late 650s, was followed by the appearance of the so-called "Pseudo-Byzantine" coins, produced around late 650s to 670s. Minted locally and made of copper as mainly aimed at meeting everyday market needs, these coins were dependent upon the issues of Constant II and, to a lesser extent, Heraclius (Album & Goodwin 2002; Foss 2004; Goodwin 2005; Walmsley 2007).

A noteworthy change can be seen with the "Umayyad Imperial Image" coin types, where the image of the Byzantine emperor was replaced by a generalised imperial image. According to a contemporary chronicle, in 660 century the first Umayyad caliph Mu 'awiya issued gold and silver coins that were not accepted because they did not bear the sign of the cross (Palmer 1993) (Fig.1.2).

Fig.1.2 Gold Imitative solidus of Byzantine type. Damascus or Jerusalem, ca. 660, American Numismatic Society, New York (1983.122.1) (Foss 2012, p. 140).

Initially issued as a local initiative at several sites like Scythopolis, Diospolis, Jerusalem, Hims and Damascus (675-mid 680s), "Umayyad Imperial Image" coins started being more extensively minted shortly after the ascension of 'Abd al-Malik in 685 century (Album & Goodwin 2002).

The reign of 'Abd al-Malik (r. 685-705 century) brought the greatest changes, the first one being the introduction of the "Standing Caliph" series (690s). Here, for the first time, the caliph replaced the imperial figure, the cross disappeared, the religious slogan (the proclamation of Faith) dominated and the inscriptions were only in Arabic (Fig.1.3) (Foss 2012; Walmsley 2007).

Fig.1.3 Gold Dinar of Byzantine Type with Arabic Inscriptions. Prob. Damascus, ca.685-694, University of Pennsylvania Museum of Archaeology and Archaeology, Philadelphia (1002.1.107) (Foss 2012, p. 141).

With the "Standing Caliph" series, coins, especially coppers, started to be produced at a greater number of mints and the chronology is less problematic than for previous phases of coinage, as the golds are dated between 693 and 696 century (Album & Goodwin 2002).

The “Standing Caliph” series was also an essential premise to the final coinage reform operated by ‘Abd al-Malik in 696-697 century, that affected all the Islamic realm. Golden coins, then followed by silver and copper, started only having religious inscriptions, and human figures disappeared (Fig.1.4).

Fig.1.4 Gold Anonymous Aniconic Dinar. Prob. Damascus, Byzantine Collection, Dumbarton Oaks, Washington D.C. (BZC.2001.29) (Foss 2012, p. 137).

The post-reform coinage was issued in three major denominations: gold (*dinar*), silver (*dirham*) and copper (*fals*). All three were characterised by inscriptions in Arabic. In a surprisingly short period of time, the earlier gold coinage was withdrawn from circulation in favour of the new post-reform denomination (Foss 2012; Walmsley 2007). The monetary reform introduced, thus, new issues with a wider distribution, minted in a number of cities and towns throughout Palestine and Jordan (Album & Goodwin 2002; Foss 2004).

“Arab-Byzantine” coins provide valuable insights into the age of transition. They show that an initial dependence on Byzantine coinage and its imitations was progressively replaced by a series of new coin issues gradually more independent of Byzantine concepts. The final point of this process was the adoption of something entirely new and different: aniconic issues and Arab inscriptions, which would have featured Islamic coinage until modern times.

1.2.3 Pottery: a tale of continuity, rejuvenation and innovation

Three major cultural trends are revisable in the analysis of pottery of the early Islamic period: unbroken continuity from the Byzantine age, early 8th century rejuvenation, and a late 8th to early 9th century innovation.

Until the 8th century, pottery provides evidence of little diversification from typologies and ornamental motifs existing immediately before[12]. Containers and cooking vessels were the most common but, at the same time, the less diagnostic groups, due to their intrinsic utilitarian nature. Containers were used for storage and transport of foods and liquids. Among the most common, there are thin-walled jars for the collection of water (Fig.5.a), and thick-walled amphorae for the long-distance transport of olive oil and wine (Fig.5.b). Cooking bowls (Fig.1.5.c,d) were mainly shock-resistant open jars and casseroles with lids, locally produced in great numbers at Jerash and Beth Shean (Walmsley 2007).

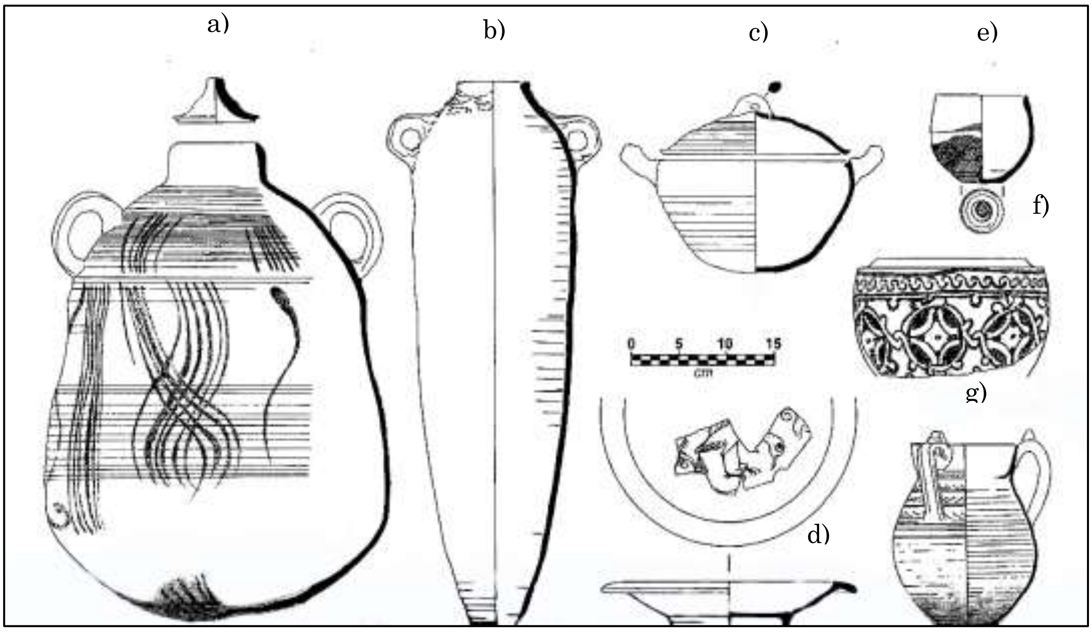

Fig.1.5 Selection of diagnostic early Islamic pottery: a) and b) storage jars, mid-7th-8th century; c) cooking bowl, 8th century; d) Jerash cooking bowl, 7th century; e) Fine Byzantine Ware, 8th-9th century; f) Red Painted bowl in mosaic pattern, 8th-9th century; g) Cream Ware, later 8th to 10th century (Walmsley 2007, p. 287).

[12] For detailed descriptions, see especially Whitcomb 1988; Sodini & Villeneuve 1992; Walmsley 1995; Sauer & Magness 1997; Schick 1998.

Serving wares represent a major indicative group, since they were conceived for display and, therefore, were finely and richly decorated.
In the 7th and early 8th century some types of fine-ware plates were brought in from Egypt and Cyprus. However, the discontinuation of this trade and the increased demand for pottery encouraged further the local manufacture and development of new types of fine wares, gradually replacing the imported Roman and Byzantine tableware products (Magness 2003; Walmsley 2000; Walmsley 2007).
Among the most popular types is the so-called *Fine Byzantine Ware*, predominating between the 6th and the 9th century. Probably intended to imitate prestige gold vessels, these products (mainly bowls, however jugs, juglets and other vessels also appear) were made in a very thin pale orange to light reddish-brown fabric, with the outside surfaces decorated featuring knife burnishing (Fig.5.e). It has been suggested that their production centre was in the Jerusalem area, and from here distributed over distances up to 150 km (Magness 1993; Sauer & Magness 1997).
In the early 8th century another ceramic category, known as *Red Painted Ware*, appeared. It is a hard, well-fired ware decorated with abstract designs of swirls, asterisks and lines in deep red to dark reddish-brown paint (Fig.5.f). Mainly distributed in Jordan, this group at first only encompassed jars and jugs but, around the middle of the century, the repertoire underwent a noticeable expansion and also cups, bowl and platters were produced.
Between the late 8th and early 9th century, a significant shift occurred in the ceramic repertoire. The introduction of new types, the *Islamic Cream Ware* (also known as *Mafjar Ware*) above all, marked a profound change in consumers' tastes. Almost certainly aimed at imitating silver vessels, this category originated in 8th century Iraq and became a common domestic ware in Samarra during the 9th century. *Islamic Cream Ware* then rapidly spread throughout modern Syria and Israel, where Raqqa, Ramla and Tiberias became major production centres (Walmsley 2007).
Cream ware vessels outlined a strong contrast with what had gone before. They were characterised by sharp, angular profiles inspired by metal prototypes and

richly decorated with incised, applied and moulded patterns (Fig.5.g), as represented in the large corpus gained from excavations at Khirbat al-Mafjar (Whitcomb 1988), Capernaum (Tzaferis 1989), Caesarea (Levine & Netzer 1986) and Pella (Walmsley 1995; Walmsley 1997).

The late 8th and early 9th century also witnessed the first massive penetration of glazed wares into the local repertoires. The so-called *Coptic Glazed Ware*, extensively found in well-dated contexts at Aqaba, in Jordan provides, for instance, evidence of the growing impact of connections with Egypt (Whitcomb 1989).

An initial period of adoption and adaptation during the early centuries of Islam was, thus, followed, by significant innovation, with ceramic art developing its distinctive styles and techniques.

The introduction of Islamic glazed pottery is amongst the greatest novelties. Though it is widely accepted that Islamic glazed pottery flourished in Abbasid Iraq in the 9th century, presumably in response to the import of Chinese hot-fired porcelains (Northledge 2001; Tite & Wood 2005; Wood et al. 2007), Oliver Watson has recently claimed that the demand for fine glazed ceramics started earlier and not in Iraq, but in Egypt and Syria (Watson 2014). According to this author, Islamic glazed pottery, frequently with opaque yellow and green decorations, first appeared in Egypt (Scanlon 1998) and then in Syria (Watson 1999) in the late 7th e 8th century. From here, the yellow glaze tradition spread to Mesopotamia where, in the 9th century, it could have provided the context for the emergence of a range of white tin-opacified wares, inspired by Chinese imports.

A recent research by Micheal Tite and colleagues (Tite et al. 2015), dealing with an archaeometric characterisation of *Coptic Glazed Ware* from Egypt, *Yellow Glazed Ware* from Syria, and comparable wares from Samarra, Kish and Susa, confirms Watson's theory. Analyses have demonstrated that tin was first used in the form of lead stannate to produce yellow opaque glazes in Egypt and Syria in 8th century, before being used in the form of tin oxide to produce opaque white glazes in Abbasid Iraq in 9th century. Interestingly, the use of lead stannate is explained by the authors as a technological transfer from contemporary Egyptian and Syrian glassmakers, who had continued the Byzantine tradition of glassmaking whilst working under Islamic rule.

With the spread of glazed pottery, the initial adoptive and adaptive phases of Islamic pottery production were definitely over.

Lustre ware, *slip-painted ware*, *silhouette ware*, *Raqqa ware*, *laqabi ware*, *minai ware*, and *lajvardina ware* (Fig.1.6) are the highest material evidence of a creative phase which, spanning from the 9^{th} to the 16^{th} century, gave rise to innovation, regional diversification, and copies in far-flung areas of the Islamic world (Keblow Bernsted 2003).

Fig.1.6 Selection of Islamic pottery: a) lustre ware, Iraq, 9th century; b) slip-painted bowl, eastern Iraq or Central Asia, 10th century; c) shilouette type painted dish, Raqqa, Syria, early 13th century; d) Raqqa type fritware dish, Raqqa, Syria, early 13th century; e) laqabi type fritware dish, Kashan, Persia, 12th century; f) minai type fritware bowl, Kashan, Persia, 13th century; g) lajvardina type fritware tile, Kashan, Persia, 13th century
(Keblow Bernsted 2003: a) p. 8; b) p. 12; c) p. 28; d) p. 39, e) p. 41, f) p. 45; g) p. 51).

1.2.4 Textiles, an embroidered transition

It is quite challenging to differentiate weavings from the transitional late antique-early Islamic period on the basis of the technique, as only in later times do these differences become more evident.

In the first decades after the Arab conquest, workshops continued their trades as before. Style of dress evolved very slowly, with the decorative elements being the first features to show changes (Vibert-Guigne & Bisheh 2007).

The enduring tradition of weaving garments to shape vanished, and clothes were cut to shape, with sewing styles accommodating new fashions and trends in decoration. In particular, abstract designs begun to replace figurative elements, and inscribed textiles became extremely popular (Colburn 2012).

Sculptures and mural paintings from the Umayyad palaces, in particular Khirbat al-Mafjar, Qusayr ʻAmra and Qasr al-Hayr West, clearly illustrate the survival in Early Islamic times of the Roman-Byzantine and Persian styles, both by side and in combination (Baer 1999; Ettinghausen et al. 2001; Fluck 2012a; Vibert-Guigne & Bisheh 2007).

In terms of materials and techniques, under the Arab rule wool, instead of linen, became the predominant fibre for warp and weft and backgrounds could be vividly coloured, often in red or blue (Colburn 2012).

Furthermore, of the most interesting technological innovations introduced after the Arab conquest is revisable in the use of a lac dye to achieve a bright red tone (Wouters 1995): to imitate the hue obtained by using Tyan purple, the most valuable and expensive dyestuff, fibers were sometimes dyed with an ingotin-containing dye and madder (De Moor et al. 2010).

Textiles can undoubtedly offer a window into the cultures of their epoch. Unfortunately, primarily due to the fragile nature of making materials, examples of complete textiles are extremely rare to find. Moreover, it has to be bear in mind that most garments depicted on artworks represent clothing of some members of the high society: the modest, more convenient and functional clothing worn, for instance, by nomads and country-dwellers, also existed, but only sporadic images survive.

As Cäcilia Fluck has correctly stated: "*In age of transition, with its myriad cultural currents, the only feature that unequivocally identifies a textile as Islamic is an Arabic inscription*" (Fluck 2012b).

The term *tiraz* (pl. *turuz*), said to be of Persian origin and originally meaning "made with the needle", is also referred to the Arabic inscriptions on textiles. The *tiraz* style, that consisted in putting texts on textiles, was very popular in the Early Islamic period. Under the Umayyad caliphate, royal textile workshops were introduced, at first only serving the caliph and his court, later (but still under the Umayyads) also working for a wider clientele (Fluck 2012b). The *turuz* have the value of historical documents, as they often mention the name of the ruler, the producer and, sometimes, a date. For the people of the time, they were items symbolising royal power and social prestige (Helmecke 2006; Lombard 1978).

The *tiraz* style was not restricted to Muslims: even if in less abundance, examples with inscriptions in Greek and Coptic have also been found, with the same intent to convey a message and signify a privileged social status.

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Chapter 2

A changing material in a changing world
An overview on glass and its industry in the Islamic Near East

"God is the Light of the heavens and the earth, the likeness of His Light is as a niche, wherein is a light, the light in a glass, the glass as it were a glittering star."

Qur'an 24:35 II.1-4

This verse, taken from the *Surah an-Nur* ("Light" section) of the Qur'an, is one of the most frequently bold, in Arabic calligraphy, on mosque lamps made of glass, together with the names of their patrons.
Designed to lighten mosques, funerary complexes and private royal residence built by Mamluk sultans and their emirs, these wonderful and sumptuously adorned objects represent the highest expression and the worldwide most treasured symbol of Islamic glass manufacture. Furthermore, they are among the most significant contributions to the history of glassmaking worldwide, especially in virtue of technical and artistic skills needed for their production.
Nevertheless, at least five centuries had to pass since the beginning of the first Islamic caliphate, that of the Umayyads (661-750), to have such luxurious and precious objects on the market.
More than a few aspects of Islamic glass industry lack exhaustive research and the emerged scenario is still fragmentary and uncomplete to deliver a proper understanding of its development.
Being an expression of material culture, the products of glass industry are a mirror of the historical period when they were made. Thus, when discussing upon glass manufacture and consumption, several interrelated aspects need to

be accurately considered, like the choice of raw materials, the recipes, and the variety of shapes and ornamental motifs, as well as their development.

The purpose of this chapter is that of synergistically illustrating all the above issues, with the aim of delineating a concise and, as far as possible, comprehensive picture based upon the actual knowledge of Islamic glass industry in the East.

An historical overview will be provided as starting point, highlighting societal and political issues that influenced the development of glass manufacture in the Islamic world, together with a synthesis upon the archaeological discoveries that have contributed to the growth of scholarly interest in Islamic glass through time.

Then, shapes and decorative features will be discussed, starting from the issue of a continuity over time in the initial stage of Islamic glass manufacture, to progressively move to the emergence of distinctive Islamic characteristics. Last, changes in terms of raw materials and recipes employed in the glassy industry will be considered, together with a discussion upon the main factors that could have impacted on their occurrence.

The following pages will, therefore, provide an overview on glass and its industry in the Islamic world, highlighting aspects still needing further investigation. This will hopefully work as a premise to properly highlight and emphasise the significance of investigating issues related to glass manufacture, consumption and supply during the Umayyad caliphate, focus of the next chapter.

2.1 Outlining an historical frame in the light of archaeological evidence

Islamic glass has received a more limited scholarly attention if compared to other categories of artistic manufacture.

Interest in glass from Islamic lands begun at the end of the 19th century, presumably against the background of the so-called Orientalism, a fascination with the Near East that inspired European artists (Bendiner 1996).

Nevertheless, gilded and enamelled luxury objects were the only focus of this interest, considered as rarities awarding distinction to their prestigious owners. The amazing turquoise glass bowl in the treasure of St. Mark, Venice, is one of the most famous examples of such prestigious items (Fig.2.1).

Fig.2.1 Turquoise glass bowl, St. Mark's treasury (Whitehouse 2001a, p. 177).

By the first decades of the 20th century, scholars became increasingly interested in the full range of Islamic glass. This growing interest was primarily due to Carl Johan Lamm, a Swedish scholar that catalogued the full range of glass and hard-stone objects excavated at Samarra (Lamm 1928) and subsequently, with his doctoral thesis, extended his work to the central Islamic lands between the 7th and the 15th century (Lamm 1930).

The city of Samarra, in present-days Iraq, is still among the most significant excavated sites. It was occupied only for a relatively short period: from 836, when the ‘Abbāsid caliphs decided to establish a new royal city north of Baghdad, to 892, when the court moved back to the former capital.

As a consequence, the importance of Samarra primarily stems from the lack of chronological problems, since the finds can be confidently ascribed to the 9th century. The catalogue *Das Glas von Samarra* (Lamm 1928)was the first published report on glass finds from an Islamic excavation, though, unfortunately, only a scarce number of objects are illustrated. The second report, focused on the excavations conducted between 1936 and 1939 (al-Āthār al-Qadīmah al-‘Āmmah 1940), comprised a more extensive photographic documentation of the finds, with summary descriptions provided. Glass production in Samarra has attested a revival of Roman techniques that had been abandoned for at least five centuries. It is, more precisely, the case of *millefiori* mosaic tiles, employed in the royal palaces as a revetment for floors and walls and probably conceived to emulate the magnificence of the past (Carboni 2001a). In addition to that, a survey in the 1980's revealed the existence of a centre for glass production close to Samarra royal palaces (Northedge & Falkner 1987). Given the large amount of glass unearthed here, the theory of a locally production of glass is, thus, strongly plausible.

Lamm's studies and publications were the starting point for a systematic study of archaeological glasses excavated in Islamic lands, that witnessed a period of increasing growth between World War I and II.

At Nishapur, in north-eastern Iran, thousands of objects and fragments of glass were excavated in 1930s and 1940s under the patronage of the Metropolitan Museum of Art, New York[13]. Founded in the Sasanian age, the city of Nishapur was the largest and most important metropolis in the north-eastern Iranian province of Khurasan; seat of a governor in the ‘Abbasid times and capital of the Ṭāhirids rule in the 8th century, Nishapur greatly prospered in the 10th century during the Samanid dynasty, becoming an international trade centre. The city continued to flourish until the 13th century, when a combined action of catastrophic earthquakes, political turmoil and the Mongol invasion in 1211 put an end to its growth. Excavations at Nishapur unearthed vessels of about

[13] For a comprehensive summary of excavations and glass finds from Nishapur, see Kröger 1995.

25 different typologies ascribable, with their variations, to approximately 105 shapes. Bowls, plates, beakers, jars, bottles and ewers were probably used mainly as kitchenware and tableware for food and drink; glass was also employed for lamps and inkwells and for medical or alchemical purposes. Except for the two glass slabs found at the northern edge of the Qanat Tepe mound, no remains of glass furnaces, cullets, slags or wasters came to light. Thus, although it has been taken for granted that glass was produced in Nishapur, excavations have not provided definitive evidence of a local production (Hauser & Wilkinson 1942; Kröger 1995). In addition, the conspicuous assemblage of glass objects found at Nishapur lacks a precise chronological attribution, since the empirical excavation method did not produce a stratigraphy able to provide certain chronological groupings of the finds from different levels.

Fusṭāṭ and Raqqa undoubtedly were the post-World War II milestones in the study of Islamic glass, together with two fortuity and unexpected finds.

The city of Fusṭāṭ, a suburb of Old Cairo, Egypt, has provided a large amount of material, as it was an active manufacturer of glass from the 8th to the 15th century. Unfortunately, owing to the complex nature and long duration of its occupation, the site does not always provide a clear-cut stratigraphy, this highly affecting a precise interpretation of the finds[14]. A complete report was published by George Scanlon and Ralph Pinder-Wilson (Scanlon & Pinder-Wilson 2001), with a catalogue comprising 331 items of glass recovered from nine seasons of excavations carried out by the American Research Center in Egypt between 1964 and 1980. The assemblage is mainly represented by domestic glassware, medical appliances and a single example of an official measure, all current in Fusṭāṭ from about 750 to 1050. The household glassware included storage vessels for liquids such as bottles, jars, flasks, handled jugs, ewers and sprinklers; serving bowls and dishes and individual bowls; drinking vessels with a decorative function as vases. Toilet articles

[14] The chronological attribution of the finds is primarily related to field data, rather than to the dating of published objects. However, in some cases, the finds were dated by association with the contents of the pits they were recovered from, since not all of them were discovered in undisturbed loci (Scanlon & Pinder-Wilson 2001).

(small flasks and bottles for scent, and jars for unguents) were also found in great abundance. In addition to simple wares, high-quality glass was used in Fusṭāṭ, as represented by mould-blown and relief-cut vessels, mainly colourless and transparent, as well as by objects with stained decorations; gilded and enamelled pieces were recovered as well, ascribable to the 13th and 15th century and represented by surface finds (Pinder-Wilson & Scanlon 1973; Pinder-Wilson & Scanlon 1987; Scanlon & Pinder-Wilson 2001).

The relevance of Raqqa, in northern Syria, primarily stems from its being the only scientifically excavated inland Islamic glassmaking complex where both primary and secondary production occurred in the 8th-9th, 11th and 12th century (Henderson 1999; Henderson 2013). As it will be discussed later in more detail, production at Raqqa is not only significant because of its massive scale occurrence, but also as it provides evidence for the change to a domination of plant ash over natron glass industry.

Research on Islamic glass has also benefited from two surprising and unexpected finds. The first was the discovery, in 1973, of a ship carrying a huge quantity of broken glass and lumps, sunk short after 1025 at Serçe Limani, near Bodrum (Turkey). Excavated between 1977 and 1979 under the direction of George Bass and on display at the Bodrum Museum of Underwater Archaeology, the reconstructed fragmentary glass material has shown a detailed picture of the wide variety of colours, shapes (i.e. plates, cups, bowls, beakers, jars, bottles, ewers) and working techniques (mainly mould-blowing and wheel-cutting). Furthermore, this extraordinary find has also provided evidence for a firmly establishment of the commerce of finished and raw glass in the eastern Mediterranean regions (Bass 1984).

The second valuable find was a lucky discovery made in August 1981 in the crypt of a stupa in north-eastern China, which was sealed in 874 century. Together with a treasury of gold, silver, porcelain and silk, 19 intact pieces of Islamic glass were found, demonstrating that Islamic glass was highly esteemed in China and exported here, too (Xiaoneng 1999).

The cities of Aleppo (Syria) and Tyre (Lebanon) have also been interpreted as possible glassmaking sites. The cosmographer al-Qazwīnī mentions the "market of the enamellers" in Aleppo, where amazing decorated objects were sold (Irwin 1998); furthermore, information about materials and techniques are given by Yāqūt, who refers to the use of a specific fine white sand used as colourant in glass (Heidemann 2006; Irwin 1998). A number of historical references support the theory of Tyre being a glassmaking centre: the 10th century geographer al-Muqaddasī reports that cut and blown glasses were manufactured at Tyre (Henderson 2013); in 1163, the Spanish Rabbi Benjamin of Tudela reported that about 400 Jews were engaged in glass-production in Tyre (Wright 1848); the 12th century geographer al-Idrīsī wrote that Jews in the suburbs of Tyre produced both glass and ceramics (Chebab 1979). In addition, Tyre has also provided the most complete evidence of tank furnaces used for the production of glass in use between the 10th and 12th century (Aldsworth et al. 2002).

The above excursus has outlined how a conspicuous and gradually increasing number of finds unearthed by archaeological excavations has led, especially during the 20th century, to a noticeable growth of interest in the study of glass from Islamic lands. Despite that, several aspects related to its production, manufacture and technology remain puzzling and need to be further investigated, to begin with what occurred during the transitional period from Byzantine to Islamic domain and under the Umayyad caliphate, the first Islamic dynasty.

It has long been stated (and, to a certain extent, taken for granted) that, for architectural decoration and everyday items, the Umayyad rulers relied on the pre-existing decorative language established under the Romans and Sasanians. In this panorama, accompanied by a presumed lack of interest in patronising the glass industry manifested by Umayyad rulers, glassmakers were not asked to develop new products, but continued to create objects that attracted the average buyer, neglecting the artistic potential of glassmaking[15]. (Carboni 2001b; Carboni 2001c).

[15] See chapter 3 for an exhaustive discussion on this issue, as well as on manufacture and consumption of both vessel and mosaic glass tesserae in the Umayyad period.

Later, from about the beginning of the 9th century, more evident changes and innovations in shapes and decorative features begun to appear, presumably in response to specific artistic trends. Glass was widely produced during the periods in which long-lived powerful dynasties dominated, like the 'Abbāsid (749-1258 century), the Fatimid (969-1171 century) and the Seljuq (1040-1194 century), but this material was not regarded as important enough to have the name of the rulers carved or moulded on. The willing of patronising glass manufacture appeared for the first time under the Ghaznavids, who ruled between 977 and 1186 century in present-day Afghanistan and Pakistan. A group of coloured medallions from the Ghaznavid Palace at Old Termez (Uzbekistan), intended as architectural ornaments, provide evidence for this intent (Fig.2.2): they are impressed with figural patterns and show the name of the last Ghaznavid king, who ruled from 1160 to 1186 century (Carboni 2001c; Carboni 2001d).

Fig.2.2 Medaillons, impressed and coloured glass- Ghaznavid Palace at Old Termez, Uzbekistan, 12th century, The al-Sabah Collection, Dār al-Āthār al-Islāmiyyah, Kuwait National Museum (LNS 365G, 378G, 323G) (Carboni 2001d, p. 134).

During the late Ayyūbid (ca. 1169-1260 century) and the Mamluk (1250-1517 century) periods, glass reached a high royal status with the manufacture of enamelled and gilded objects in Syria and Egypt. The wonderful and richly decorated lamps made for adorning and lightening mosques and private royal residences are amongst the highest expressions of this production (Fig.2.3). They represent the only example of royal patronage of Islamic glass that lasted for more than a hundred years (end of 13th - beginning of the 15th century). Greatly appreciated by sultans, this type of product became so valuable and successful that it inspired Venetian artisans and was exported to Europe as well, until it virtually died out during the 15th century (Carboni 2001c).

Fig.2.3 Mosque lamp, free blown, applied, enamelled and gilded glass. Egypt, ca. 1329-1935, Mannheim Collection (Carboni 2001f, p. 232).

Under the following dynasties, glass was regarded as little more than a useful commodity, rather than as a luxury material. The Ottomans (1281-1923 century, Iran) the Safavids (1501-1732 century, Iran and parts of Central Asia) and the Mughals (1526-1859 century, India), were undoubtedly great patrons of the arts but, once again, they were not interested in patronising glass manufacture.

Between the 16th and 17th century, glassmaking in the Islamic lands was greatly influenced by the European world, as the trade, which had almost exclusively proceeded east to west in the Medieval period, reversed direction: Venetian, Bohemian and English products were then made for export.

2.2 Islamic glass: assessing changes from form to matter

2.2.1 Shapes and decorative features between continuity, revivals and innovation over time

In the volume *Glass from Islamic Lands*, Stefano Carboni (Carboni 2001b) coined the expression "proto-Islamic glass" to identify objects belonging to the transitional period between late Byzantine and early Islamic age (indicated as the period spanning between ca. late 6th and early 10th century). In particular, he noticed how these objects carried over pre-Islamic shapes and techniques into the new era, slowly developing into recognizable Islamic forms. Consequently, he stressed the quite challenging task to distinguish between glass objects produced immediately before the advent of Islam and those manufactured in the following century and a half.

In his book *5000 years of glass*, Hugh Tait also devoted a chapter to glass from Islamic lands, using the expression "early Islamic glass" to identify the production from the 8th to the 11th century (Tait 1991; Tait et al. 2012).

Despite the slightly different chronological frame, authors agree in identifying two broad groups, deriving from diverse traditions: the former, and by far the larger, encompasses products that witness a continuation of the Roman and Byzantine legacies; the latter, less numerous, was influenced by the Sasanian artistic tradition (Carboni 2001b; Tait 1991; Tait et al. 2012).

Concerning the first tradition, functional objects of basic shapes (like bottles, goblets and bowls), mainly free- and mould-blown[16], either undecorated or adorned by using hot-working techniques, are the most commonly encountered. Long before the expansion of Islam, blown glass had been extensively manufactured in the Mediterranean regions, especially in Egypt and Syria. This pattern of production was not dismissed after the Arab conquests, and,

[16] Invented in the 1st century in the Syro-Palestinian region, glassblowing created a remarkable change in the use and availability of glass objects, enabling craftsmen to create vessels quickly and in a wide range of shapes. Glassblowing is of two main types, namely free-blowing and mould-blowing. The former is accomplished without any accessory tool: molten glass is gathered on the end of a blowpipe and a vessel is formed by inflation; after, the glass may be reheated and reshaped in a number of ways. The latter wants molten glass to be inflated into a mould with impressed decorative patterns; in this way, the object can be formed and decorated in a single operation and in a repetitive way.

therefore, common glassware intended for everyday use continued to be made by using blowing techniques, as it is attested by the vast abundance of undecorated cups, sprinklers, bottles, pitchers and lamps found at different sites (Carboni 2001e; Tait & Tatton-Brown 2012; Whitehouse 2001c) (Fig.2.4).

Fig.2.4 a) Bottle, free blown glass. Egypt or western Asia, date uncertain, The Corning Museum of Glass, New York (54.1.129); b) Cup, blown glass in dip mould. Western Asia, 7th-8th century, The al-Sabah Collection, Dār al-Āthār al-Islāmiyyah, Kuwait National Museum (LNS 127G) (a) Whitehouse 2001c, p. 75; b) Carboni 2001e, p. 86).

Hot-worked glass was also common in the Islamic world. This type of glass was manipulated and decorated while the blown object was still hot and, thus, in its malleable state. Objects with either impressed patterns or adorned with decorative trails, both applied and marvered, belong to this category (Gudenrath 2001).

Impressed patterns were obtained by using metallic tongs that carved motif to be impressed in relief on the glass walls. The majority of objects with impressed decorations show an open profile (bowls, beakers), because the tools had to be used on both interior and exterior walls. The pattern was repeated at irregular intervals, with motifs commonly limited to basic geometric figures (Fig.2.5). Impressed glass was still manufactured in the 12th century, as witnessed by the medallions found in present-day Afghanistan and attributed to the

Ghaznavid and Ghūrid dynasties, intended to be used as architectural decorations (see Fig.2.2) (Carboni 2001d; Tait 1991; Tait et al. 2012).

Fig.2.5 Bowl, free blown and impressed glass. Egypt, 9th-10th century, The Corning Museum of Glass, New York (59.1.512) (Carboni 2001d, p. 126).

The continuity of decorative patterns between Late Antiquity and the early Islamic period is also well represented by vessels with applied trails. The colour of the patterns could be the same as the base glass or a contrasting one, to achieve more elaborated effects (Fig.2.6).

An evolution of this kind of decoration is represented by the so-called cage animal flasks. Used as containers for perfumes and unguents, these elaborated objects were made by building trails one upon another to create an open structure encasing the actual vessel (Carboni 2001b; Carboni 2001d; Tait 1991) (Fig.2.7).

Fig.2.6 a) Bottle, free blown and applied glass. Egypt or Syria, 7th-8th century, The Metropolitan Museum of Art, New York (x.21.210); b) Bottle, free blown and applied glass, Syria, 7th-8th century, The Toledo Museum of Art (1923.2033)
(a) Carboni 2001d, p. 110; b) Carboni 2001d, P. 114).

Fig.2.7 Cage animal flask, free blown and applied glass. Syria, 7th-8th century, The David Collection, Copenhagen (49/1979) (Carboni 2001d, p. 113).

Inspired by late Roman models, glass with applied and marvered trails met its most prolific production in the Islamic industry between the 12th and 14th century, but there is no doubt that it was continuously produced from the very early Islamic period (Carboni 2001b; Carboni 2001d). Objects belonging to the early phase of Islamic marvered glass show irregular wavy and overlapping decorative patterns, easily distinguishable from the controlled designs of the later periods (Fig.2.8).

Fig.2.8 a) Cup, free blown, applied and marvered glass. Egypt or Syria, 8th-9th century, The al-Sabah Collection, Dār al-Āthār al-Islāmiyyah, Kuwait National Museum (LSN 52 KG); b) The Durighiello Bottle, free blown, applied and marvered glass, Syria, 13th century, The British Museum, London (1913.5-22.39) (a) Carboni 2001d, p. 138; b) Carboni 2001d, p. 144).

Moving to the Sasanian legacy, it is especially revisable in the so-called facet-cut decoration, a kind of decorative pattern made by grinding the carved surface of the glass vessel with convex cutting wheels to produce areas that are flat or somewhat concave. The best-known examples of cut glass are probably the thick-walled naturally coloured and transparent vessels decorated with facets made by cutting, grinding and polishing, the most common ornaments being the “honeycomb” and the “omphalos” pattern (Fig.2.9) (Carboni 2001b; Tait 1991; Tait et al. 2012; Whitehouse 2001a).

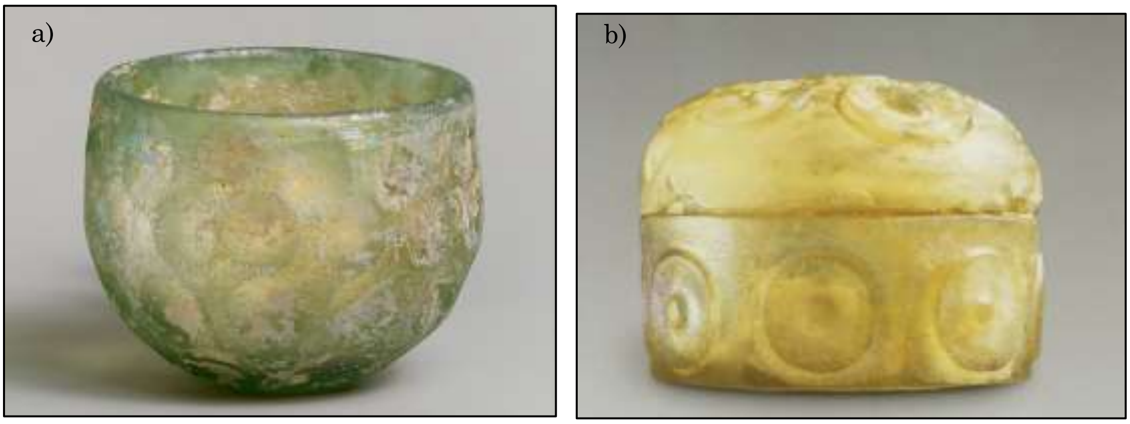

Fig.2.9 a) Bowl with wheel-cut facets. Iran, 6th-7th century, The Metropolitan Museum of Art, New York (59.34) [http://www.metmuseum.org/art/collection/search/324830]; b) Box with lid, blown and cut glass. Western Asia, 10th century, The Victoria and Albert Museum, London (c196-1939) (Whitehouse 2001a, p. 170).

This kind of working technique and decorative motifs represent an echo of the Sasanian tradition, where facet-cut objects were extensively made from the 3rd throughout the 7th century (Simpson 2014). Further evidence of a Sasanian influence is revisable in the small globular bottles adorned with small impressed roundels (Fig.2.10).

Fig.2.10 a) Vase, free blown, applied and impressed glass. Syria, 7th-8th century, The Toledo Museum of Art (1923.2015) (Carboni 2001d, p. 34).

From about the 9th century onward, Islamic glass manufacture went on systematically developing its own distinctive features. From the revival of previously established working and decorative techniques to the great era of enamelled and gilded objects, glass industry went on witnessing an extremely flourishing period that would have lasted for hundreds of years.

In the 9th and 10th century, cut and engraved glass became the most prominent form of decoration and a number of variants were developed. Scratch-engraving was, for instance, among the mainly employed techniques to engrave glass, consisting in scratching the surface with a pointed tool. Used from simple, linear and geometric patterns to more complex decorative motifs on both colourless and coloured objects (Fig.2.11), scratch-engraving was attested in the 8th and 9th century and it is frequently represented in 9th century contexts like Samarra (Lamm 1928) and Fusṭāṭ (Pinder-Wilson & Scanlon 1973; Pinder-Wilson & Scanlon 1987).

Fig.2.11 a) Cup, blown and engraved glass. Syro-Palestinian region or Egypt, 8th-9th century, The Corning Museum of Glass, New York (55.1.112); b) Bottle, blown and scratch-engraved glass. Syro-Palestinian region or Egypt, 9th century, The Corning Museum of Glass, New York (68.1.1) (a) Whitehouse 2001a, p. 163; a) Whitehouse 2001a, p. 167).

A revival of the cameo glass technique is attested in western Asia or Egypt in the 9th century (Fig.2.12). Colourless glass was totally or partially covered with a layer of translucent vividly coloured glass, then partially ground away to create a bold contrast. The results were somewhat never seen before: extremely weightless objects that nevertheless had a strong sculptural appeal (Carboni 2001b; Tait 1991; Whitehouse 2001a).

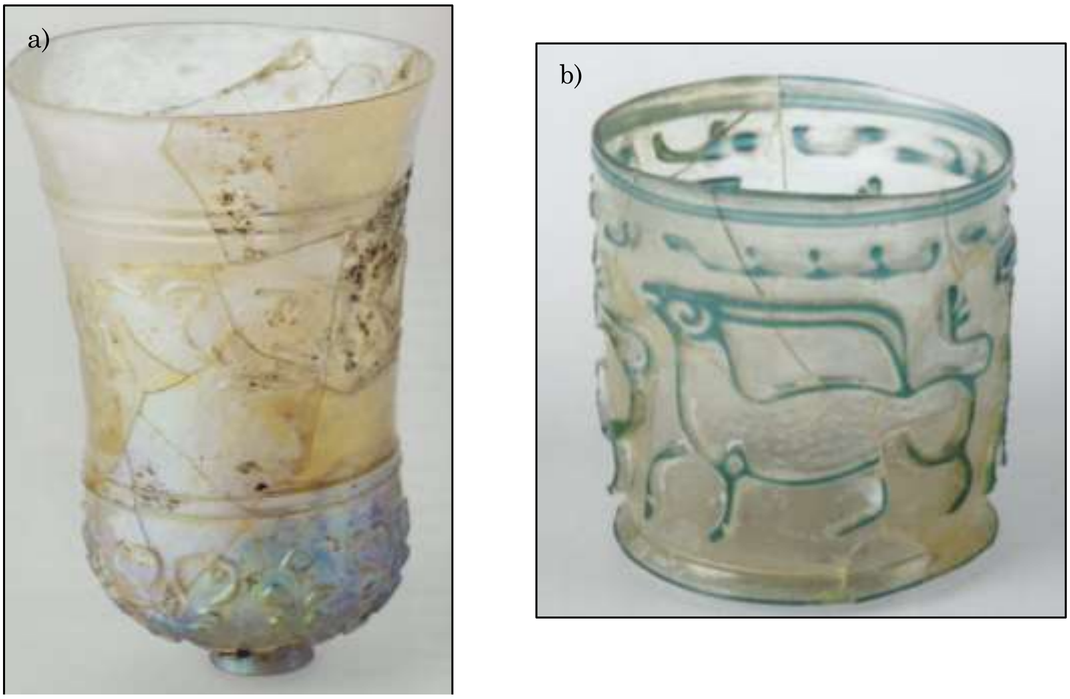

Fig.2.12 a) Beaker, blown and relief-cut glass. Western Asia, 9th-10th century, The L.A. Mayer Museum for Islamic Art, Jerusalem (673-71); b) Cup with Ibexes, blown, cased, cut and drilled glass. Western Asia or Egypt, 10th century, The L.A. Mayer Museum for Islamic Art, Jerusalem (624-69) (a) Whitehouse 2001a, p. 174; b) Whitehouse 2001a, p. 182).

Sandwich glass is the term applied to define an exiguous group of vessels and fragments with stylised decoration in gold leaf, often together with pale blue dots, enclosed within two layers of colourless glass. Though its scarce occurrence makes, to date, accurate historical and contextual analyses difficoult, it is likely that this kind of glass was manufactured between the 9th and 10th century in Syrian and Mesopotamia areas, where it has more conspicuously been found. This technique was probably an echo of the so-called gold-glass, originated in the eastern Mediterranean before the 3rd BC, but continued into the 4th century in Rome and the Rhineland (Carboni 2001b; Tait 1991; Whitehouse 2001a).

Millefiori glass, also known as mosaic glass[17], experienced a vivid revival too, as attested by the fragments of vessels and tiles recovered at Samarra, in the ruins of the 9th century dated palace built by caliph al-Mu'tasim (Lamm 1928). Here, spectacular objects and tiles were used to decorate the floors and, probably, the walls of the royal palace (Fig.2.13). Unfortunately, there is no evidence for continuity of this production after the 9th century, as the finds from Samarra seem to be the only fixed chronological point (Whitehouse 2001b).

Fig.2.13 a) Tile fragment, *millefiori* glass. Samarra, Iraq, 9th century, Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Museum für Islamische Kunst (Sam.309) (Whitehouse 2001b, p. 148).

The technique of luster-painting represents one of the highest achievements in Islamic glazed pottery of the 'Abbasīd 9th century Iraq, coloured with metallic compounds and then fired in the kiln (Caiger-Smith 1985; Watson 1985). Painting on glass that achieves a similar lustrous effect to that on pottery was thought to be intimately related to luster-painted pottery and is, therefore, defined as "luster-painted" or "stained" (Carboni 2001b; Carboni 2001f; Tait 1991; Tait et al. 2012). Exclusively made in Syria and Egypt, but traded as far

[17] This type of glass has been made intermittently from the Bronze Age to the present (in Murano, it is nowadays called *murrina*). Especially appraised in the Hellenistic period, most mosaic glass was made by fusing slices of canes having patterned cross sections. If the desired shape was an open vessel, the slices were fused in a disk then slumped over a mould; if a closed shape wanted to be obtained, the slices were picked up on a gather of molten glass or fused in a mould.

away as modern Sri Lanka and China, this type of glass decoration originated in Egypt, where, in the 3rd century, Coptic craftsmen used silver and copper alloys as substitute for gold on different media, including glass (Caiger-Smith 1985). In the 8th - early 9th century, silver stains were applied on glass in one or more colours, all of them in the shades of amber and brown, generally on both sides of vessels to highlight details (Fig.2.14).

Fig.2.14 a) Cup, free blown and stained glass. Damascus, Syria, 8th century, The Corning Museum of Glass, New York (69.1.1) (Carboni 2001f, p. 208).

Later, the use of copper mixed with silver and the search for new chromatic effects gave rise to the production of yellow, orange, and red stains[18]. This polychrome phase, ascribable to the 9th-10th century, probably lasted until the Fatimid period, when the selection of colours became very pale and monochrome brown stains were preferred (Carboni 2001b; Carboni 2001f; Carboni & Adamjee 2002b). Between the 11th and 12th century (late Fatimid – early Ayyūbid period), stained glass became an established art form: double-sided painting was abandoned to concentrate on a single pictorial surface and more complex decorative patterns were created. Stained glass become increasingly less popular and confined to minor areas, whilst gilding and enamelling techniques gradually became the principal methods of painting on glass (Carboni 2001b; Carboni 2001f).

[18] See Brill 1999 and Brill 2001 for a detailed discussion upon the making technology and the chemistry of stained glasses.

During the Ayyūbid (1169–1250) and Mamluk (1250–1517) caliphates in Syria and Egypt, gilded and enamelled glasses underwent their golden age, destined to become the most celebrated and treasured type of glass from the Islamic world. Gold and/or enamels (powdered opaque glass) were applied to the surface using an oil-based medium and a brush or a reed pen. High technical skills were needed, because gilt and enamel colours had different specific chemical properties requiring different temperatures to permanently fix them on glass. Furthermore, attention had to be payed to avoid the risk of deforming the shape of the object through reheating (Gudenrath et al. 2006).

Highly prized and presumably only used for special occasions, enamelled and gilded glass was also a commercial product, extensively traded in Europe and the Far East. Though it mainly developed in Syria and Egypt between the 12th and the 15th centuries, the origin of enamelled glass is still an open question: although it is almost certain that enamelling begun in the Syrian area (Raqqa most probably being the first centre of production), it is also likely that glassmakers at Fusṭāṭ became active soon after the Mamluks made Cairo the capital of their empire (Carboni 2001b; Carboni & Adamjee 2002a; Ward 1998). Glassmakers experimented a huge variety of forms and decorative motifs. Whilst, at an earlier stage, beakers, bottles and small perfume flasks were almost exclusively manufactured, from the 14th century a larger variety of shapes became available, like mosque lamps, long-necked decanters and vases of various sizes and typologies (Fig.2.15). Concerning the decorative patterns, geometrical, figurative and animal motifs were the most common, realised by using quite a rich and variegate palette of colours (Carboni 2001f).

Fig.2.15 a) Mosque lamp, free blown, applied and enamelled glass. Egypt, ca. 1350-1360, The British Museum, London (OA81.9-9.3); b)Bottle, free blown, enamelled and gilded glass. Syria, 13th century, Furussiya Arts Foundation, Vaduz, Liechtenstein (a) Carboni 2001f, p. 237; b) Carboni 2001f, p. 243).

The late 14th century witnessed a decline in production and, by the early 15th century, lessening patronage eventually caused workshops to close. As a consequence, by the late 15th century, the production of most enamelled glass had shifted to Europe, and to Venice. In particular, presumably due to a combination of economic, political, and artistic factors (Carboni & Adamjee 2002a).

Although the peak of Islamic glassmaking ended in the 14th century, craftsmen produced high-quality glassware also in the empires of the Ottomans (Turkey, the Near East, and the Balkans), the Safavids (Iran), and the Mughals (India). These later pieces often show a distinct European influence, certainly ascribable to the increasing number of imported products from Venice, Bohemia and England from the 16th century onward.

Fig.2.16 Graphical abstract summarising the evolution of the most frequently encountered shapes and decorative patterns from the 8th to the 14th century.

2.2.2 Production sites, raw materials and recipes

The previous summary upon shapes and decorative patterns has highlighted how an initial stage of reliability on pre-established traditions was gradually followed by the emergence of distinctive features that marked the products of Islamic glass industry.

Analogously to shapes and ornamental features, raw materials, recipes and, by extension, the technology of glass making underwent key transformations as well. Therefore, a proper depiction of the development of Islamic glass industry cannot be considered exhaustive without having properly addressed technological issues as well.

The production of glass has always been dependent upon the combination of several factors (i.e. distinctive skills, access to raw materials, availability of fuel, a market for the finished products), and different models have been developed to describe the ways these factors were organised.

For the Roman and Byzantine periods, the widely accepted model states, for instance, the existence of primary production sites located in Egypt and along the Levantine coast[19], settled near combustibles and raw materials, which melted tonnes of raw glass, then broken into chunks and distributed to a large network of secondary production centres, processing the primary glass (as well as recycled cullet) into the final artefacts (Freestone et al. 2000).

In contrast, medieval European and Islamic glass industries seem to have functioned around integrated workshops, combining the production of raw glass and the forming of artefacts for the local or regional market. Since, in the East, plant-ash based glass making had persisted throughout the Roman and Byzantine periods in the Sasanian Empire and Central Asia, it is generally assumed that this led to its gradual re-adoption in the Levant and Egypt. The availability of high-quality raw materials and a social environment favourable to the development of the arts and crafts under the early Abbasid rulers led to a flourishing art of glass making (Rehren & Freestone 2015).

[19] Detail discussion upon production centres located in Egypt is given in: Nenna 2014, Nenna 2014 and Nenna et al. 1997, 2000; for centres located on the Levantine coast, see: Freestone 2006, Freestone et al. 2000, Gorin-Rosen 1995, 2000.

Such a radical change in the organisation of glass making did not happen overnight: there was a period of transition from the Late Antique mineral-natron based glass factories to the newly-established industries, based on the adoption of new raw materials and recipes.

Properly framed, changes in glass composition can yield important information on broader issues, like the changing distribution of primary production sites, the supply of glass between different regions of the eastern Mediterranean and how these changes relate to wider social, economic and political factors.

For this main reason, the progression of changes affecting both compositional features and the selection of raw materials will be here examined in strict relation with evidence underpinned for production sites, in the attempt to highlight the complexity of a scenario that, though highly improved by recent research, cannot still be considered exhaustive.

2.2.2.a The natron-based industry: between continuity and "hidden" symptoms of change

The shift from natron to plant ash as fluxing agent has long been inferred as the major technological change occurred in Islamic glass industry, manifest sign of a breakdown with previously established Roman and Byzantine traditions and starting point for the setting up of a truly Islamic glass industry. Rather than a strict innovation, this change was a reintroduction of the most ancient technology to make glass, datable to about 2500 BC. Since plant-ash based glassmaking had persisted throughout the Roman and Byzantine periods in the Sasanian Empire and Central Asia between the 2nd and the 6th century (Mirti et al. 2008), it is generally assumed that this was the route to its relatively easy re-adoption in the Levant and Egypt (Rehren & Freestone 2015). Nevertheless, symptoms of changes in the glass manufacture started at least 100-150 years before this transition occurred, and they are traceable in the compositional changes that affected natron glass industry.

Natron deposits, the best known of which being located at Wadi Natrun in Egypt, had been used as flux in glass production from the 1st millennium BC through the Mediterranean and Levantine regions, until its apparent shortage during the 7th to 9th century and its subsequent replacement with plant ash[20]. Several theories have been postulated to explain the reasons responsible for the shift from natron to plant ash as fluxing agent. Together with environmental and climatic factors, social and political events have also been considered as actors playing a primary role.

Danièle Foy and Marie-Dominique Nenna (Foy & Nenna 2001) and, slightly later, Maurice Picon and co-workers (Picon et al. 2008) suggested that an

[20] Strictly speaking, natron is the mineral name for the sodium carbonate 10-hydrate. Its addition to the batch reduces the melting point of silica, the vitrifying agent, from c. 1710°C to c. 1200-1100°C, acting as fluxing agent. First evidence for the use of natron in the production of vitreous materials dates back to the 4th millennium BC, when it was used in the manufacture of the glaze applied to Egyptian steatite beads ascribable to the Badarian Period. However, there is very limited and no conclusive evidence for the use of natron as a glass making flux before the 1st millennium BC. By the 5th century BC, natron was the flux mainly used in primary glassmaking sites located in Egypt and along the Syro-Palestinian coast; in Iran and Central Asia, plant ash continued to be used as a flux, and natron does not appear to have displaced it for any significant period. The plants sources of the alkali grew, and still grow, in semi-desert environments, often on the edges of deserts, in saline maritime environments and in inland salinas. Plants like *Salsola* and *Salicornia* tolerate high levels of alkalis in the soil and incorporate alkaline salts, as sodium carbonate, in their tissues.

increase in heavy rainfall could have reduced the amount of natron in the evaporite deposit of Egypt, presumably because less evaporation occurred and less natron was formed. Andrew Shortland (Shortland 2004) analysed the implications that seasonal and annual variations in the evaporites of Wadi Natrun, in particular due to a reduction in temperature, could have had on ancient exploitations. As a direct consequence of these events, the amount of natron available for glassmaking underwent a consistent reduction, this affecting the supply of natron to the Syro-Palestinian area.

The influence of important political events occurred within the Delta and the adjacent regions of northern Egypt between the 7^{th} and the 9^{th} century has also been evaluated. More specifically, it seems likely that the Persian invasion of the Delta region occurred in 619 century resulted in the disruption of markets and communication lines. Subsequently, intercity trade was also negatively affected by the Muslim conquest, these events highly affecting the Mediterranean trade (Shortland et al. 2006; Whitehouse 2002).

Recent research has highly contributed to develop a framework within which the technological change from natron to plant ash and the reasons for its occurrence can be better understood.

The histogram in Fig.2.17 is the best way for summarising the results of this research, undertaken by Phelps and colleagues (Phelps et al. 2016). Plotting percentage frequency of vessel compositional types against time, the graph has been drawn according to the analyses of 271 vessels covering the period from the 7^{th} to the 12^{th} century, selected on the basis of precise chrono-typological criteria and choosing diagnostic fragments of well-contextualised, common and domestic vessel type (like beakers, bottles, bowls and goblets), trying to avoid rarities.

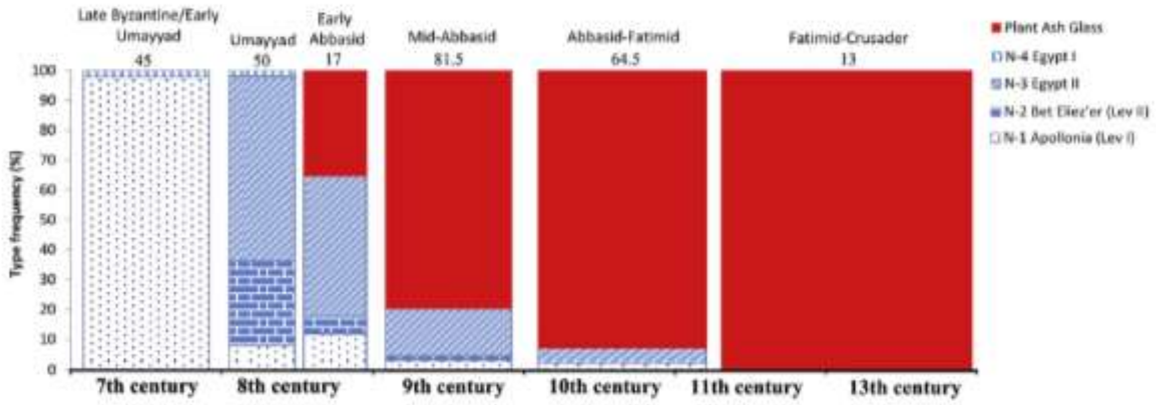

Fig.2.16 Histogram plotting percentage frequency of vessel compositional type against time (Phelps et al. 2016, p. 65).

Apart from providing evidence for the first occurrence of plant ash-based glass in Palestine in the second half of the 8th century (early Abbasid period), results from this research distinctively highlight the existence of a high variability of glass typologies and recipe changes, supportive in shedding new light on the falling of natron supply.

If we focus the attention on the period before the first plant ash glasses were found, which is the span from the 7th to the first half of the 8th century, the high variability of encountered compositional categories is certainly the most eye-catching data (Fig.2.17). Compositionally, the 7th century was almost entirely dominated by the so-called Apollonia-type glass. In Israel, in the early 1950s, two furnaces for raw glass production were discovered during salvage excavations at Apollonia/Arsuf, north of Tel-Aviv (Gorin-Rosen 2000). In 2002 another raw glass furnace was unearthed (Tal et al. 2004), strengthening the hypothesis that the city was a major centre for primary and secondary glass making between the 6th and 7th century (Freestone et al. 2008). Also known as Levantine I (Freestone et al. 2000), the glass produced at Apollonia-Arsuf was of a soda-lime-silica type[21], made by using natron as a fluxing agent. The sand source is low in oxides from heavy accessory minerals (titanium oxide, iron

[21] In this type of glass: silica is the network-former, being the basic building structure of the glass; soda is the network modifier, acting as fluxing agent to lower the melting temperature of silica, and derived either from natron or coastal plant ash; lime has the role of network stabiliser, increasing the durability of glass and strengthening its structure.

oxide and zirconium), but relatively high in alumina (>3wt%), suggesting a mature high silica sand (SiO_2 ca. 70wt%) with a significant feldspar content (Freestone et al. 2008). Lime is typically high (7-9wt%) as is strontium oxide (ca. 550 ppm), the strong correlation between them implying the use of a marine sand where lime is mainly found as shell (Freestone et al. 2003; Phelps et al. 2016). Hence, the Apollonia-Arsuf glass is thought to have been made using local coastal sand from the region (Freestone 2006; Freestone et al. 2008).

The early 8th century witnessed a dramatic diversification of the glass supply in Palestine. In the first half of the 8th century, Apollonia-type glass drastically fell, whilst the Bet Eli'ezer-type was seen for the first time (Phelps et al. 2016). In 1992, during a salvage excavation, 17 tank furnaces were unearthed at Bet Eli'ezer, near Hadera (Israel), each of which would have produced about 8 tonnes of raw glass in a single firing (Gorin-Rosen 1995; Gorin-Rosen 2000). Although the dates of the beginning and the end of the production at Bet Eli'ezer are currently unclear, the initial hypothesis that the furnaces could have been operational between the 6th and the 8th century (Freestone et al. 2000) has been replaced by the theory that glassmaking at Bet Eli'ezer had been short-lived, suggested at just a few seasons (for no more than 50-100 years) and ending in the late 8th/early 9th century (Phelps et al. 2016). Also known as Levantine II (Freestone et al. 2000), the glass produced at Bet Eli'ezer was of a soda-lime-silica type, made by using natron as a fluxing agent. The sand used as silica source shows geochemical features extremely close to those outlined for the Apollonia-Arsuf glass, this suggesting that glass production at both sites occurred by using similar sands, but not the same. Differences can be, in fact, observed in terms of major oxides contents: Bet Eli'ezer glass has higher silica (73-76wt%) and lower soda (11-13wt%), implying a different batch recipe, as well as lower lime but higher alumina, suggesting that a different sand was being used (Freestone et al. 2000). The hypothesis of a coastal sand is, however, always supported by the high strontium oxide contents and its correlation with lime (Phelps et al. 2016).

Together with primary production sites, archaeological research has also uncovered evidence for the existence of several secondary glass workshops located in the Near East, especially in Israel[22] (Fig.2.18). In particular, those discovered at Bet She'an, Ramla and Tel Aviv are of a special interest and deserve, therefore, specific attention.

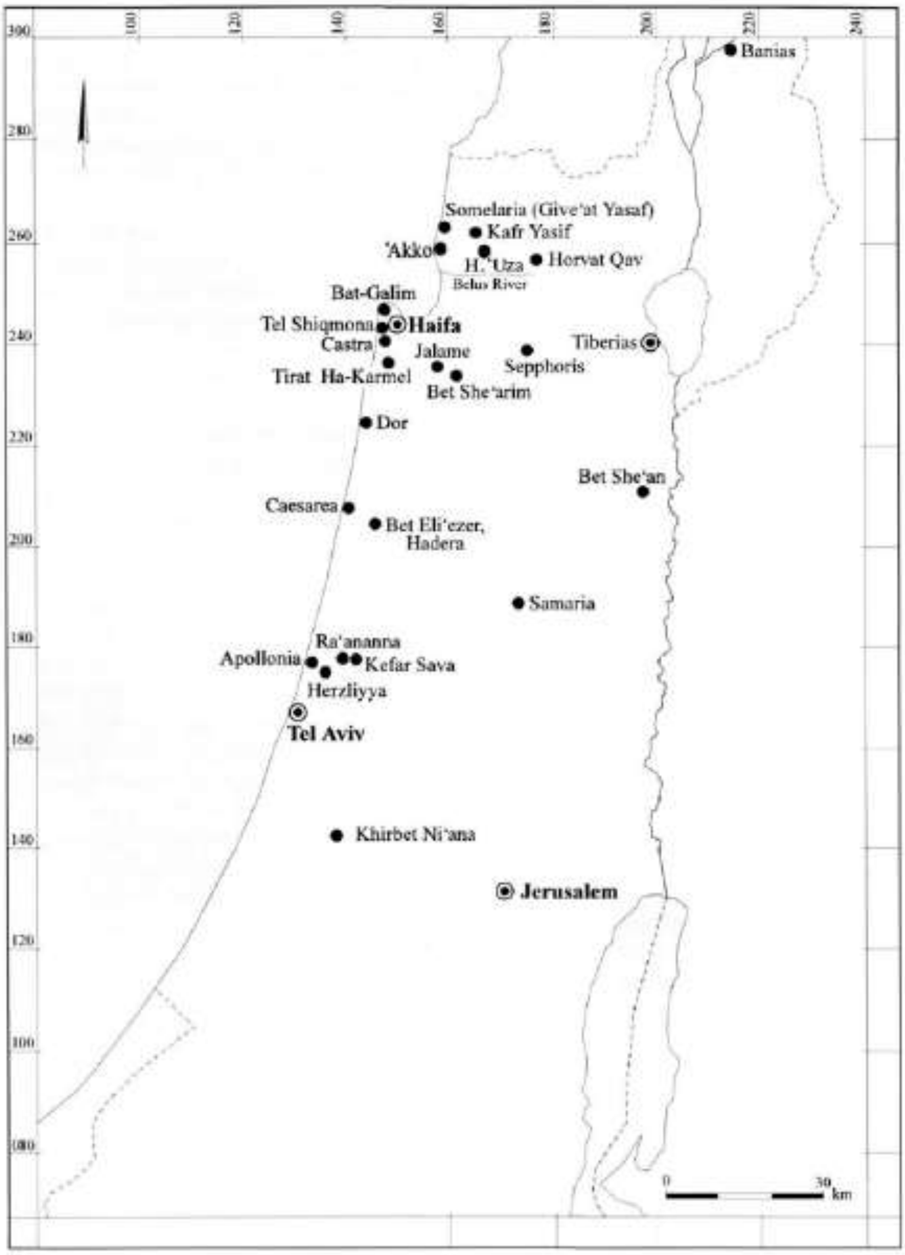

Fig.2.18 Map showing sites where primary and secondary production sites have been discovered in Israel (Gorin-Rosen 2000, p. 51).

[22] Secondary glass production is documented in Israel by finds dating from the Early Roman to Medieval periods (a survey is provided by Gorin-Rosen 2000). An important discovery is the furnace remains from Jalame, in northern Israel, dated to the second half of the 4th century (Weinberg 1988). Remains of secondary glass workshops in Israel were unearthed at Kafr Yasif, Horbat Qav, Sepphoris (Fischer & McCray 1999) Raqit (Jacobson 2004), Khirbat el-Ni'ana (Gorin-Rosen & Katsnelson 2007), and at a few other sites including: Apollonia-Arsuf (Freestone et al. 2008), Khirbat Jarrar, Jatt, Horbat Hermas, Lod and Khirbat el-Faṭuna (Gorin-Rosen 2004; Gorin-Rosen 2005; Gorin-Rosen & Katsnelson 2007; Elisha 2007).

Attributed to the late Byzantine period (late 6th-early 7th century), the workshop at Bet She'an was unearthed in 1994, preserved in an excellent state of conservation (Gorin-Rosen 2000). This secondary workshop produced a small variety of forms, mainly everyday glassware conceived for a domestic use. According to its compositional feature, glass worked at Bet She'an shows affinities with that produced at the primary furnaces of Apollonia-Arsuf (Tal et al. 2008b). Interestingly, the glass found at Ramla is of a similar composition. During a salvage excavation, debris from a secondary glass workshop, vessel production remains and fragments of final products were found inside the late Byzantine occupation layer datable to the 6th-7th century (Tal et al. 2008a; Tal et al. 2008b). Analyses demonstrated that all glasses are of a natron-type, and their compositional features match the glass produced at the primary site of Apollonia-Arsuf and at the secondary workshop of Bet She'an. Moreover, remains of vessels from early Islamic contexts were found at Ramla, showing closer similarities with glass produced at Bet Eli'ezer (Tal et al. 2008a; Tal et al. 2008b). These data suggest that glass of a different recipe was being used in Ramla after the abandonment and, presumably, the dismantlement of the late Byzantine furnace, prelude to the flourishing glass industry of early Islamic Ramla (Jackson-Tal 2008).

Data obtained by the analysis of glass vessels, chunks and moils found inside a refuse deposit at HaGolan Street, Khirbet al-Ḥadra (Tel Aviv), ascribable to a secondary early Islamic workshop datable back to the 7th-8th century, are particularly remarkable. Archaeometric analyses demonstrated that the glass at HaGolan Street derived from three sources: "Group A" from an unknown Levantine source, "Group B" from the Beth Eli'ezer furnaces, and "Group C" from the so-called Egypt II source, which appears to have originated in inland Egypt. The importance of the HaGolan Street assemblage stems from the fact that it is the first documented use of Levantine and Egyptian glass to make vessels in the same workshop at about the same time, suggesting that the glassworkers could choose which raw glass to use (Freestone et al. 2015).

If we look back at the histogram in Fig.2.17, we can notice that the early 8th century also shows the presence of vessels matching the so-called Egypt I and

Egypt II compositional categories. Glasses belonging to these groups were made by using sand sources higher in heavy accessory minerals. Compared to Apollonia-Arsuf and Bet Eli'ezer types, they show higher contents of iron oxide (1-2 wt%), titania (0.3-0.5wt%) and zirconia (200-300 ppm), as well as an enrichment in rare-earth elements. This geochemical signature matches that of Egyptian sands and, together with the higher soda content, is consistent with Egyptian glass (Foy & Picon 2003; Nenna 2014).

Though they share a common Egyptian origin, Egypt I and Egypt II are separate groups: Egypt II has higher lime (9-10 wt%), lower alumina (2-3 wt%) and a low CaO/Sr ratio, suggesting that the lime is derived from a limestone source rather than from a coastal sand; Egypt I has distinctively lower lime (2-3 wt%) and strontium, but they are positively correlated, this suggesting the use of a coastal sand (Phelps et al. 2016).

Initially detected in a secondary workshop at El-Ashmunein (Middle Egypt) (Bimson & Freestone 1985), Egypt II glass was also identified by Gratuze and Barrandon (Gratuze & Barrandon 1990) - named Group 2 - in a study concerning coin weights from Fusṭāṭ (Egypt). Vessels dating back to the Abbasid period (mid 8th to the end of 9th/beginning of 10th century), were also found belonging to Egypt II group, referred to as Group 7 by Foy and co-workers (Foy et al. 2003). Egypt II compositional group was also detected by Kato and co-workers at Raya (Sinai peninsula, Egypt): more precisely, they label this group as N2-b, with the majority of the analysed objects falling within it (Kato et al. 2009). Group C recognised by Ian Freestone and colleagues (Freestone et al. 2015), including vessels, chunks and moils recovered from an early Islamic secondary workshop at HaGolan Street, is also equivalent to Egypt II compositional category. Matt Phelps and co-workers (Phelps et al. 2016) identified 57 samples made of Egypt II glass (Group N-3), belonging to the period of the so-called Byzantine-Islamic transition. Lastly, some 6th-7th century Byzantine glass weights from the British Museum and the Bibliothèque Nationale de France were also found matching the Egypt II compositional category (Schibille et al. 2016).

As far as the so-called Egypt I group is concerned, several studies witness its occurrence in the late Byzantine/early Islamic period. Groups 8 and 9 identified by Foy and colleagues (Foy et al. 2003) refer, for instance, to glass vessels dating to the Umayyad period (661-750): Group 8, characterised by higher levels of iron, alumina and titanium, matches Gratuze and Barrandon's 1B group; Group 9, which may pre-date Group 8, corresponds to Gratuze and Barrandon's 1A group (Gratuze and Barrandon 1990). Egypt 1A (Group 9) and 1B (Group 8) categories were supposed to have been manufactured in the primary workshops located at Wadi Natrun (Egypt), where surveys and excavations have attested the presence of primary glass furnaces datable between the 1st and the 2nd century (Nenna 2014; Nenna et al. 2005; Picon et al. 2008). However, it has been stressed that this hypothesis needs to be reconsidered as, to date, no production evidence has been underpinned for the Islamic period at this site (Nenna 2014; Nenna 2015).

By analysing a conspicuous assemblage of glass finds excavated from two well-dated archaeological layers (from the 8th and the 9th centuries) at Raya (Sinai), Kato and co-workers identified the N2-a2 type, a low lime – high alumina glass comparable to Egypt I compositional category (Kato et al. 2009). A recently published study on late antique vessels and window glass from Cyprus (Ceglia et al. 2015) also outlines the presence of some few samples matching the Egypt I compositional category. Finally, among 133 analysed vessels, well-contextualised from selected excavations in the Near East and ascribable to the 7-12th centuries, Matt Phelps and colleagues (Phelps et al. 2016) only found two samples corresponding to Egypt I group (Group N4).

At its present stage, research seems to suggest that the decline in natron availability started earlier than the 9th century and occurred over a more extended timeline. As a consequence, long term factors seem more likely to have gradually impacted upon the contraction of natron glass industry and, then, upon the shift to plant ash. According to Phelps et al. 2016, a combination of environmental changes and influences of cultural and political developments is the most suitable hypothesis: an environmental change which might have restricted natron formation (Foy & Nenna 2001; Picon et al. 2008), and the contemporary use of the same material for other purposes, like soap-making and medicines (Forbes 1965; Lovejoy 2002), is likely to have impacted on a reduction of the quantities available for glassmaking.

In addition, the occurrence of Egyptian glass suggests that a change in the Levantine industry was taking place, possibly through a contraction of production due to natron shortages, or increased coasts of the glass, or a preference for Egypt-made glass due to its working properties.

Whichever the reason(s), it can undoubtedly be affirmed that, before the famous shift from natron to plant ash occurred, the natron-based industry underwent another kind of transition. Its symptoms are hidden in the variety of chemical compositions and, therefore, recipes, which marked the period between the 7th and the 8th century.

2.2.2.b Playing with materials: evidence for the experimentation of recipes in the core of the transition

Periods when technological changes occur are the most inclined to meet phases of experimentation, often based upon fusion and incorporation of previously established knowledge.

Evidence unearthed at Bet She'arim and Raqqa clearly attest that something analogous also interested the glassmaking industry.

In the early 1960s, the so-called "great glass slab" was discovered at Bet She'arim, primary glassmaking site located in Israel (Freestone & Gorin-Rosen 1999): it is a really huge piece of glass, measuring 3.80x1.95x0.45m and weighting about 9 tons. Preliminary investigations by Robert Brill and John Wosinksi (Brill & Wosinski 1965) demonstrated that the slab was melted from raw materials in its actual position and left there after melting, probably the result of a failed process. Chemical analyses showed, in fact, that the glass was extremely high in lime (15.9 wt%), suggesting that it either did not fully melted during the firing cycle or extensively devitrified upon cooling.

Following research shed new light on the outstanding composition of the great slab, demonstrating that the melting process failed because the glass was made by combining a coastal sand, high in lime, and plant ash as flux, also containing considerable amounts of lime (Freestone & Gorin-Rosen 1999). These peculiar features also allowed to date the Bet She'arim slab to about the early 9th century, at a time when an important technological transition was taking place in the glassmaking industry: the shift from natron to plant ash as a fluxing agent[23].

Raqqa, located in northern Syria, is, to date, the only scientifically excavated inland Islamic glassmaking complex where both primary and secondary production of glass occurred on a large scale (Henderson 2013). The furnaces were located in an industrial complex consisting of up to 7 m of stratified material set in an area known as Mishlab, where glass manufacture occurred together with glazed and unglazed pottery production (Henderson 1999;

[23] Due to its relevance, this issue will be more extensively discussed in the next paragraph.

Henderson et al. 2005). Rescue excavations have provided evidence for glass production at three excavated sites: Tell Zujaj, where archaeological dating suggests that two glass workshops operated between the second half of the 8th and the early 9th century, when Raqqa was the capital of the 'Abbasid caliphate (Henderson 1999; Henderson 2000); Tell Fukhkar, where raw green glass was found attached to tank furnace fragments dated to the 11th century (Tonghini & Henderson 1998); Tell Bellor, where a third 12th century tank furnace for glass production was unearthed (Henderson et al. 2004).

Chemical analyses of glass found at Raqqa show that both natron and plant-ash glasses were being worked there, and the shift from one flux to the other is here revisable in the variety of chemical compositions encountered, the widest range from any ancient glassmaking site in the Levant (Henderson 2002; Henderson et al. 2004).

The bi-plot in Fig.2.19 highlights the different types of glass made at Raqqa: type 1 was made from plant ash and quartz pebbles; type 2 was a mixture of type 1 and type 3, type 3 was made by using natron and sand; type 4 was made from plant ash and sand (Henderson 2002; Henderson et al. 2004).

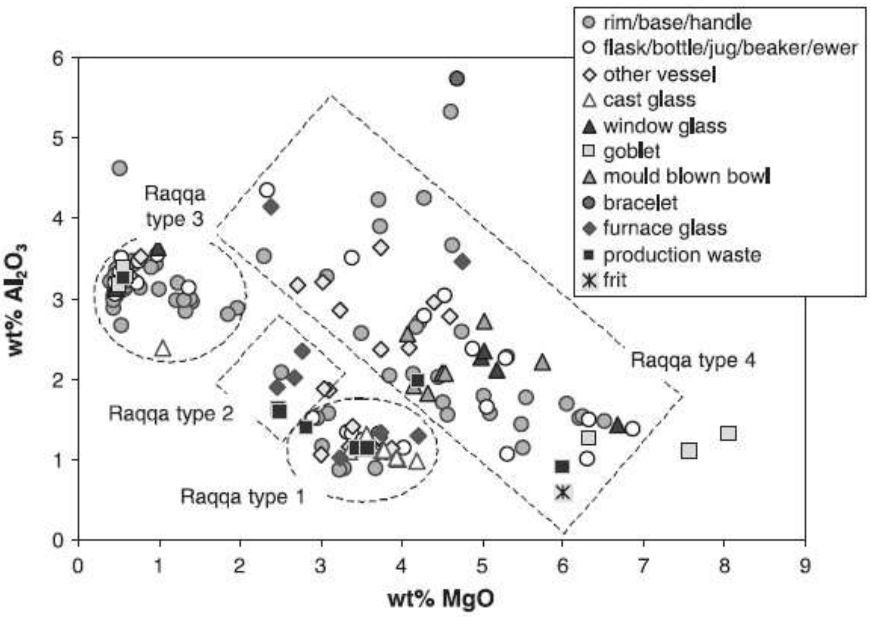

Fig.2.19 Bi-plot Al_2O_3:MgO encompassing all Raqqa type glasses identified by Henderson and co-workers (Henderson et al. 2004, p. 452).

It can be noticed that the group encompassing the majority of samples is Raqqa type 4, also displaying a wide range of compositional variation. According to its compositional features, Raqqa type 4 has been interpreted as the result of experimentation with raw materials and the consequent recycling or reuse of cullet resulting from such experimentation. This type of glass was made by using plant ash as fluxing agent (although a different one from that used for Raqqa type 1) and a sand as source of silica (while for Raqqa type 1 quartz pebbles were employed). Moreover, the weak positive correlation between phosphorus pentoxide and calcium oxide was interpreted by the authors as a possible indicator of the addition of bone fragments to the melt, intended to balance the lower calcium oxide levels in the plant ash used and, therefore, to stabilise the glass. Raqqa type 4 was in use only for a short period of time, about 150-200 years spanning from the 8^{th} to the 9^{th} century: the majority of analysed glasses from Tell Zujaj are consistent with this group, whilst only 6 bracelets, 2 bottles and 1 vessel fragment from Tell Fukhkhar match Raqqa type 4, interpreted as the result of recycling or reuse of earlier glass (Henderson et al. 2004).

So-called Raqqa type 2 glass showed compositional features that originally led to the hypothesis it was made by mixing natron and plant ash glasses found at Raqqa (Henderson et al. 2004). Recent research (Simpson 2014, Rehren and Freestone 2015) has demonstrated that Raqqa type 2 glasses are compositionally equivalent to Sasanian glass, and, thus, unlikely to be experimental.

The great slab from Bet She'arim and the Raqqa type 4 glass are striking examples of the occurrence of a certain degree of experimentation in the heart of the transition from natron to plant ash.

Despite the fact that the experiment of the great slab failed, whilst the experimentation at Raqqa was successful, they both provide evidence for a marriage between two different glassmaking traditions, happened at a time when the earlier natron-based practice was still remembered (and, probably, in use), but plant ash was, silently, becoming more and more familiar.

2.2.2.c Plant ash-based glassmaking in the Levant: a still fragmentary picture

The histogram in Fig.2.16 clearly highlights how plant ash glass totally replaced the natron-based one by the 11th century. According to recent research, its first occurrence in Palestine is dated to the second half of the 8th century (early ʿAbbasīd period), similar in date to plant ash glass from Raqqa (Phelps et al. 2016).

Though plant ash-based technology dominated almost entirely Islamic glass industry from the 9th century onward, several issues related to its manufacture and consumption still need to be addressed. The main reason responsible for the highly fragmentary nature of this picture can be identified in the lack of an exact chronological attribution for the majority of the objects that have been studied, contributed by excavators of different archaeological sites or coming from collections in the museums.

It is, for instance, the case of the conspicuous glass assemblages from Nishapur and Fusṭāṭ introduced at the beginning of this chapter, whose primary problematic is related to the absence of a clear-cut stratigraphy, highly affecting a precise chronological attribution of the finds.

Analyses on more than 200 glass samples from Nishapur were carried out by Robert Brill (Brill 1995; Brill 1999). According to typological features, the fragments under study are consistent with an attribution to the 9th-10th century. Apart from the mixed natron-plant ash type mentioned before, two other different glass compositions were identified: the former, labelled by Henderson "Nishapur type 4" as it was similar to Raqqa 4 type (Henderson 2002), is likely to have been made by mixing together raw glass and raw materials (plant ash and a sand rich in alumina); the latter, only encompassing colourless samples, shows considerably higher silica and magnesia as well as lower soda and alumina contents; these features are consistent with a different recipe, based on a combination of plant ash and quartz, rather than sand. Glasses with this composition also have higher manganese oxide content, added as a decolouring agent (Brill 1995; Brill 1999).

Concerning glass assemblage from Fusṭāṭ (Old Cairo, Egypt), analyses performed by Robert Brill (Brill 1999; Brill 2001) demonstrated that both natron and plant ash-type soda glasses occurred on the site. Two different types of sand were probably used, as the differences in alumina and iron seem to attest. To date, these are the only available data concerning glasses found in a city that was an active manufacturer of glass from the 7th to the 15th century, especially famous for stained decoration (Scanlon & Pinder-Wilson 2001).

Recent on-site analyses carried out on an assemblage of glass vessels dated from the 9th to the 11th century and excavated from Raya[24], a consumption site located on the Sinai Peninsula (Egypt), allowed classifying the objects into three main compositional type. Two types of plant ash-based glasses were found, along with a natron-based type from 9th century sediments at the Raya Fort (Kato et al. 2009; Kato et al. 2010). Concerning the plant ash-based recipes, authors further distinguished between colourless and coloured glasses. More specifically, they suggested a manufacture in the Mesopotamian region for colourless objects with facet-cuts decorations, (comparable to those commonly encountered in the Sassanian tradition), whilst colourless glass with luster-stained or enamelled decorations was more likely to have been made in Egypt or along the Syro-Palestinian coast; finally, coloured objects show compositional features comparable to those identified for Fatimid glass weights dated to the late 10th-11th century and analysed by Bernard Gratuze (Gratuze 1988).

Analyses carried out on an assemblage of glass finds from Sirāf (Iran) dated between ca. 9th and 11th century has allowed distinguishing between two main groups, both plant ash-based: the former, encompassing the majority of objects, is probably a locally manufactured glass, unique to Sirāf; the latter is compositionally similar to Sasanian and Islamic plant ash glass from Iraq and Iran (Swan et al. 2017).

The cities of Aleppo and Tyre also have produced archaeological evidence for primary glass production during the Ayyubid domain (12th-13th century).

[24] For a description of the site and related finds, see: Shindo 2003 and Shindo 2009.

Aleppo (Syria) was a primary glassmaking centre: the cosmographer al-Qazwīnī mentions the "market of the enamellers" in Aleppo, where amazing decorated objects were sold (Irwin 1998); furthermore, information about materials and techniques are given by Yāqūt, who refers to the use of a specific fine white sand taken on the south site of the Euphrates and used as colourant in glass (Heidemann 2006; Irwin 1998).

A number of historical references support the theory of Tyre (Lebanon) being an important glassmaking centre[25]: the 10th century geographer al-Muqaddasī reports that cut and blown glasses were manufactured at Tyre (Henderson 2013); in 1163, the Spanish Rabbi Benjamin of Tudela reported that about 400 Jews were engaged in glass-production in Tyre (Wright 1848); the 12th century geographer al-Idrīsī wrote that Jews in the suburbs of Tyre produced both glass and ceramics, emphasising the high quality of glass objects manufactured there (Chebab 1979). In addition, Tyre has also provided the most complete evidence of tank furnaces used for the production of glass in use between the 10th and 13th century (Aldsworth et al. 2002). It is likely that furnaces operated at Tyre until 1291, when the city was destroyed by an army of the Mamluk sultan Qalawun (Carboni et al. 2003). Chemical analyses performed on glass produced at Tyre have shown that it was plant ash-based, whose features resemble those of some glasses from the Serçe Limani shipwreck (Freestone 2002).

By the time of the Mamluk caliphate (beginning c. 1250), glass was apparently manufactured in Damascus when it was under state supervision by a low-grade soldier (Henderson 2013), and there is evidence that it was worked in Beirut (Jennings 2006).

By the end of the 13th and into the 14th century enamelled vessels, especially mosque lamps, were commissioned by Mamluk rulers in Cairo. By this time, Cairo took over as the centre of the Mamluk caliphate, and it is likely that large numbers of vessels, especially those commissioned by wealthy rulers, were made there (Henderson 2013).

[25] A complete analysis of written sources related to glassmaking in Medieval Tyre has been provided by Carboni et al. 2003.

Unusual compositions also have been detected in assemblages of Islamic glasses found in an east and a west region of the Islamic world, respectively Afghanistan and Jordan. Analyses on Islamic glass from Afghanistan, carried out on samples spanning from the 7th to the 13th century, were undertaken by Robert Brill (Brill 1972; Brill 1989; Brill 2001). He suggested that the glasses containing potassium oxide levels greater than c. 4.0wt% were characteristic Afghan products, probably indicating that a different plant ash composition was used. A peculiar type of high alumina glass has been identified by Stéphanie Boulogne and Julian Henderson (Boulogne & Henderson 2009) among an assemblage of armlets from Mamluk and Ottoman Tell abu Sarbut and Khirbat Faris, Jordan. The alumina levels detected range from 5.95 to 10.25wt%, consistently higher than found in typical Islamic plant ash glasses. They also contain higher potassium oxide and phosphorus pentoxide levels, and relatively low calcium oxide. According to their compositional features, these armlets have been interpreted as resulting from a mixture of Middle Eastern plant ash glass and high alumina glass found in Africa, India, Sri Lanka and south-eastern Asia (Brill 1987; Lankton & Dussubieux 2006; Dussubieux et al. 2008). The mixing of these glasses may have occurred in the Middle East using imported high alumina glasses from India, or possibly Afghanistan (Boulogne & Henderson 2009).

Analyses performed by Nadine Schibille (Schibille 2011) on an assemblage of glass objects from Pergamon, Turkey, also including bracelets, provided the first evidence for the occurrence of a 8th to 14th century Byzantine glass type with high alumina and boron, possibly linked to a local/regional production. Further research on glasses found at Pergamon has demonstrated that this regionally produced high-boron high-alumina glass falls into several sub-groups, suggesting the existence of different production sites. According to trace element patterns, it has been assumed that this glass was made in the region east of Pergamon and north of Sardis, near the borate deposits in western Asia Minor (Rehren et al. 2015).

Interestingly, its use is not restricted to Pergamon, since it seems to also have been found in Bulgaria (Borisov 1989) and in Ḥiṣn al-Tīnā, southeast Turkey.

Analyses have shown that 10th-12th century bracelets from Ḥiṣn al-Tīnā were made of a peculiar high-boron and high-alumina glass, likely to be locally-made according to trace element patterns (Swan et al. 2018).
The introduction of this fluxing agent does not seem to be linked to the collapse of natron supply; it can, more likely, be interpreted as a direct consequence of the availability of boron-rich minerals in western Asia Minor.
It is evident that the outlined scenario on plant ash glassmaking technology in the Levant is challenging and far from being complete: several questions remain concerning plant ash glass production and supply in the Near East, especially on its geographical spread, and its commercial routes and networks across time. Results obtained from recent research are helping to lay useful foundations to answer these questions.
In 2016, Julian Henderson and colleagues published a first broad survey of 8th –15th century plant ash glass from the Middle East, across a 2000 miles area stretching from Egypt to northern Iran. Trace element analyses seem to prove the existence of regional production zones in the Levant, northern Syria and in Iraq/Iran, as well as production sub-zones associated with large cosmopolitan urban hubs with thriving economies and presumably supplying local, regional and supra-regional markets (Henderson et al. 2016).
Archaeometric analyses undertaken by Matt Phelps on well-dated vessel glass excavated from seven sites in Ramla allowed identifying three main compositional groups, corresponding to three regional glass compositions: Eastern Mediterranean, Mesopotamian Type 1 and Mesopotamian Type 2 (Phelps 2018). These broad regional compositions have provided a useful framework in which further studies on plant ash-based glasses can be better contextualised and, thus, interpreted.

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Chapter 3

Glass in the Umayyad caliphate (661-750 century)

"Fusaifisā [Arabic word for mosaic, derived from the Greek ψήφος] *is a substance made of glass and of little stones baked together and combining much brilliancy and beauty with a great variety of colours; this substance is sometimes mixed with gold and silver*."

Khalīl, *Kitāb al-'Ayn*

The Umayyad caliphate was the first Islamic dynasty to emerge in the Near East following the conquest of the region by the Arabs.
Founded by Mu'awiya in the summer or autumn of 661, the Umayyad dynasty lasted until 750, when Marwān II was defeated at the Battle of the Great Zāb River. Members of the Umayyad house were hunted down and killed, but one of the survivors, ʿAbd al-Raḥmān, escaped and established himself as a Muslim ruler in Spain (756), establishing the dynasty of the Umayyad in Córdoba which would have lasted until 1031 century[26].
In outlining a history of Islamic glass through time, it has been noticed how Umayyad caliphs have long been thought not interested in patronising the glass industry, the roots of this theory primarily lying in two main reasons: the absence of objects with moulded inscriptions, which would indicate that glass was granted an official status, and the lack of entirely new products and typologies.
Nevertheless, it would be biased to conclude that Umayyad caliphs and affluent people of the time did not promote glassmaking only because of the scarcity of fine glass.
To appropriately understand the production of glass just before and after the advent of the first Islamic caliphate, it has to be borne in mind that the spread

[26] For an extensive discussion on Umayyad caliphate, see, for instance: Al-Ajmi 2014; Blankinship 1994; Bewley 2002; Crone 2008, Donner 1981; Donner 2008; Ettinghausen et al. 2001; Fowden 2004; ; Hawting 2005; Kennedy 2004; Robinson 2011.

of the glassblowing technique allowed glass to become a common material, more accessible for everyday use and, consequently, made it less attractive to affluent patrons of the time.

In addition, it is difficult to ascertain whether the crucial political changes occurred shortly after the death of the Prophet Muhammad disrupted the quiet life of the glassmakers, who had been blowing glass in their workshops along the eastern Mediterranean coast and in Egypt for more than six centuries before the advent of Islam and the arrival of the new rulers (Carboni 2001).

It is undeniable that, when dealing with glass manufacture datable either to the Byzantine-Islamic transitional phase or to the Umayyad caliphate, we have to evaluate a still fragmentary and complex picture. This difficulty primarily stems from the relatively scarce abundance and fragmentary nature of well-dated finds related to these periods. Moreover, methodical research on "transitional" and Umayyad glass only started about twenty years ago, whilst earlier studies were mainly centred upon artistic features of individual pieces (Avni 2014; Walmsley 2007).

This chapter is aimed at providing a state of the art on glass under the Umayyad caliphate. Glassware will firstly be examined and evaluated, paying a specific attention to typologies, shapes and decoration techniques showing some preliminary symptoms of novelty as early as the Umayyad age.

Then, an in-depth discussion upon mosaic glass tesserae manufacture and consumption in the Umayyad age will be provided. A specific attention will be devoted to an excursus upon literary sources implying, on the one hand, a gathering of materials and craftsmen from Byzantium and, on the other hand, legacies other than Byzantines in the manufacture of mosaics adorning Umayyad mosques.

3.1 Glassware between tradition and innovation

Umayyad glassware is particularly under-represented in the literature and very few glass assemblages from well-dated Umayyad contexts have been published to date, the main reason being the limited and fragmentary nature of the unearthed finds.

Recent research shows that the Umayyad glassware repertoire essentially represents a continuity of previously established Roman and Byzantine traditions, though the emergence of new typologies and decorative patterns has also been noticed (Gorin-Rosen 2016). This theory is nowadays widely accepted among scholars, which have dismissed the use of terms like "Byzanto-Umayyad" and "Late Byzantine/Early Umayyad".

In virtue of these new outcomes, the even more general expressions "proto-Islamic" or "Early Islamic" should also be avoided when discussing upon glass manufacture ascribable to the first centuries of the Islamic domain in the Near East, since, in the last decades, these expressions have commonly been used to embrace too large chronological ranges (see chapter 2), making it difficult to evaluate and trace both typological and compositional changes.

In this paragraph, a summary of the main typologies and decoration techniques where these symptoms of novelty are more clearly revisable will be provided. In order to do so, only assemblages found in well-dated Umayyad contexts will be considered, as those recovered at Bet She'an, Caesarea, Ramla and Tiberias[27].

[27] Bet She'an has yielded the most extensive corpus of Umayyad glass vessels, published by Shulamit Hadad (Hadad 2005) and Tamar Winter (Winter 2011). Typological and technological study of glass vessels from the first phases of the Islamic occupation layers at Caesarea (640-969) is provided by Rachel Pollak (Pollak 2003) (more specifically, the so-called stratum VIII - located at the south-eastern edge of the Temple Platform - represents the transition from the Byzantine to the Islamic period, datable between 640 and 749). Umayyad glassware from Ramla is extensively discussed by Yael Gorin-Roen (Gorin-Rosen 2008; Gorin-Rosen 2010; Gorin-Rosen 2016) Natalya Katsnelson (Katsnelson 2013) and Rachel Pollak (Pollak 2007). In the vicinity of Ramla, assemblages of early Islamic glass with similar Umayyad vessels were also found, at Horbat 'Illin (Katsnelson 2012) and Khirbat el-Thahiriya (Jackson-Tal 2012). Excavations at Tiberias have also yielded a conspicuous amount of glass finds, about 10.000 pieces; glass vessels from the excavations conducted in 1973-1974 were published by Ayala Lester (Lester 2004), while those from the excavations in 1989-1994 were published by Nitzan Amitai-Preiss (Amitai-Preiss 2004); in 2008, Shulamit Hadad also published glass finds recovered in the so-called House of the Bronzes (Hadad 2008). Vessels are mainly ascribable to the Roman and to the Abbasid-Fatimid periods of occupation of the site, while only a few are assigned to the Umayyad. More specifically, the so-called stratum V has provided glass finds referable back to the period of the Byzantine-Umayyad transition (Lester 2004).

From all mentioned sites, assemblages are mainly composed of domestic ware, like bowls, bottles, beakers, wineglasses, jugs, jars, oil lamps and windowpanes. Objects are generally free-blown, with a few mould-blown pieces; the glass is translucent, mainly in shades of light blue and light green, with only a few yellowish brown or colourless pieces.

Regarding the decorative techniques and patterns, the application of trails is the most common in the Umayyad repertoire, followed by mould-blowing and pinching.

In particular, it can be noticed that traceable symptoms of innovation in terms of typologies and decorative techniques and features are specifically revisable in bowls, bottles, beakers and wineglasses, and oil lamps[28].

Umayyad bowls generally show spherical shapes, with a flat or slightly concave base, curving walls and rounded rims, either folded-out or infolded. Bowls with rounded folded-out rims (Fig.3.1) are a continuity of previously established late Roman and Byzantine forms, very common in the Syro-Palestinian region. Conversely, large and deep bowls with thick walls and infolded rims (Fig.3.2) represent a new type, very common in contexts from Umayyad to Abbasid-Fatimid periods (Gorin-Rosen 2008; Gorin-Rosen 2010; Gorin-Rosen 2016; Hadad 2005; Jackson-Tal 2012; Lester 2004; Winter 2011).

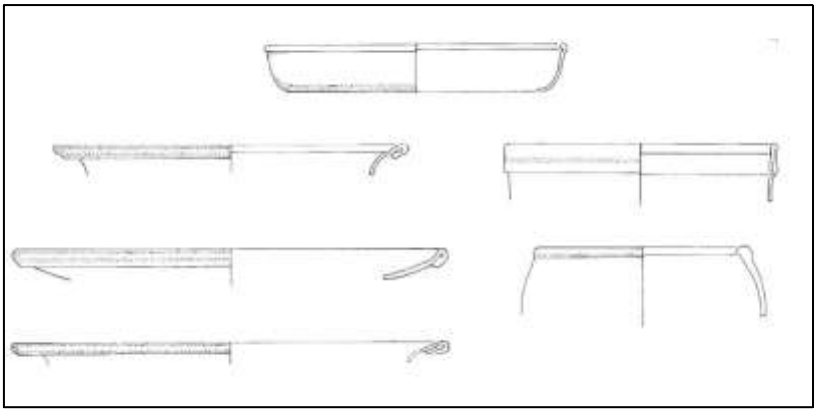


Fig.3.1 Exemplars of bowls with folded-out rims
(adapted from Jackson-Tal 2012, p. 58).

[28] Please note that the following pages do not intend to provide a comprehensive discussion on the typological development of glassware under the Umayyad caliphate, as this would go beyond the purpose of this study. Due to this reason, the comparisons between finds from different sites for each typology of vessel is here avoided, though it can be ascertained comparing the available literature on the subject, quoted in the text.

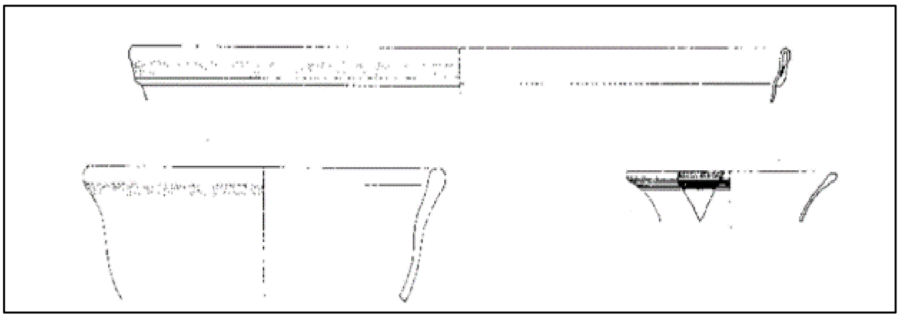


Fig.3.2 Exemplars of bowls with infolded rims
(adapted from Winter 2011, p. 347).

Together with these two main typologies, several variants have also been encountered. At Ramla, two unique pieces of large footed bowls were unearthed, made of three parts: an upper shallow bowl, a short beaded stem and an applied foot (Fig. 29) (Gorin-Rosen 2008; Gorin-Rosen 2016). Ramla also yielded evidence for the occurrence of three bowls with out-folded rims and tubular base-rings (Fig.3.3), a typology probably representing a continuity of old traditions into the Umayyad period and disappeared afterward (Gorin-Rosen 2016).

Fig.3.3 Bowls unearthed at Ramla: pieces 1 and 2 are made of three different parts, while drawings 3 and 4 have out-folded rims and a tubular base-ring (Gorin-Rosen 2016, p. 43).

Bowls ascribable to the Umayyad period are mainly plain. When decorations occur, pinching is among the most frequently encountered techniques, while mould-blowing and applied trails are less common. Equidistant vertical ribs beginning at the base and ellipses and circles adorning the whole body are typical mould-blown patterns found on bowls (Pollak 2003; Hadad 2005). Pinching is generally made in the lower part of the bowl, very close to the base, and the decorative motif is represented by one or two horizontal rows of nips (Fig.3.4) (Hadad 2005).

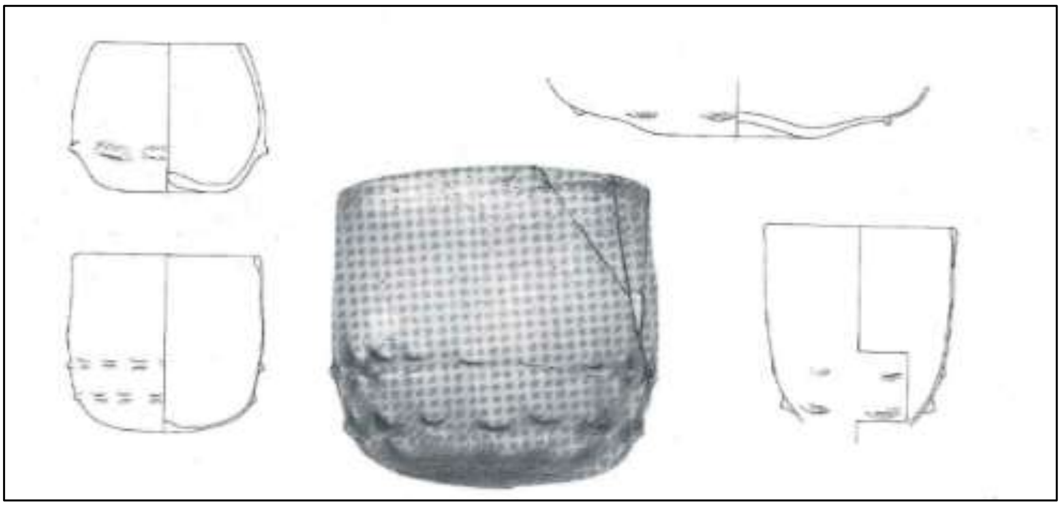
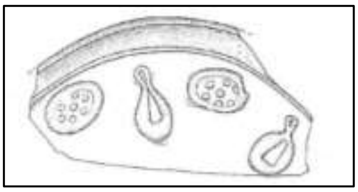
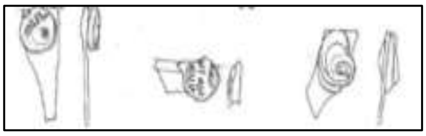


Fig.3.4 Bowls with pinched decorations (adapted from Hadad 2005, p. 97).

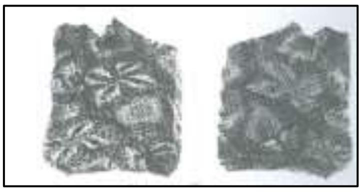
Excavations at Bet She'an also brought to light unusual bowls ascribable to the Umayyad age: a shallow bowl whose base is adorned with medaillons displaying stylised flowers and figure-of-eight motifs (Fig. 3.5a); five bowls bearing stamps with inscriptions, presumably used for commercial purpose (Fig. 3.5b); one miniature mosaic glass bowl (Fig. 3.5c), whose decoration and colours differ from the Hellenistic and Roman models (Hadad 2005).



a)



b)



c)

Fig.3.5 Unusual bowls from Beth She'an: a) adorned with medaillons; b) bearing stamps with inscriptions; c) miniature mosaic bowl (adapted from Hadad 2005, p. 97).

Bottles are the most numerous category of glassware encountered at all the examined sites, showing the highest variability in terms of forms and decorations.

Exemplars with a squat globular body and a funnel-shaped mouth (Fig.3.6) were widespread during the Byzantine age and continued into the Umayyad (Gorin-Rosen 2016; Hadad 2005; Lester 2004; Pollak 2003; Winter 2011).

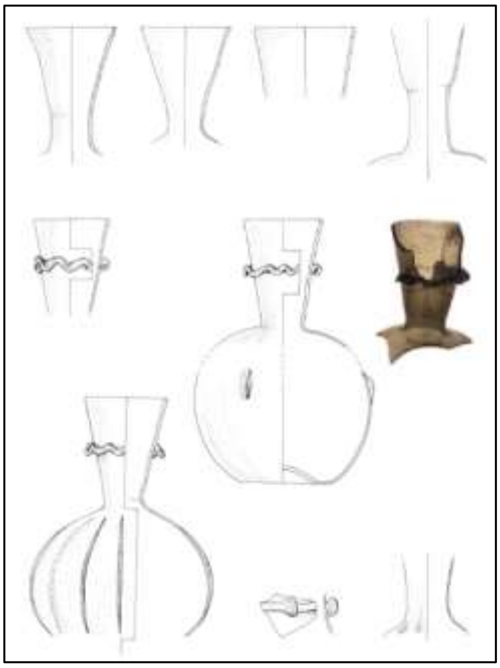


Fig. 3.6 Bottles with globular bodies and funnel-shaped mouths (Gorin-Rosen 2016, p. 48).

An evolution of this type, representative of the Umayyad period and commonly found, is revisable in small bottles with a squat globular body, a short straight neck and a folded-in flattened rim (Fig.3.7) (Gorin-Rosen 2016; Hadad 2005; Lester 2004; Pollak 2003; Winter 2011).

A less common typology is represented by rectangular bottles, as those unearthed at Bet She'an in the shops of the *sūq* of Hisham (Hadad 2005).

Fig.3.7 Small bottle with globular body, a short straight neck and a folded-in flattened rim (adapted from Hadad 2005, p. 105).

Applied trails, generally in a colour darker than the body, are the most frequent decoration attested on bottles, while pinching and mould-blowing are less recurrent. Though applied trails decorative technique was widely used in the Byzantine period, Tamar Winter (Winter 2011) has noted how variations in its arrangements can be helpful in defining a more precise chronological attribution. A thin trail wound horizontally around the neck of the bottle is, for instance, more typical of the Byzantine period, whilst uneven irregular trails and a single thick wavy trail around the neck or mouth are more typically Umayyad; in addition, some bottles bear more than one variation of trail decoration (Fig.3.8).

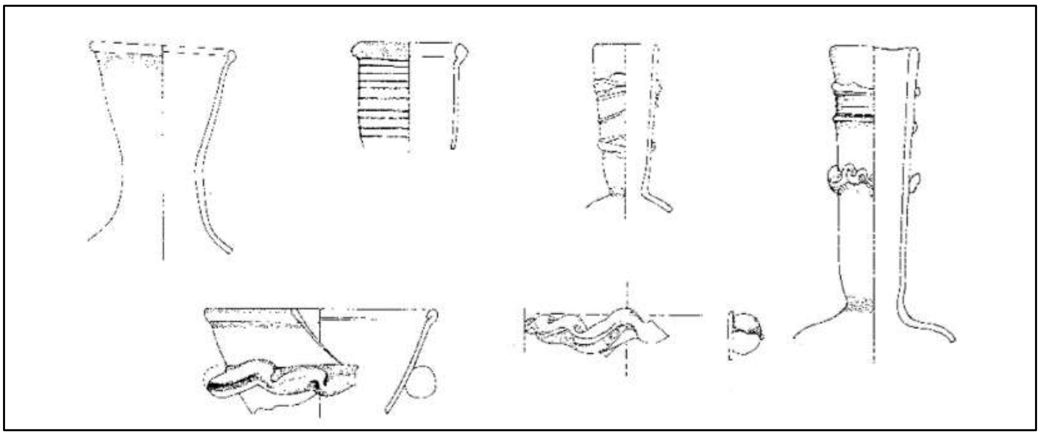


Fig.3.8 Variations of trail decoration applied on bottles (adapted from Winter 2011, p. 347).

Bottles with stamps attached to the rim or slightly below it were also found at Bet She'an. The context where they were recovered (the shops of the *sūq* of Hisham) suggests these bottles were used for commercial purposes, presumably refilled by the sellers for further use (Hadad 2005).

Beakers and stemmed goblets were also among the most commonly encountered vessel types in Umayyad assemblages.

Beakers generally have a slightly thickened, rounded, incurving rims and a flattened or slightly concave base (Fig.3.9). This type is distinctive of the Umayyad period, as it also finds a direct comparison with the analogous bowls discussed above (Hadad 2005; Jackson-Tal 2012; Winter 2011).

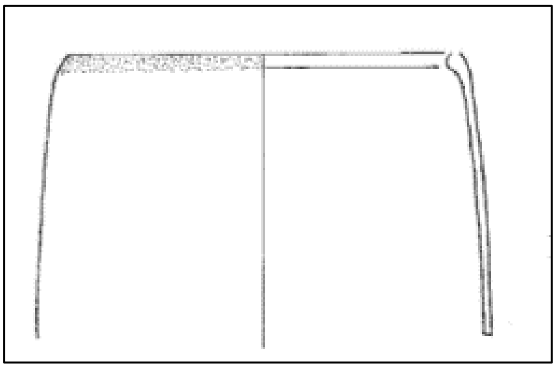


Fig.3.9 Beaker with slightly thickened, rounded and incurving rim (adapted from Jackson-Tal 2012, p. 58).

Concerning stem-footed vessels (wineglasses), they were widespread during the 6th and 7th century. The typical wineglass has a rounded or infolded rim, convex or flaring walls and a stem ending in a hollow or solid ring base. The stem could be either straight or knobbed (Hadad 2005; Lester 2004). Regarding the bases, Tamar Winter (Winter 2011) has noted that the hollow bases are more characteristic of the 6th century, whereas the solid are more frequent in the 7th century and onward (Fig. 3.10).

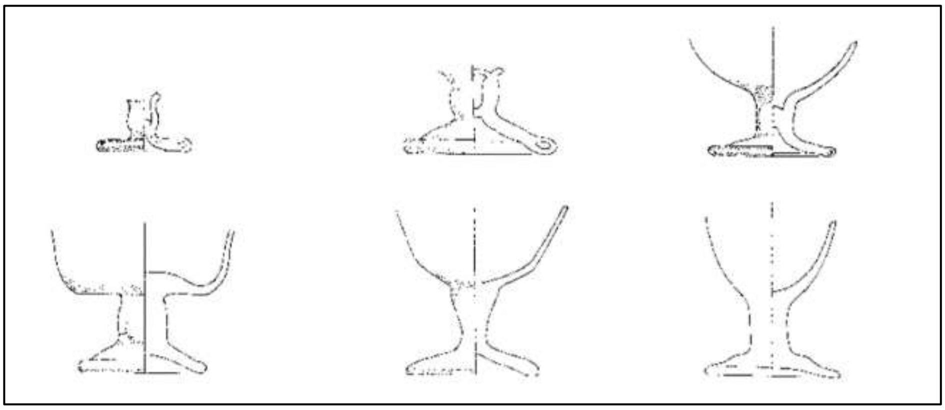


Fig.3.10 Stem-footed wineglasses
(adapted from Winter 2011, p. 347).

Oil lamps were also commonplace during the Byzantine and Umayyad periods, and two main typologies were unearthed from Umayyad contexts: bowl-shaped with a cut rim and stemmed (Fig.3.11).

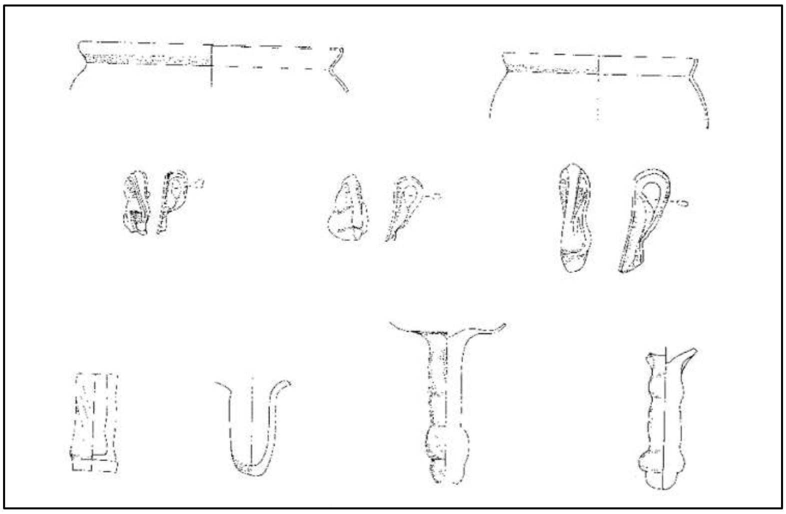


Fig.3.11 Bowl-shaped oil lamps and some typologies of stems
(adapted from Winter 2011, p. 351).

Globular and ovoid bowl-shaped oil lamps appeared in the second half of the 4th century and continued into the 7th century. They generally also have three handles attached to the shoulder (Hadad 2005; Winter 2011).

Concerning stemmed oil lamps, they were widespread during the Byzantine period and continued into the Umayyad caliphate. Intended to be set into suspended *polycandela* and mainly used to lighten public buildings, the stems appear in several variations: hollow, solid and beaded (Hadad 2005; Jackson-Tal 2012; Winter 2011).

An entirely new Umayyad oil lamp type is revisable in the so-called "Type 5" unearthed at Bet She'an (Hadad 2005). Made of light or dark bluish green or olive green glass, these lamps have a smooth, hollow stem narrow at the bottom and wider toward the top (Fig.3.12).

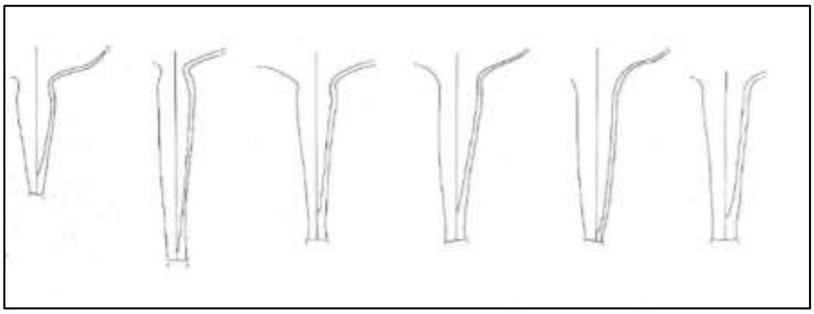


Fig.3.12 "Type 5" oil lamps from Bet She'an
(adapted from Hadad 2005, p. 135).

The above summary depicts how a continuity of Roman and Byzantine traditions is revisable in forms and decorations among the main typologies of Umayyad domestic glassware. However, it is undeniable that new elements also began to appear. In terms of forms, the best examples of innovation are represented by bowls and beakers with infolded and flattened rim, as well as by the squat globular bottles with straight neck and a flattened infolded rim. Decorative styles and patterns also start to show some symptoms of change in the Umayyad period, the most evident case being represented by introduction of new arrangements in the way applied trails are wound around the vessels.

3.2 Mosaic glass tesserae: an ongoing enigma

3.2.1 *Spolia* from Byzantium? The gathering of mosaic glass tesserae under the Umayyad caliphate

Between 2007 and 2010, the Leverhulme Trust undertook the funding of an International Network aimed at exploring the nature of Byzantine glass wall mosaics, with particular emphasis on addressing technical issues related to the manufacture of the tesserae and their distribution across time and space.

In order to examine mosaics and mosaic making in an interdisciplinary context, the network brought together scholars from Europe and America interested in scientific analyses of Byzantine glass together with those concerned with the formal and cultural aspects of Byzantine mosaics [http://www.sussex.ac.uk/byzantine/mosaic].

Lastly updated in 2012, this database comprises 292 entries of mosaics datable between the 4th and 15th century and distributed across the Mediterranean area (Fig. 3.13).

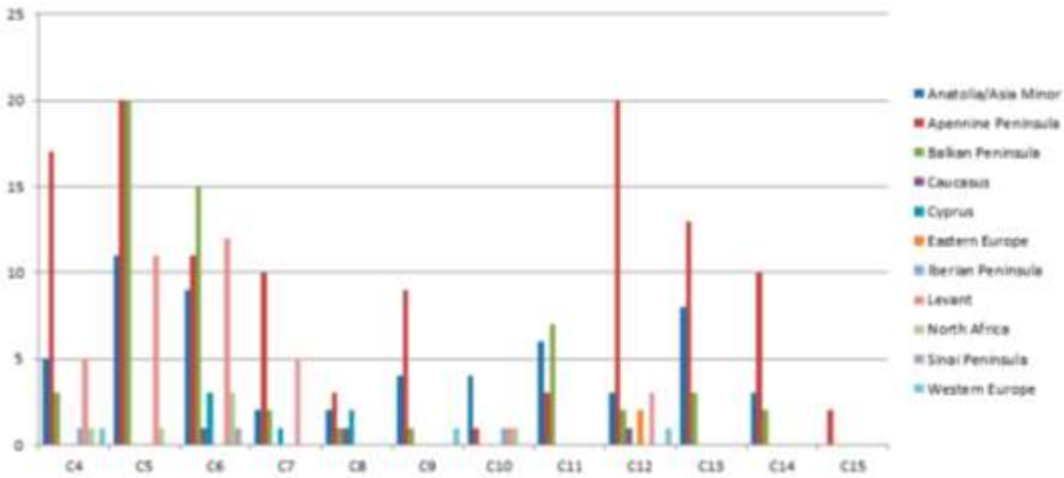


Fig.3.13 Graph showing new mosaics by century and region between 4th and 15th century (James et al. 2013, p. 323).

If a closer look is given at these "*Mosaics by Numbers*" (James et al. 2013), it can be noticed that a progressive increase in the number of recorded newly built mosaics was observed between the 4th and the 6th century (33, 63 and 55 records respectively), with the survived evidence implying their use in major cities. The majority are, indeed, located in Italy (especially Rome), but the eastern provinces of the Empire also contribute as well as the Levant (Syria, Jordan and Israel), well-represented especially by the 5th century.

This "golden age" was then followed by a noticeable decline between the 7th and 8th century. The number of mosaics decreased in the 7th century from more than 50 to 20 exemplars: 9 Italian (8 in Rome) and several churches from the Levant are included, with the Dome of the Rock in Jerusalem being the first example of an Islamic religious building adorned with mosaic. A further drop occurred in the 8th century, with the number of mosaics decreasing at only 9: 3 in Rome and 6 from the Levant (among which, the Great Mosque in Damascus).

Though a precise reason for this phenomenon still needs to be recognised, it has been stated that major political events might have affected such a decrease in the production of mosaic works, like the Arab conquest of the 7th century and the advent of Iconoclasm in the following (James et al. 2013).

Interestingly, the domain of the Umayyad caliphate collocates itself exactly in the period when the number of registered mosaics underwent major decreases: the 7th and the 8th century. Even more interestingly, among the newly built buildings adorned with mosaic decorations there are two of the highest expressions of Umayyad religious architecture: the Dome of the Rock (Jerusalem) and the Great Mosque in Damascus.

In 1958, when discussing upon the Arabs-Byzantine relations under the Umayyad caliphate, Hamilton Gibb affirmed: "*The Umayyad relations with Byzantium were not confined to simple national or regional hostility, but governed by more ambivalent attitudes of both attraction and opposition*" (Gibb 1958, p. 223). Furthermore, he stated that, though proofs supporting this statement were not easy to find, mainly due to the scarcity of written sources focused on other than political affairs, some clues could be identified in the increasing tendency of the Umayyad to adopt Byzantine usages. This tendency was, for instance, witnessed by the Byzantine design adopted for the earliest gold coinage of the Caliph 'Abd al-Malik[29], as well as by the re-shaping of Byzantine legal and administrative norms (Schacht 1950). However, above all,

[29] See the dedicated discussion in Chapter 1.

the most noticeable legacy of the Byzantine imperial heritage was revisable in the Umayyad policy of constructing imperial religious monuments.

The 10th century geographer al-Maqdisī reported a local tradition that the Umayyad Caliphs ʻAbd al-Malik and al-Walīd built the Dome of the Rock in Jerusalem and the Great Mosque in Damascus by fear that the Muslims were tempted away from their faith by the magnificence of Christian religious buildings in Syria (Lambert 1956).

In addition to that, al-Maqdisī was the first author who mentioned the despatch of materials from the Byzantine emperor for the construction of the Great Mosque in Damascus:

"[…] *Al-Walīd, they say, gathered together for its construction skilful artisans of Persia, India, the Maghreb, and Rūm. He devotee to it the proceeds of the Land Tax of Syria for seven years, employing also eighteen shiploads of gold and silver which sailed from Cyprus, without counting the tools and the mosaics which were sent to him by the King of the Rūm*[30]"[31].

Information on requests and gathering of implements, as well as skilled workmen and materials, to be involved in the construction and decoration of newly built mosques, are provided by further sources.

Concerning the Prophet's Mosque in Medina, the first allusion to the participation of Byzantium occurs in Ya'qūbī (874 century):

"*Al-Walīd sent to the Emperor of Rūm informing him that he had demolished the Mosque of the Prophet of God, so let him help him with regard to it; so he sent him 1000.000 mithqāl of gold and one hundred workmen and forty loads of mosaic, and al-Walīd sent all of that to ʻUmar and he repaired the mosque and finished* [re-]*building in the year 90"*[32].

[30] The word *Rūmī* means, in Arabic, Byzantines. It designates all the Byzantine Greeks and Melkites of Syria and Egypt who lived in the time of the Umayyads.
[31] al-Maqdisī, *The Best Divisions for Knowledge of the Regions* (985 century), cited in Gautier-van Berchem 1969, p.233-234.
[32] Ya'qūbī, *Ta 'rikh* (874 century), cited in Gautier-van Berchem 1969, p.231.

Dinawārī (895 century) speaks of materials only and not mosaicists being sent to Medina for the construction of the mosque:

"*He* [al-Walīd] *wrote to the sovereign of the Greeks informing him of the decision that he had taken [to enlarge the mosque] and to ask him to send him what he could of cubes for mosaic: the latter sent him 40* wasq, *which al-Walīd sent to 'Umar ibn 'Abd al-Azīz*"[33].

Ibn Rusta (903 century) also reports information concerning Byzantine aid for the construction of the Mosque of Medina:

"[…] *The Emperor sent loads of mosaic and more than twenty workmen, others say ten workmen only; and he* [al-Walīd] *wrote to him: "I have sent you ten workmen who are well worth a hundred* […]"[34].

In his 10th century *Chronicle*, al-Tabarī reports:

"[…] *al-Walīd had sent to inform the lord of the Greeks that he ordered the demolition of the mosque of the Prophet, and that he should aid him in this work. The latter sent him 100.000* mithqāls *of gold, and sent also 100 workmen, and sent him 40 loads of mosaic cubes; he gave orders also to search for mosaic cubes in ruined cities and sent them to al-Walid, who sent them to [his governor in Medina] Omar b. Abd al-Aziz*"[35].

Furthermore, in the *History of Medina*, composed in the 9th century by the scholar Ibn Zabāla, the following account is found:

"[…] *al-Walīd b. 'Abd al-Malik wrote to the King of the Greeks: "We purpose to restore the greatest mosque of our Prophet; aid us therefore to do so by workers*

[33] Dinawārī (895 century), cited in Gautier-van Berchem 1969, p.232.
[34] Ibn Rusta (903 century), cited in Gautier-van Berchem 1969, p.232.
[35] al-Tabarī, *Chronicle* (915 century), cited in Gibb 1958, p.232.

and mosaic cubes". And he sent him loads of mosaic cubes and some twenty-odd workmen [...]"[36].

In c. 1160, Ibn Asākir is the first author to mention craftsmen being sent to Damascus after the caliph had threatened the emperor:

"*When al-Walīd ibn 'Abd al-Malik wanted to build the Mosque of Damascus, he needed a great number of workmen, so he wrote to the Byzantine Emperor: "Send me 200 Rūmī workmen, for I wishj to construct a mosque, the like of which has never been built and never will be again. If you do not comply I will invade your country with my armies. I will destroy all the churches in my territory, including those of Jerusalem, Edessa, and all the Rūmī monuments* [...]"[37].

Written sources seem, therefore, imply that the movement of tesserae and craftsmen around the Mediterranean was not unknown under the Umayyad caliphate[38].

Nevertheless, the issue of the sent mosaic cubes and skilled workmen has arisen several problems due to the reliability of the sources themselves: should these texts be read as propaganda pieces aimed at enlightening the power of the Muslim rulers or, on the contrary, could they imply that the trade between Muslims and Byzantines went on despite their rivalry? (Cutler 2001; Gibb 1958; James 2006).

If, on the one hand, answers to these questions still need to be provided, on the other hand it has to be stressed that the state of knowledge on the use of glass as a material in the manufacture of Byzantine mosaics is still quite fragmentary.

Research on the use of glass tesserae in the manufacture of Byzantine mosaics has, indeed, been largely non-existing. This statement should not sound unexpected to scholars working in the field of historical glass studies, since

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[36] Ibn Zabāla, *History of Medina* (814 century), cited in Gibb 1958, p.225.

[37] Ibn Asākir, *Damascus Manuscript* (c. 1160 century), cited in Gautier-van Berchem 1969, p.234.

[38] In addition to the quoted sources, later texts spanning between the 12th and 16th century also report information on gathering of materials and artisans from Byzantium for the construction and decoration of Islamic mosques. These are extensively discussed in Gautier-van Berchem 1969, p.234-242.

Byzantine glass has long been defined as an enigma, with several questions deserving proper answers: does it mean glass produced in Costantinople? Or glass produced in the territories of the Byzantine Empire? Or glass of a recognisable Christian character? (Keller 2010). Thought these queries firstly arose in the 20th century, when the knowledge of glass within the Byzantine Empire was too scanty and a recognisable Byzantine style in glass could not be established, it can be affirmed that proper answers are still lacking today[39].

Back to the use of glass in Byzantine mosaics, its occurrence started to be mentioned in publications of the late 19th century. In 1878, Alexander Nesbitt stated that "*glass was largely used for works in mosaics*" (Nesbitt 1878, p. 49). Slightly later, in 1908, Anton Kisa (Kisa 1908) affirmed that glass used for mosaics was the exception to his denial of the existence of a Byzantine glass. A short overview on the use of glass tesserae in wall mosaics of early Byzantine churches in Palestine was then published in 1941 (Crowfoot 1941); in the late 1960s, some notes on the use of glass tesserae in mosaics of Byzantine Syria (Zhoudi 1969), and a brief summary on the general topic (Bovini 1969) were published.

It was Liz James who, in 2006, published the first comprehensive consideration on the state of research on Byzantine glass mosaic tesserae, as well as on future studies to be undertaken (James 2006). In her paper, she extensively discusses the concept of wall mosaic employed as a status-symbol, an indicator of prestige and, therefore, a medium restricted to secular and religious rulers. James goes on highlighting the commonplace of glass wall mosaics being scarce and limited to major cities, emphasising how this theory has led to the assumption that mosaicists must have been based in the major centres and, where mosaics are found outside the Empire, these must reflect an import or a borrowing of techniques, workmen and materials. In her pivotal paper (James 2006) and in later studies (James 2010; James et al. 2013) she opposes this theory, the main proof being the considerable archaeological evidence provided by numerous surveys for wall mosaics stretched far beyond the surviving examples in well-

[39] Discussion on several aspects related to Byzantine glass production, trade, manufacture and technology has highly benefited from recently published research, like Drauschke & Keller 2010 and Entwistle & James 2013.

known churches in the main Byzantine centres like Constantinople and Thessaloniki[40].

In her most recent publication (James 2017), Liz James also underlines how the study of medieval (from Late Antiquity to 15th century) mosaics has been dominated by the analysis of their style. The term "Byzantine" has loosely been used of artists, with a lack of distinction between ethnicity and nationality. As a consequence, medieval mosaic has been presented as a Byzantine art form, this leading to the belief that Byzantine mosaicists were superior in skill and travelled the Mediterranean taking this expertise with them and presumably teaching it to natives.

If the scenario of the distribution of Byzantine wall mosaics is still uncomplete, what is known about the production process of mosaic glass tesserae is very limited as well. Little evidence of tesserae-making has been discovered at the major glass-objects sites in the Mediterranean basin. At Beth Shean, for instance, where containers of previously used tesserae were found, there is no evidence for their manufacture at the site (Shugar 2000). A glass factory with tesserae from the same context was believed to have been discovered on Torcello, dating perhaps to the 7th or 8th century (Gasparetto 1967); however, analyses carried out on the tesserae have indicated that the glass was not made in the region and that the tesserae consisted of recycled and reused glass, probably imported from elsewhere (Andreescu-Treadgold et al. 2002).

These limited material remains seem to suggest that a limited number of specialised factories involved in the production of glass tesserae existed (James 2010). Nevertheless, the *chaîne opératorie* these factories were based upon, is still an enigma: how, when and where was the glass coloured and opacified? Was the glass used in the manufacture of mosaics imported as raw glass or already as a finished product?

The picture of the manufacturing process of mosaic glass tesserae is, thus, still unclear and puzzling, with specific reference to how and where the raw glass was opacified and coloured. Tesserae could have been made by directly adding

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[40] The sites are all included in the Leverhulme Database [http://www.sussex.ac.uk/byzantine/mosaic], where detailed descriptions of the finds are also provided.

colourants either to the primary batch, or in a secondary process, as mentioned, for instance, by Pliny the Elder for the Roman age (Pliny, *Naturalis Historia*, 36, 66, 193). Currently, the main archaeological evidence is for Roman and Late Antique glass making sites producing only naturally coloured glass (Freestone et al. 2000; Gorin-Rosen 2000; Nenna et al. 2000), though it is uncertain whether the secondary production of tesserae was a centralised business, where a single workshop produced tesserae of different colours, or whether multiple workshops specialised in one colour at the time (Schibille et al. 2012; Neri et al. 2017).

Since, considering the manufacture of Byzantine glass tesserae, the only current surviving evidence is that of the tesserae themselves, archaeometric analyses are a crucial step forward: the chemical composition of the base glass can be linked to the location of the primary workshop, whilst colourants and opacifiers are related to the secondary workshop(s) where the glass cakes were made[41].

The International Network working on the Leverhulme Database has undoubtedly represented a fundamental step forward in the research aimed at understanding the use of glass tesserae in the manufacture of Byzantine mosaics, but the work cannot be considered concluded. To date, few comparative studies have been undertaken between analysed assemblages of tesserae, and much remains to be done both to pull together these separate finds and to expand the range of tested tesserae.

[41] Published results achieved through archaeometric studies of Byzantine glass tesserae will not be discussed at this point of the dissertation. They will accurately be taken into account when discussing data obtained by analyses carried out on the materials under study for the present research, in order to better evaluate and highlight analogies and differences concerning both the glass compositions and colourants and opacifiers and, therefore, linked to the manufacture technology.

3.2.2 Legacies other than Byzantines: evaluating further theories on the manufacture of Umayyad mosaics

In the previous pages, it has been stressed that the issue of the sent mosaic cubes and skilled artisans from the Byzantine emperor has arisen some problems ascribable to the reliability of the sources themselves. The interpretation of written sources reporting on workmen and materials gathered from Byzantium by the Umayyad caliphs appears to be quite controverted and non-univocally accepted among scholars.

In the first edition of Creswell's *Early Muslim Architecture*, the archaeologist Marguerite Gautier-van Berchem clearly expressed her scepticism on the subject of Byzantine assistance in the construction and decoration of Umayyad mosques, strongly competing against the information reported by al-Tabarī on the Prophet's Mosque at Medina, as well as about the assumptions made by al-Maqdisī regarding the Great Mosque of Damascus (Creswell 1932, pp. 156-157). Her theory was also supported by the historian Jean Sauvaget, who interpreted the participation of workmen from Byzantium to the construction of the Prophet's Mosque at Medina as "*a tradition of a legendary character*" (Sauvaget 1974, pp. 10-11).

Between 1927 and 1928, after having spent several weeks examining the mosaics adorning the octagonal arcade of the Dome of the Rock and the technique they were made, Marguerite Gautier-van Berchem came to the following conclusion: "[…] *I became convinced that I was actually in the presence of an autochthonous work of art, not executed by mosaicists from Byzantium but by Syrian artists trained in the great artistic traditions of which Syria had, in the course of the centuries, been the centre. My examination of the mosaics of the Mosque of the Umayyads in Damascus had led me to the same conclusions with regard to their origin*" (Gautier-van Berchem 1969, p. 223).

Interestingly, in the same contribution, she also asserted: "*the rapidity with which the Dome of the Rock was erected and decorated must have necessitated a recourse to foreign labour and possibly to a large number of artisans from neighbouring countries*", and an analogous consideration was also made with

reference to the Great Mosque in Damascus (Gautier-van Berchem 1969, pp 322, 371).
Marguerite Gautier-Van Berckem refers to several ancient documents that support her hypothesis. The oldest is a text written by al-Balādhurï (868 century), concerning the Mosque of Medina:

"*Al-Walīd wrote to 'Umar, son of 'Abd al-Azīz, his Governor at Madīna, ordering him to demolish the mosque and to reconstruct it. He had money, mosaics, and marble sent to him and eighty Rumī and Coptic craftsmen, inhabitant of Syria and Egypt* […]"[42].

The geographer al-Maqdisī is also taken as an example, since it clearly refers of craftsmen from Syria and Egypt working at the Mosque of Mekka:

"*The Mosque of Mekka was* [re-]*built by al-Mahdī. The walls of the porticoes are covered on the outside with mosaic. Craftsmen of Syria and Egypt were brought thither for the purpose. Their names are to be seen there*"[43].

Official documents also report that caliph 'Abd al-Malik set aside the tax revenues of Egypt for seven years to pay for the Dome of the Rock, and the same was done by his son, caliph al-Walid, with the land tax revenues of Syria to pay for the construction and decoration of the Great Mosque in Damascus (Gautier-van Berchem 1969; Hillenbrand 1999).
The Dome of the Rock in Jerusalem and the Great Mosque in Damascus are the masterpieces of Umayyad religious architecture[44].
Earliest surviving Umayyad monument, the Dome of the Rock was erected by caliph 'Abd al-Malik in 691 AD on the Temple Mount in Jerusalem, according to the inscriptions on it (Rosen-Ayalon 1989)[45]. The building was embellished

[42] Balādhurï (868 century), cited in Gautier-van Berchem 1969, p.231.
[43] al-Maqdisī, *The Best Divisions for Knowledge of the Regions* (985 century), cited in Gautier-van Berchem 1969, p.233.
[44] Specific attention will be devoted to these monuments in chapter 4, as they are among the sites whence the materials under study were collected.
[45] Finished in 691/692 AD: Creswell 1969; begun in 692 AD: Blair 1992.

with mosaics both inside and outside. As those on the outside were replaced by tiles by 1552 (Allen 1999; Creswell 1969; Richmond 1924), the surviving mosaics of the Dome of the Rock are in its interior and, despite some repairs, they still reflect the original decorative scheme (Allan 1989; Gautier-van Berchem 1969; Rosen-Ayalon 1989; Stern 1972). Their patterns stem from a combination of motifs indicating, on the one hand, a continuity with classical traditions (like the achantus scrolls and the naturalistic trees), and, on the other hand, a Sasanian influence, revisable in the plant candelabra and stylised trees with lotus or tulip-shaped flowers (McKenzie 2007; McKenzie 2013).

The palette of the mosaics is very distinctive: it is dominated by a gold background, with the main colours of the motifs being shades of blue, green and gold, and some highlights in red. There are also silver cubes and much use of mother of pearl on the surfaces that do not face the light (Gautier-van Berchem 1969).

There are, however, few written references mentioning whence artisans and workmen employed on building the Dome of the Rock came. When describing the construction of the Dome of the Rock, the 11th century Jerusalemire preacher al-Wasiti relates that ‘Abd al-Malik gathered craftsmen from all his dominions and asked them to provide him with the description and form of the planned dome before he engaged its construction (McKenzie 2007).

An official correspondence, written in Greek (the so-called “Aphrodito papyri”) and preserved as letters on papyrus found at Kom Ishqaw, Upper Egypt, records that experienced workmen sent from Egypt were employed in the construction of the al-Aqsa Mosque by caliph al-Walid, from 706 to 715 (Bell 1910; Bell 1911; Creswell 1969). The same document also mentions skilled craftsmen (and their maintenance) being sent from Egypt to work on the Great Mosque in Damascus in 706/7 and 709 (Allan 1989; Bell 1910; Bell 1911; Creswell 1969). Moreover, another letter, dated 710, mentions materials being sent to Damascus together with skilled craftsmen (Bell 1910; Bell 1911).

The Great Mosque of Damascus was built between 706 and 714/5 by caliph al-Walid inside the former enclosure of the temple of Jupiter Damascenus, then rebuilt as the cathedral of St John the Baptist, which was demolished for the

erection of the mosque (McKenzie 2013). When the Great Mosque was constructed, it was entirely covered with mosaics on both the inside and the outside walls. Though large areas of the original decoration still survive on site, some repairs have been made through centuries and they are generally mentioned in inscriptions, like those undertaken in the late 11th century under the Seljuq Tutush and in 1159 under the Zengid sultan nur al-Din, and those in 1269 by the Mamluk sultan Baibars[46]. The most extensive repairs are the most recent as well, completed in the 1960s (Gautier-van Berchem 1969).
The choice of colours in the mosaics of the Great Mosque is based upon the peculiar combination of a gold background with patterns mainly in shades of blue and green, with highlights in mother of pearl, reddish tones and black, already observed for the Dome of the Rock. According to iconographic and technological features, Marguerite Gautier-van Berchem hypothesised that the mosaics adorning the Dome of the Rock and the Great Mosque in Damascus had been executed by the same school of mosaicists, whom she considered to be Syrian (Gautier-van Berchem 1969). A different theory was supported by Mab van Lohuizen-Mulder, who suggested that the mosaics decorating the Great Mosque in Damascus were the product of Alexandrian mosaicists with the contribution of Syrian workmen (van Lohuizen-Mulder 1995). Interestingly, in a recently published paper, Judith McKenzie (McKenzie 2013) has further explored a possible Alexandrian component in the mosaic of the Great Mosque. Her studies are based on a detailed re-evaluation of the depiction of Alexandrian architecture in the Landscape Panorama, the largest intact area of mosaic dating back to the Umayyad decoration of the mosque, and on the mosaics adorning the east end of the north arcade, with a specific attention devoted to the boat on the river.
Located on the west arcade of the Great Mosque, the Landscape Panorama is a combination of monumental architecture, cityscapes and landscape, resulting in a distinctive decorative scheme. Similarities between the Landscape Panorama and 1st century Roman wall paintings belonging to the Second Style had been firstly noted by the restorer Eustace de Lorey, who uncovered the

[46] A summary of the original decoration is reported in Creswell 1969.

scenes in the 1920s (de Lorey 1931). However, according to McKenzie, in the Great Mosque mosaics new elements also occur, not derived from the Roman wall paintings but by Egyptian or Alexandrian architecture (McKenzie 2007; McKenzie 2013).

The mosaics of the east end of the north arcade have attracted little scholarly attention compared to the Landscape Panorama. Though they are not ascribable to the Umayyad period but to a later reconstruction probably occurred under the Seljuq domain[47], these mosaics are a copy of those adorning the west arcade, datable to the Umayyad caliphate (Gautier van-Berchem 1969). McKenzie specifically focuses her attention on the boat depicted on the north arcade, highlighting how it shows a very distinctive shape typical of Nile boats, here represented in a different way compared to others in Roman and Late Antique mosaics. According to the author, the presence of a peculiar Nile boat in the original Umayyad decorative programme could provide further evidence for the presence of an Alexandrian legacy in the making of the mosaics of the Great Mosque in Damascus.

However, the written sources on materials and workmen employed in the construction of the Great Mosque in Damascus are fragmentary and not clear. As mentioned in the previous paragraph, Ibn Qutayba (889 AD) relates that the Byzantine emperor complained to caliph al-Walid about the demolition of the previously built church of St John's the Baptist for the construction of the mosque (Gautier van-Berchem 1969). Slightly later, the 10th century geographer al-Maqdisī reports that al-Walid gathered together skilful artisans from Persia, India, the Maghreb and Rum (Gautier van-Berchem 1969). About five hundred years after the construction of the mosque, the historian Ibn Asākir (1160 AD) related that the Byzantine emperor sent two hundred Greek workmen after al-Walid threatened to destroy the remaining churches (Gautier van-Berchem 1969).

[47] Two inscriptions located on the back wall of the north arcade mention its reconditioning under Seljuq rule, which lasted in Syria from 1078 to 1117: one refers to the western part of it, reconditioned under sultan Muhammad in 1109-1110 (Gautier van-Berchem 1969); the other, dated 1089-1090, mentions reconstruction of the eastern part of this wall under Tutush (Gautier van-Berchem 1969).

"*Whether the mosaic cubes were imported from Constantinople or manufactured in Egypt or Syro-Palestine is something which it should now be possible to ascertain by chemical analysis*" (McKenzie 2007, p.367): these words close Judith McKenzie's reflections upon the actual presence of Byzantine, Egyptian and Syrian influences on the manufacture of mosaic decorations adorning Umayyad religious buildings. The following pages of this thesis are aimed at unravelling this question through the contribution of archaeometry, shedding new light upon Umayyad mosaic technology.

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Chapter 4

Materials inspiring methodology. Toward a *tailor-made* approach for the study of glass tesserae

4.1 The need for a *tailor-made* archaeometric approach in the study of glass tesserae: a re-starting point

It goes without saying that research into ancient glass production, manufacture and supply has provided captivating insights into the history and technology of a challenging and heterogeneous material.

Thanks to this research, our knowledge of the history of glass across time and space has significantly been enhanced, and a quite intricate scenario has been depicted: though considerable geographical and chronological gaps still exist, the development of a larger picture - as seen, for instance, in the definition of organisational models of ancient glass industries as well as in a better understanding of trade networks - has started being defined (Rehren & Freestone 2015).

If, however, a careful examination of the available literature is made, it can be perceived as a specific category of glass-made objects, that is mosaic tesserae, has always been deserved a minor attention compared to glassware.

Reasons behind this probably mainly lay in the fact that tesserae are conceived as a kind of trivial glass objects, unfeasible to be studied according to typological criteria able to define - as it is commonplace for glassware - a distribution of peculiar shapes and decorative features through time and space.

As a consequence, the picture of the manufacturing process and supply of mosaic glass tesserae is, to date, still incomplete and puzzling, and many questions still remain without proper answers, like how and where the raw glass was opacified and coloured (Boschetti et al. 2016; James 2006; James 2010; James 2017; Neri et al. 2017).

Tesserae could have been made by directly adding colourants either to the primary batch, or in a secondary process, as mentioned, for instance, by Pliny the Elder (Pliny, Naturalis Historia, 36, 66, 193). It is, however, still unclear whether the secondary manufacture of tesserae was a centralised business, where a single workshop produced tesserae of different colours, or whether multiple workshops specialised in one colour at the time (Neri et al. 2017; Schibille et al. 2012).

As we cannot benefit from the support of typological studies, the contribution of archaeometry to the study of mosaic glass tesserae plays an even more fundamental role, and the definition of a methodical and systematic analytical protocol needs to be cautiously and meticulously assessed.

As archaeological scientists, we need to be truly aware of the need of applying a carefully thought out, *tailor-made*, protocol, equally evaluated on both the potentialities/limits of each technique and the material features of mosaic glass tesserae, which can have highly inhomogeneous micro-structures and, thus, be particularly challenging to investigate.

Apart from the archaeological relevance of the assemblages under study and the contribution they can give to the history of ancient glass tesserae manufacture and supply, this research is also aimed at outlining how the application of a "best practice" protocol, specially shaped for mosaic glass tesserae and their particular features, can be the starting point for providing highly comparable outcomes, aimed at enhancing our knowledge of this material category.

As Liz James has appropriately stated in her recent volume (James 2017, p. 41):

"*Currently, the analyses of tesserae are patchy and very incomplete, work on colourants is in its very early stages, and the complexities of recycling glass add another level of uncertainty. It is almost impossible at present to work out detailed groupings within and across mosaics because we simply do not have enough data*".

In addition to the scarcity of data, the problem is linked to the lack of a common and consistent analytical approach, shared within the scientific community as well.

In Tab.4.1 a summary of published analytical data for assemblages of mosaic glass tesserae from sites located in the eastern Mediterranean basin and datable back to the 5th-10th century[48] is taken as an example.

If a closer look is given at the analytical methods, the absence of a well-defined and repeated protocol can be observed: though several (and, in most cases, undoubtedly suitable) techniques have been employed to carry out archaeometric studies of mosaic glass tesserae, a shared multi-analytical approach aimed at thoroughly characterising, on the one hand, the base glass, and, on the other hand, the colourants and opacifiers, is still lacking.

As a consequence, data comparison can be extremely demanding and, at times, unfeasible, with the impossibility of outlining a reliable and exhaustive scenario on manufacturing processes and supply of glass tesserae.

An example is given to make this statement clearer. Hypothesize that we have to compare two assemblages of tesserae, which we will call X and Y. Assemblage X is studied by carrying out EPMA measurements aimed at investigating the nature of the base glass and SEM-EDS analyses for the characterisation of colouring agents and opacifiers. Assemblage Y is, conversely, investigated with a different methodological approach: the base glass is studied through EPMA and LA-ICP-MS, arriving to formulate hypotheses on glass recipes and source of raw materials. Then, through a combination of, as example, SEM-EDS, micro-Raman and XRD measurements, we proceed to the study of the micro-structure. To add a further element of difficulty, we can also hypothesize that, for tesserae belonging to the assemblage X, the colours have been determined on the basis of visual observation alone; f tesserae of the assemblage Y, the colour determination was carried out with instrumental analyses (as VIS-RS).

[48] This selection stemming from the necessity of using these specific assemblages as comparative material for this research.

What if we try to compare the two datasets? How far could we go? Well, not so far…It would be impossible to compare raw materials used in the production of the base glass and, therefore, any hypothesis on eventually shared geographical areas of production would be unfeasible.
The possibility of comparing the materials used to colour the tesserae would also very limited, because, for the assembly Y, we would have been able to achieve an in-depth molecular and mineralogical characterisation of these materials, while for assembly X we would only have obtained an elemental characterisation. Finally, we would be unable to make precise comparisons between, for example, the agents responsible for the yellow shades of the tesserae of one and the other assemblage, since we would have no scientific basis to describe the colours uniformly.
Made this premise, the following pages are aimed at illustrating analytical methods selected in the context of this research for an in-depth and systematic characterisation of mosaic glass tesserae, together with analytical parameters used.
After a summary of preliminary operations (like samples' cleaning, selection and documentation), the importance of a multi-analytical approach for the study of colouring and opacifying agents will be set as a starting point. The proposed analytical protocol is based upon a combination of several techniques; results presented and discussed in chapter 6 will show how a meticulous comparison between data obtained through their integration can allow achieving a precise characterisation of materials employed as colourants and opacifiers.
It is here important to underline that chromatic (NCS and VIS-RS), morphological and micro-textural (SEM-BSE investigation), semi-quantitative elemental (SEM-EDS), molecular (micro-Raman) and mineralogical (XRPD) characterisation of these phases should always be carried out before that of the base glass. This is significant especially for opaque coloured tesserae, as they show extremely heterogeneous micro-structures which need to be investigated before the composition of the base glass in order to avoid interferences, mistakes and misunderstandings in data evaluation.

In order to investigate the base glass, both in terms of compositional recipes and provenance of raw materials, a combination of EPMA (for major and minor oxides) and LA-ICP-MS (for trace elements) analyses has been selected, together with specific data processing discussed in paragraph 4.2.3.

In chapters 6 and 7, where results will be introduced, discussed and contextualised, it will be shown how the suggested *tailor-made* archaeometric protocol (Fig.4.1), evaluated for properly investigating mosaic glass tesserae by taking their compositional features and micro-texture into account, has played a fundamental role in developing hypotheses upon raw materials, recipes and manufacturing technology of the assemblages under study.

It has to be stressed that the analytical protocol evaluated and proposed here has not to be considered as the only possible one to be applied to the study of mosaic glass tesserae. Rather, it is a proposal that takes into account the possibility of having complete and comparable results with generally accessible techniques and with a relatively low cost.

Therefore, the chance of integrating the described methodology with further analyses, aimed, from time to time, to obtaining specific answers to precise and well-defined research issues, is set as a fixed and indispensable point.

In Tab.4.2 a scheme of other alternative analytical techniques is presented, suitable for the study of the base glass and the micro-structure (colourants and opacifiers) of glass tesserae.

In the section dedicated to conclusions, further considerations will be made on advantages, limits and potentialities of each technique employed, to critically evaluate their integration on the basis of achieved results.

Site	Century	Base glass	Colourants and Opacifiers										Analyses	References
			Yellow	Green	Red	Blue	Turquoise	Amber	Purple	Black	White	Colourless		
Photios Church (Huarte, Syria)	5th century	Foy-2, Levantine I	Stannate and calcium phosphate			Coablt + Calcium phosphate	Copper + Calcium phosphate						SEM-EDS	Lahanier 1987
Neonian baptistery (Ravenna, Italy)	5th century	Roman, Levantine	Lead antimonate	Lead antimonate + copper	Cu (metallic or cuprite)	Cobalt	Copper				Calcium antimonate or calcium phosphate		SEM-EDS	Verità 2011
Kilise Tepe (Turkey)	5th-6th century	Foy-2 Levantine I	Lead stannate	Lead stannate and metallic inclusions	Metallic Cu	Cobalt	Copper + calcium phosphate			Metallic Cu			EPMA, LA-ICP-MS, SEM-EDS	Neri et al. 2017
Tyana Baptistery, (Turkey)	5th-6th century	Levantine	Lead Stannate	Lead Stannate + Copper			Iron, copper and cobalt + calcium phosphate					Manganese	EPMA, SEM-EDS, m-Raman	Silvestri et al. 2016; Lachin et al. 2009
Petra Church (Turkey)	5th-6th century	Levantine I	Lead and tin oxide particles	Lead and tin oxide particles + Copper oxide					MnO	Iron oxide	Calcium phosphate	MnO	SEM-EDX, EPMA	Marii 2013; Marii and Rehren 2012; Marri and Rehren 2009
Hagios Polyeuktos, (Constantinople, Turkey)	6th century	Roman, Levantine	Lead Tin Yellow	Lead Tin particles	Metallic Cu or Cu_2O	Cobalt (+ calcium antimonate)	CuO	Lead Tin Yellow				MnO	EPMA, LA-ICP-MS	Schibille and McKenzie 2014
Hagia Sophia (Constantinople, Turkey)	6th century	Levantine											p-XRF, SEM-EDS (surface analysis)	Moropoulou et al. 2016
Roman Baths and Apollo Klarios Temple, Sagalassos (Turkey)	6th century	Roman (Bath), Roman and HIMT (Temple)	Pb2Sb2O7	Pb2Sb2O7 + Copper	Metallic Cu + SnO_2	Cobalt (+$CaSb_2O_6$)	Copper (+$CaSb_2O_6$)				$CaSb_2O_6$	Sb_2O_5	EPMA, LA-ICP-MS, SEM, XRPD	Schibille et al. 2012
Chrysochous, Ayioie Pente; Acropolis basilica; Kalavasos-	6th century	Foy-2 Levantine I	Lead Tin Yellow type II	Lead Tin Yellow type II + Cu^{2+}	Metallic Cu	CoO + (SnO_2)	Fe^{2+} + calcium phosphate	Fe^{3+} S^{2-}	Mn^{3+}		SnO_2	Antimony	VIS-RS, SEM-EDS, m-Raman	Bonnerot et al. 2016

Kopetra (Cyprus,Greece)														
St. Vitale basilica (Ravenna, Italy)	6th century	Roman, Levantine I	PbO + Sb_2O_3	PbO + SnO_2 + CuO	Iron oxide + copper	CoO	Copper oxide/iron oxide		MnO				XRF, ICP-AES, AAS	Fiori et al. 2004
St. Severus basilica (Classe, Ravenna, Italy)	6th century	Levantine I	Lead antimonate	Lead antimonate + copper	Copper							Antimony	XRF-WDS, SEM	Fiori 2011
		Between Roman and Levantine	Lead and antimony	Lead stannate and copper	Copper	Cobalt (+ antimony)	Copper (+ antimony)		Manganese and iron	Manganese and iron	Calcium antimonate	Antimony	XRF-WDS, EPMA	Fiori 2013
		Roman, Levantine I, weak HIMT		Pb, Sn-based opacifier + copper	Cu_2O	Cobalt (+ calcium antimonate)	Copper (+ calcium antimonate)					Antimony	EPMA, SEM-EDS, XRPD	Vandini et al. 2014
St. Apollinare Nuovo basilica (Ravenna, Italy)	6th century	Roman, Levantine										Antimony	SEM-EDS	Verità 2012
St. Prosdocimus (Padova, Italy)	6th century	Foy-2, Roman, Levantine I	$Pb_2Sb_2O_7$ or $PbSnO_3$	Cu^{2+} (+ $Pb_2Sb_2O_7$ or calcium phosphate or $PbSnO_3$)	Metallic Cu or Cu_2O	CoO (+ $CaSb_2O_6$ and/or $Ca_2Sb_2O_7$)	Cu^{2+} (+$CaSb_2O_6$ and/or $Ca_2Sb_2O_7$)	Mn^{3+} + Calcium phosphate			$CaSb_2O_6$ and/or $Ca_2Sb_2O_7$		VIS-RS, SEM-EDS, EPMA, XRPD	Silvestri et al. 2012, 2014
Amphitheater (Durre, Albany)	6th-8th century	Foy-2, Levantine I	Lead stannate	Lead stannate + copper	Metallic Cu or Cu_2O	Cobalt	Copper oxide (+ bubbles)		Mn	Mn		Mn	SEM-EDS, LA-ICP-MS	Neri et al-2017
Baths of Qusayr ‘Amra (Jordan)	8th century	Levantine, Egyptian	Lead stannate	Copper + lead stannate	Metallic Cu or Cu_2O		CoO (+ calcium phosphate)			Fe_2O_3	Calcium phosphate		SEM-EDS	Verità et al. 2017
Lower City Church (Amorium, Phrygia)	10th century	Levantine	Lead Tin Yellow crystals	Lead Tin Yellow crystals + Copper	Cu_2O	CoO	Copper + calcium phosphate		Manganese				SEM-EDS/WDS	Witte 2013, Wypyski 2005

Tab.4.1 Summary of published data for mosaic glass tesserae. All assemblages are from sites located in the eastern Mediterranean basin and datable between the 5th and the 10th century according to archaeological evidence. Data on base glass, colourants and opacifiers are reported according to information provided in the quoted papers.

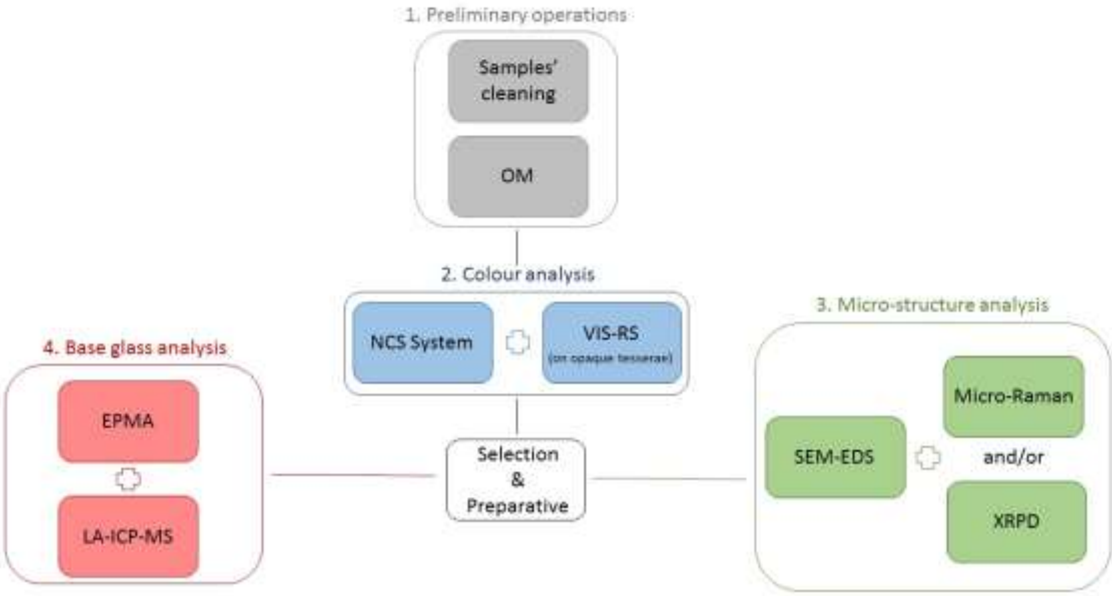

Fig.4.1 Scheme of the selected analytical methodology.

This research		Further possible techniques	
Base glass	Colourants and opacifiers	Base glass	Colourants and opacifiers
EPMA	NCS + VIS-RS	ICP-OES	SEM-EBSD
LA-ICP-MS	SEM-EDS	IBA (PIXE, PIGE)	micro-XRD
	micro-Raman	Isotope Analyses	FORS
	XRPD	NAA	EPR
		Surface Analysis (AFM, SIMS)	XANES
			XAFS

Tab. 4.2 Summary of other available analytical techniques for the study of glass tesserae. Exhaustive discussion upon each technique, with recent advances in applied research, is provided in Janssesns (2013).

4.2 Analytical methods[49]

4.2.1 Preliminary operations

Before carrying out analytical investigations, all samples were preliminary cleaned by using demineralised water and dentist tools, softly scraping the surfaces to remove remains of soil and dirt.

An Olympus S761 stereomicroscope (magnification up to ×45) associated with an Olympus Soft Imaging Solutions GMBH model SC100 camera was, then, used for a preliminary morphological observations and documentation of all samples, as well as to evaluate the occurrence of surface degradation morphologies.

A Natural Colour System Index chart (NCS) was employed to provide a first objective discrimination and description of the colours, both for opaque and translucent samples. NCS is a logical colour system built on how the human being perceives colours visually. For this reason, the NCS System allows describing any surface colour by means of so-called NCS-notations. Each notation represents a specific colour percept, a suitable global standard to define and communicate colours avoiding subjective descriptions. An example of NCS-notation is S 1050-R90B, where:

- S means that the colour is part of the visual selection of NCS 1950 standard colours, illustrating the NCS System;
- the first part of the code (1050) describes the nuance of the actual colour R90B, having 10% blackness and 50% chromaticness. The remaining 40% out of 100% is whiteness, which is not printed out in the NCS-notation;

[49] Unless otherwhise specified, analyses were performed by the candidate at the Conservation Science Laboratory, Department of Cultural Heritage, University of Bologna – Ravenna campus.

- the second part of the NCS notation (R90B) is the hue. Code R90B is a reddish blue colour, described as a red (R) with 10% resemblance to red and 90% resemblance to blue (B)[50].

In chapters 6 and 7, it will be shown how the use of NCS System has been particularly suitable for a preliminary selection among opaque coloured tesserae, as it allowed distinguishing between the chromatic macro-categories the tesserae fall into (i.e. green, blue, red, black), avoiding any subjective descriptions of the colour shades.

These groups were defined in accordance with NCS co-ordinates and, more precisely, by taking the second part of the NCS- notation into account, which describes the hue by means of a numerical code (see Tab. 5.3-5.5, in chapter 5). For example, a tessera with a NCS-notation S 2030-G70Y will be described as of a yellow colour, code G70Y indicating a greenish yellow described as a yellow (Y) with 70% resemblance to yellow and a 30% resemblance to green (G).

All NCS measurements were carried out outside, in daylighting. Observation and lighting conditions remained constant for all measurements.

[50] For a complete guide to NCS System, see http://ncscolour.com/about-us/how-the-ncs-system-works.

4.2.2 Investigating colourants and opacifiers

The multi-analytical approach selected for analysing colourants and opacifiers is focused upon a combination of Visible Reflectance Spectroscopy (VIS-RS), Scanning Electron Microscopy coupled with Energy Dispersion Analysis (SEM-EDS), Raman Microscopy (micro-Raman), and X-Ray Powdered Diffraction (XRPD)[51].

After preliminary NCS-aided attribution of the tesserae to chromatic macro-categories, further data on optical properties (L*a*b* numerical coordinates and the reflectance percentage for each wavelength in the visible spectrum) were collected by visible reflectance spectroscopy (VIS-RS), to provide an objective discrimination between different colour shades within the same chromatic macro-category. For VIS-RS, a MINOLTA CM-2600d portable spectrometer was used. The system is equipped with an internal integrating sphere of 56-mm diameter, in reflectance geometry d/8, with three Xenon pulsed lamps, and a D65 illuminant was used; calibration was performed against a $BaSO_4$ standard plate; the spectral range is 400-700 nm, with a spectral resolution of 10 nm and the area of sight of 3 mm diameter. *SpectraMagic* software was employed to elaborate data; specular component excluded (Scentury/0) was selected, according to the literature (Johnston-Feller 2001).

Polished sections were prepared by embedding micro-fragments of the samples in a polyester resin. After polishing, sections were carbon-coated to perform scanning electron microscopy (SEM) investigation, for high-resolution textural and morphological inspection of the inclusions dispersed in the glassy matrix.

Back-scattered electron signal (BSE) was used for the inspection of the morphological features of the inclusions, coupled with EDS spot measurements to achieve a preliminary qualitative and semi-quantitative elemental analysis of the inclusions themselves. Images and EDS spectra were collected on a low-

[51] In the following chapters, it will emerge how a critical and cautious integration of the data obtained from these analyses has allowed to achieve precise chromatic, micro-structural, morphological and compositional characterisation of colourants and opacifiers detected in the tesserae under study. Closing remarks on advantages, limits and potentialities of the techniques will be addressed in the Conclusions.

vacuum ESEM FEI Quanta 200, equipped with an EDAX energy dispersive spectrometer. Analyses were performed in high-vacuum, using an acceleration voltage of 25kV and an energy resolution of ~ 200 eV; working distance was set at 10 mm, spot size was between 4 and 5 µm.

In order to provide a more in-depth characterisation of these inclusions, so as to formulate hypotheses on raw materials responsible for the colour and opacity of the tesserae, a combined Raman Microscopy (micro-Raman) and X-ray powdered diffraction (XRPD) approach was used.

Whilst micro-Raman was carried out on all the tesserae under study, XRPD was only performed on selected samples (where micro-Raman analyses were not discriminant), due to its destructive nature. XRPD analyses were performed on finely powdered samples manually pressed on an Ag sample holder in a Rigaku Miniflex diffractometer employing CuKα1 radiation, in the range 2Θ: 4°-64°, Θ scan speed: 1°min^{-1}.

Raman spectra were collected by using a Bruker Senterra dispersive Raman spectrometer equipped with an integrated Olympus BX40 microscope. A 785 nm He-Ne laser was employed, in the 300-3500 cm^{-1} region. Analytical measurements were performed with a 50X long working distance objective, operating at a power of 10 mW (red and blue samples) or 25 mW (yellow and green samples) with a spectral resolution of 3.5 cm^{-1}. Raman measurements were performed on polished section after carbon-coating removal.

4.2.3 Investigating the base glass

To determine the bulk chemistry of all samples under study, electron probe microanalysis (EPMA) was performed on polished and carbon-coated sections[52]. Chemical analyses of major and minor elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, S, Cl, Cr, Co, Cu, Sn, Sb and Pb) were performed using a CAMECA-CAMEBAX equipped with four scanning wavelength-dispersive spectrometers (WDS). A beam current of 2 nA, an acceleration voltage of 20 kV and a spot size of 5 µm were used for Na, K, Si and Al; for all other elements, a beam current of 20 nA, an acceleration voltage of 20 kV and a spot size of 1 µm were used. Synthetic pure oxides were used as standards for Al, Cr, Fe and Sn, synthetic $MnTiO_3$ for Mn and Ti, wollastonite for Si and Ca, albite for Na, periclase for Mg, PbS for Cl and Pb, orthoclase for K, apatite for P, sphalerite for S, Sb_2S for Sb and pure elements for Co, Cu, Ni. SMITHSONIAN GLASS A standard (Jarosewich 2002) was also employed as a reference sample. Ten points were analysed on each sample, and the mean values were calculated. The measured accuracy for the analysed elements was better than 3%. The standard deviations among the analysed points resulted to be between 1–3 and 3–5% for major and minor constituents, respectively. The detection limit for the minor elements was between 0.01 and 0.04 wt%. The correction program is based on the PAP method (Pouchou & Pichoir 1988) and was used to process the results for matrix effects.

In order to compare the base glass composition of the opaque tesserae with the categories reported in literature for naturally coloured glass, EPMA data were recalculated to minimise any effect caused by elements intentionally added as colourants/decolourants and/or opacifiers[53]. According to the procedure proposed by Brill 1999, the reduced composition was obtained by subtracting the oxides of the elements probably due to additives, and by normalising to 100 the remaining data. In particular, oxides considered for subtractions were CuO,

[52] EPMA measurements were carried out at the Department of Geosciences, University of Padova.

[53] The calculation of the reduced compositions is, to date, still not a common and shared practice in the processing of data regarding the composition of the base glass of mosaic tesserae. Such a recalculation is, however, to be considered necessary so that the comparison with the compositional categories known in the literature can be carried out as much as possible and not only in an approximate way.

SnO_2, PbO, MnO, Sb_2O_3 and CoO. FeO and TiO_2 were not removed when calculating the reduced composition (even though the presence of iron may be due to an intentional addition), since these elements are typically found as sand contaminants related to heavy minerals.

Laser ablation fixed with inductively coupled plasma mass spectrometry (LA–ICP–MS) was carried out to determine the concentration of 37 trace elements[54]. The analyses were performed by a Thermo Fisher X-Series II quadrupole based ICP–MS coupled with a New Wave ablation system with a frequency quintupled (λ = 213 nm) Nd:YAG laser. Laser repetition rate and laser energy density on the sample surface were fixed at 20 Hz and ~18 J/cm^2, respectively. Analyses were carried out using a laser spot diameter of 100 µm on the same polished samples used for EPMA, after carbon-coating removal. Due to the highly heterogeneous micro-structure of the tesserae, six points were analysed on each sample and the mean values were then calculated. External calibration was performed using NIST 610 and 614 glass as external standards; NIST 612 was also used as a secondary reference sample to check precision and accuracy (Pearce et al. 1997). ^{29}Si was employed as internal standard, whose concentration was determined by EPMA following the method proposed by Longerich and colleagues (Longerich et al. 1996). The distribution of REE and of the other trace elements was analysed by normalising the data to the upper continental crust (Kamber et al. 2005).

In this research, major and minor oxides (expressed as wt%) were analysed by EPMA, whilst LA-ICP-MS was carried out for determining trace elements (expressed as ppm).

Recent research has undoubtedly demonstrated that close correspondence is generally observed between data achieved by EPMA and “new generation” LA-ICP-MS equipment (i.e. Ceglia et al. 2017; Gratuze 2013; Gratuze 2016). Furthermore, nowadays LA-ICP-MS can perform major to trace element analysis of almost all elements within a sample during a single run, thanks to

[54] LA-ICP-MS analyses were performed: at the CIGS, University of Modena and Reggio Emilia, for the assemlages from Khirbat al-Mafjar and the Dome of the Rock; at FunGlass Centre, Alexander Dubček University of Trenčín, for the assemblage from the Great Mosque of Damascus. Instruments had the same technical speciofications and the same analytical paramenters were set.

specific quantification protocols like Internal Standard Independent (ISI) and Sum Normalization (SN) methods (Cagno et al. 2016).

Although the potentialities of this technique are significant, its application to the study of mosaic tesserae still needs to be thoroughly explored. In particular, it has to be noticed that the most commonly used quantification method (the Sum Normalization) assumes that glass is almost exclusively comprised of oxides in known oxidation states and that the sum of the concentration of all oxides should equal 100% (Cagno et al. 2016). The first statement is quite difficult to be verified when dealing with deeply coloured and opaque glasses, like tesserae, when the addition of several compounds is responsible for the colour shades and the opacity.

Moreover, it has been noticed that, when dealing with the study of tesserae, the deviation from recommended values and the accuracy are generally better for LA-ICP-MS data, with the exception of lime, soda, lead and chlorine (Neri et al. 2017). Lime and soda are of a particular relevance when dealing with the identification of compositional recipes of mosaic glass tesserae, as it will be discussed in chapter 6.

Further studies are, therefore, needed on the specific application of LA-ICP-MS for the quantification of not only trace, but also major and minor elements in coloured glass tesserae. For this prime reason, in this research major and minor oxides (expressed as wt%) were analysed by EPMA, whilst LA-ICP-MS was carried out for determining only trace elements.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	CoO	CuO	SnO_2	Sb_2O_3	PbO
Smithsonian A	14.05	2.97	0.93	66.36	0.08	0.15	0.12	2.83	5.39	0.79	1.15	1.12	0.20	1.29	0.23	1.79	0.09
StDev	0.42	0.11	0.08	0.39	0.04	0.02	0.02	0.15	0.09	0.04	0.03	0.05	0.02	0.04	0.04	0.09	0.07
Vicenzi et al. 2002	14.30	2.66	1.00	66.56	0.13	0.13	0.09	2.87	5.03	0.79	1.09	0.17	1.17	0.00	0.19	1.58	0.12
Accuracy	0.98	1.12	0.93	1.00	0.62	1.13	1.33	0.99	1.07	1.00	1.05	6.57	0.17		1.19	1.13	0.78

Tab. 4.3a EPMA data acquired on glass standard Smithsonian A during the analyses in comparison with certified data from the literature.

	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Zr	Nb	Sn	Sb	Ba	La
NIST612	30.6	35.09	38.88	33.40	32.56	35.92	35.69	39.50	35.19	32.93	63.70	22.73	25.55	32.81	30.82	29.58	30.28
StDev	1.90	2.45	1.15	3.54	2.62	2.80	2.91	3.56	3.04	1.48	4.32	2.74	3.18	2.32	2.51	1.81	2.32
Pearce et al. 1997	36.71	48.11	39.22	39.88	35.26	38.44	36.71	37.92	36.24	31.63	76.15	35.99	38.06	37.96	38.44	37.74	35.77
Accuracy	0.83	0.73	0.99	0.84	0.92	0.93	0.97	1.04	0.97	1.04	0.84	0.63	0.67	0.86	0.80	0.78	0.85

	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	Th
NIST612	36.30	32.03	23.78	24.63	26.70	21.75	28.30	21.25	28.73	22.43	26.91	24.40	27.76	21.69	24.78	3.74	41.98	27.24
StDev	2.60	2.38	2.74	2.87	2.99	2.99	3.76	3.02	4.08	3.05	3.88	3.50	3.95	3.33	3.37	0.93	5.08	3.44
Pearce et al. 1997	38.35	37.16	35.24	36.72	34.44	36.95	35.92	35.97	37.87	37.43	37.55	39.95	37.71	34.77	39.77		38.96	37.23
Accuracy	0.95	0.86	0.67	0.67	0.78	0.59	0.79	0.59	0.76	0.60	0.72	0.61	0.74	0.62	0.62		1.08	0.73

Tab. 4.3b LA-ICP-MS data acquired on glass standard NIST612 during the analyses in comparison with certified data from the literature. Values refer to the first round of analyses, on tesserae from Khirbat al-Mafjar, carried out at CIGS, University of Modena and Reggio Emilia.

	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Zr	Nb	Sn	Sb	Ba	La
NIST612	40.75	43.60	37.93	36.10	34.58	38.90	36.13	38.12	35.26	31.09	77.87	37.83	39.67	43.73	37.75	39.57	35.10
StDev	0.74	1.66	1.30	0.30	0.75	0.52	1.81	1.28	0.88	0.50	2.56	0.45	1.09	15.91	0.38	0.63	0.99
Pearce et al. 1997	36.71	48.11	39.22	39.88	35.26	38.44	36.71	37.92	36.24	31.63	76.15	35.99	38.06	37.96	38.44	37.74	35.77
Accuracy	1.11	0.91	0.97	0.91	0.98	1.01	0.98	1.01	0.97	0.98	1.02	1.05	1.04	1.15	0.98	1.05	0.98

	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	Th
NIST612	38.40	36.83	35.24	37.58	34.41	36.12	35.42	35.70	38.07	38.37	37.80	38.62	36.23	34.82	39.83		37.68	37.47
StDev	0.55	1.03	1.32	0.69	0.85	0.88	0.89	0.70	0.48	0.41	0.83	0.82	0.96	0.61	0.58		5.20	0.67
Pearce et al. 1997	38.35	37.16	35.24	36.72	34.44	36.95	35.92	35.97	37.87	37.43	37.55	39.95	37.71	34.77	39.77		38.96	37.23
Accuracy	1.00	0.99	1.00	1.02	1.00	0.98	0.99	0.99	1.01	1.03	1.01	0.97	0.96	1.00	1.00		0.97	1.01

Tab. 4.3c LA-ICP-MS data acquired on glass standard NIST612 during the analyses in comparison with certified data from the literature. Values refer to the second round of analyses, on tesserae from the Great Mosque of Damascus, carried out at FunGlass Centre, Alexander Dubček University of Trenčín.

	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Zr	Nb	Sn	Sb	Ba	La
NIST612	33.83	40.57	35.17	36.82	33.51	38.17	36.81	34.65	34.80	29.11	66.26	33.44	30.25	36.07	32.11	34.74	35.02
StDev	4.85	2.78	1.73	0.75	0.75	0.98	1.26	1.43	1.16	1.20	3.46	4.63	1.75	0.93	0.89	1.79	2.41
Pearce et al. 1997	36.71	48.11	39.22	39.88	35.26	38.44	36.71	37.92	36.24	31.63	76.15	35.99	38.06	37.96	38.44	37.74	35.77
Accuracy	0.92	0.84	0.90	0.92	0.95	0.99	1.00	0.91	0.96	0.92	0.87	0.93	0.79	0.95	0.84	0.92	0.98

	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	Th
NIST612	33.00	30.50	34.89	37.67	32.81	34.03	31.68	31.33	32.15	31.64	31.22	36.73	31.10	32.46	30.71	4.51	33.25	26.15
StDev	1.34	1.66	2.32	2.98	2.04	3.30	3.05	3.22	3.30	3.39	3.36	3.49	3.37	3.44	2.67	0.18	5.32	2.44
Pearce et al. 1997	38.35	37.16	35.24	36.72	34.44	36.95	35.92	35.97	37.87	37.43	37.55	39.95	37.71	34.77	39.77		38.96	37.23
Accuracy	0.86	0.82	0.99	1.03	0.95	0.92	0.88	0.87	0.85	0.85	0.83	0.92	0.82	0.93	0.77		0.85	0.70

Tab. 4.3d LA-ICP-MS data acquired on glass standard NIST612 during the analyses in comparison with certified data from the literature. Values refer to the third round of analyses, on tesserae from the Dome of the Rock, carried out at CIGS, University of Modena and Reggio Emilia.

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Chapter 5

An introduction to sites and materials under study

5.1 The assemblage from Khirbat al-Mafjar

The *qasr* (Arab word for "palace") of Khirbat al-Mafjar is an amazing example of so-called "Castles in the Desert"[55].

Located in the plain of Jericho, about 3.5 km north of the city (Fig.5.1), the complex of Khirbat al-Mafjar is considered one of the most meaningful archaeological evidence of the early Islamic period in Palestine (Whitcomb & Taha 2013).

Fig.5.1 The *qasr* of Khirbat al-Mafjar, a view of the site (https://educated-traveller.com/2015/01/14/the-west-bank-jericho-and-hishams-palace/).

Archaeological research has demonstrated that the *qasr* underwent different phases of construction and occupation. It was built between 736 and 746, and in 747/748 an earthquake seriously damaged the site without interrupting its

[55] The *qusur* were wealthy and huge palaces mainly located on the fringe of the desert, whose function is still under debate: they could either have been winter residences of the caliphs, or agricultural estates where members of the Arab aristocracy used to live. For extensive discussion on these palaces, see, for instance, Creswell 1969, Grabar 1963, Hillenbrand 1982.

occupation. The Palace met, indeed, its major period of occupation during the Abbasid caliphate (ca. from 800 until 950), when new buildings were constructed and added to the pre-existent structures (Cirelli & Zagari 2000; Grabar 1955; Grabar 1963; Grabar 1993; Hattstein & Delius 2001; Whitcomb 1988; Whitcomb & Taha 2013). Firstly excavated between 1934 and 1948 and again in the 1960's (Grabar 1955; Hawari 2010; Whitcomb 1988; Whitcomb & Taha 2013), the *qasr* has recently been the focus of the Jericho Mafjar Project (Hawari 2010; Whitcomb 2013; Whitcomb 2014).

During the 2011 season, glass vessels and tesserae were found inside the so-called Original Residence or Northern Building, completely excavated by Awni Dajani (under Jordanian authority) at the beginning of the 1960s, but no published records are available; in addition to that, no reports of the massive not stratigraphic excavation have been found up to now. Thanks to recent analyses and surveys on the structures and some trenches within small parts of the site (never investigated previously), a new drawing of the building with a wider comprehension of the phasing has been provided. According to archaeological evidence, it can now be stated that the Original Residence was contemporaneous with a Grape Press for wine production, recently discovered and early Umayyad in date. Moreover, during the last research seasons, it also emerged that this phase was probably connected to a wider building, identified by remote sensing investigations that highlighted several differently orientated hidden structures, in a middle area between the palatial complex and the northern building (Whitcomb 2013; Whitcomb 2014). The central area of the new building was never excavated and it is probably connected to an earlier period of occupation, dating back to the Late Roman (end of the 7th century) or early Umayyad (7th-8th century), possibly belonging to the period of Sulayman ibn 'Abd al-Malik (715-717).

The mosaic tesserae and the other glass fragments belong to a second phase, dated to the Hisham's caliphate (724-743), and they were connected to the court of the Northern Building, soon after the abandon of the large agricultural estate. Moreover, the Northern Building was abandoned after having been

damaged by the earthquake, and, consequently, the findings can be confidently ascribed to the period between 724-748\9 (Whitcomb 2013).
A set of 21 fragments of naturally coloured glass vessels and 16 mosaic glass tesserae was collected from the northern side of the Northern Building (Fig.5.2).

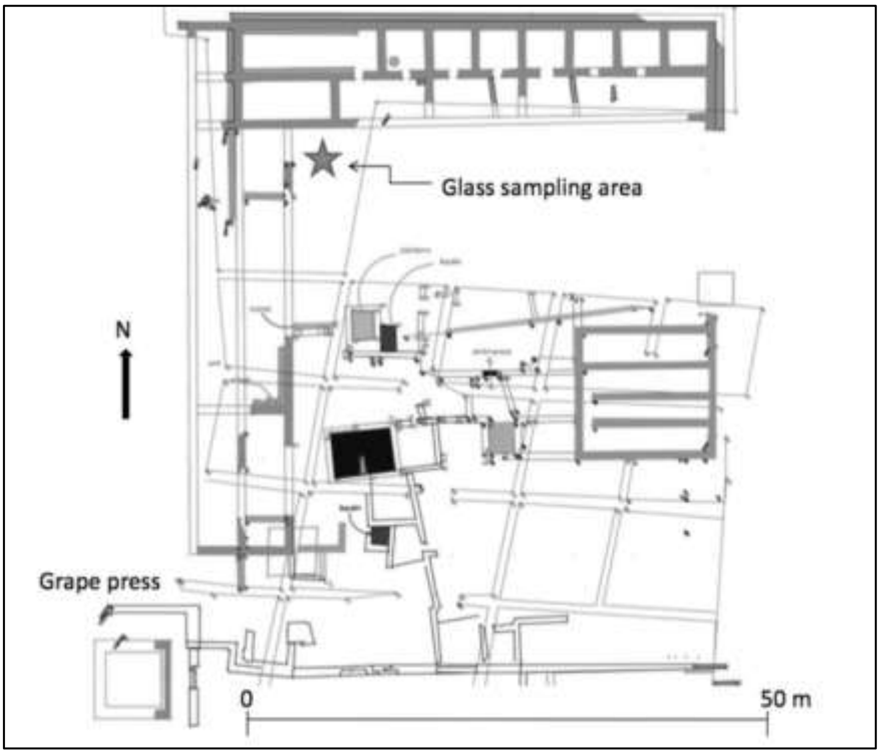


Fig.5.2 Area of the site where the glass finds were recovered (Fiorentino et al. 2018, p. 225).

Among the full set of vessels, 7 fragments were selected to be investigated through a multi-analytical approach. This selection was made on the basis of archaeological and chrono-typological criteria, by preferably choosing the samples referable to documented or recognisable forms. About the tesserae, the complete set of available samples was investigated, due to the variety of the different colours and degrees of opacity.
Concerning the recovered vessels, 2 rims, 2 bottoms, 1 handle and 2 fragments of decorated walls were selected to be analysed. All of them were accurately micro-sampled, to preserve the integrity of the profile. The identified forms are summarised and described in Tab.5.1.

Sample	Object	Photo	Typology	Datig (by form)	References
KH01	Loop handle with pinched thumb-rest		Cup or cup-shaped oil lamp	end 7th - 8th century	Hadad 2005, pl. 21, n. 398 (first half of 8th century); Gorin-Rosen & Katsnelson 2005, p. 112, n. 40 (8th century); Gorin-Rosen & Katsnelson 2007, p. 49, n. 9 (Abassid/Fatimid period); Gorin-Rosen 2008, p.124, n. 16 (Late Byzantine/ Umayyad period); Gorin-Rosen 2010, p. 252, pl. 10.11, n. 4 (without thumb-rest) (Abassid/Fatimid period)
KH02	Wall with trails		Unidentified vessel with bifurcated ribs decoration?	3rd – 8th century	Harden 1936, pl. XVIII, n. 593 (2nd-3rd century); Crowfoot 1957, fig. 94, n. 12 (3rd century); Clairmont 1963, pl. V, n. 189 (2nd-3rd century); Barag 1978, p. 24, fig. 12.50 (late 3rd-4th century); Weinberg & Goldstein 1988, p. 81, fig. 4-39 (2nd-4th century); Dussart 1998, BX.3211c, n. 11 (end 3rd-4th century); Gorin-Rosen 2016, p. 52, n. 27 (late Byzantine-Umayyad period); Gorin-Rosen & Katsnelson 2007, p. 107, fig. 15.1 (late Roman-Early Byzantine period); Antonaras 2010, fig. 3 (last on the second row) (mid 3rd-4th century)
KH03	Wall with trails		Unidentified vessel with bifurcated ribs decoration?	3rd – 8th century	Harden 1936, pl. XVIII, n. 593 (2nd-3rd century); Crowfoot 1957, p. 410, n. 94.12 (4th century); Clairmont 1963, pl. V, n. 189 (2nd-3rd century); Barag 1978, p. 24, fig. 12.50 (late 3rd-4th century); Weinberg & Goldstein 1988, p. 81, fig. 4-39 (2nd-4th century); Dussart 1998, BX.3211c, n. 11 (end 3rd-4th century); Gorin-Rosen 2016, p. 52, n. 27 (late Byzantine-Umayyad period); Gorin-Rosen & Katsnelson 2007, p. 107, fig. 15.1 (late Roman-Early Byzantine period); Antonaras 2010, fig. 3 (last on the second row) (mid 3rd-4th century)

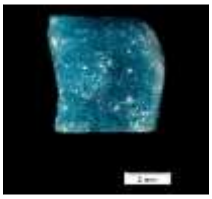
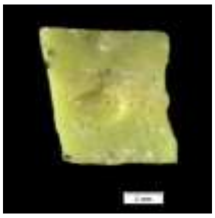
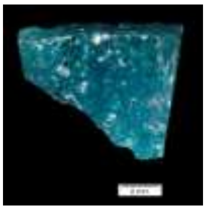
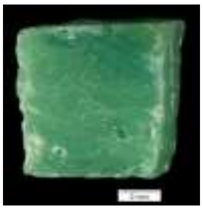
KH04	Straight rim with wall folded toward inside		Small bottle	Second half 4th – first half 8th century	Dussard 1998, BX.3244, n. 29 (second half 4th-6th century); Hadad 2005, pl. 7, n. 126 (first half 8th century)
KH05	Small infolded rim		Small bottle	7th – 8th century	Katsnelson 1999, p. 72, fig. 3, n. 3 (late Byzantine); Dussart 1998, BXIII.1931bI, n. 19 (first half 8th century); Gorin-Rosen 2010, p.234, pl. 10.6, n. 3 (Umayyad period)
KH06	Slightly concave bottom		Globular bottle	5th – 8th century	Katsnelson 1999, p. 72, fig. 3, n. 14 (5th-6th century); Foy 2012, pl. 18, n. 36 (8th century)
KH07	Central fragment of bottom		Unidentified vessel	Undated	Hadad 2005, pl. 11, n. 208 (Umayyad period)?

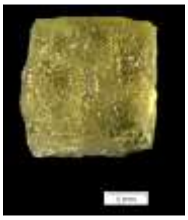
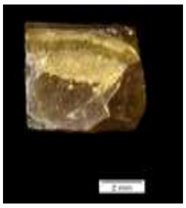
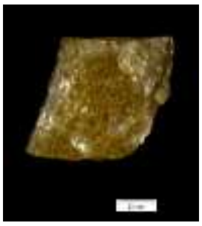
Tab.5.1 Summary and documentation of the vessel fragments selected for this study (Fiorentino et al. 2018).

Among the most interesting selected finds, there is a loop handle with a slightly pinched thumb-rest, preserved as two contiguous fragments (KH01) made of weak green glass. Attributable to a cup, or a cup-shaped oil lamp, the handle has different possible comparisons in the Islamic world, with or without the thumb-rest, generally dated to the Umayyad period (Gorin-Rosen 2008a; Gorin-Rosen 2008b; Gorin-Rosen 2010; Gorin-Rosen & Katsnelson 2007). However, the closest similarity is shown with a handle found at Bet Shean (or Bet She'an – Israel), recovered under the debris of the 749 earthquake from the sūq of Hishām (Hadad 2005). Datable back to Late Byzantine-Umayyad period, it is a small neck with an infolded rim, made of weak turquoise glass (KH05). Fragment KH04 is a straight rim with wall folded towards the inside, quite common in the glass productions of Byzantine and Umayyad period; this fragment can be referred to a small bottle made of weak olive green glass (Dussart 1998; Hadad 2005). Find KH06 is a slightly concave base of weak turquoise glass, resembling those documented in archaeological contexts dated from the Late Byzantine-Umayyad period onwards and often occurring as a reproduction of earlier typologies (Foy 2012; Katsnelson 1999). KH02 and KH03 are two fragments of weak green-coloured walls, showing traces of a trailed decoration made in the same colour of the body, probably referable to a bifurcated ribs decoration. This kind of decorative motif, showing either vertical or horizontal orientation, is frequently attested from Roman to Umayyad period, documented for different typologies of vessels (Antonaras 2010; Barag 1978; Clairmont 1963; Crowfoot 1957; Dussart 1998; Gorin-Rosen 2016; Gorin-Rosen & Katsnelson 2007; Harden 1936; Weinberg & Goldstein 1988). The set also includes a small fragment of the central part of a base, made of weak turquoise glass (KH07). The find resembles a concave base of bottle identified by Hadad in the *sūq* (market) of Hishām and dated to the Umayyad period (Hadad 2005); however, the small dimensions of fragment KH07 do not allow a certain identification of the original typology.

Among the tesserae, a set of 16 coloured samples (11 opaque and 5 translucent) was selected (Tab.5.2). The opaque sub-group comprises 6 tesserae of various shades of green (Vsr4, V5, Vc8, Vc9, A6, Ga10), 2 tesserae in tones of pale blue

(A7, A7 bis), 1 of a red glass (R1), and 2 yellow tesserae (G2, G/V3). The translucent sub-group is formed by 4 tesserae of different shades of yellow (Am/Au11, Am12, G/V13, Am14), and 1 of a light blue glass (A15).

Tessera	Colour	L*	a*	b*	Tessera	Colour	L*	a*	b*
 R1	Red (opaque) [NCS S 5040-Y80R]	34.21	23.81	14.39	 A6	Green (opaque) [NCS S 5040-B80G]	31.69	-12.45	-1.59
 G2	Yellow (opaque) [NCS S 2040-G90Y]	65.79	-0.81	44.28	 A7	Blue (opaque) [NCS S 4040-B20G]			
 G/V3	Yellow (opaque) [NCS S 2040-G80Y]	60.98	-3.95	43.13	 A7bis	Blue (opaque) [NCS S 4055-B40G]	29.86	-13.33	-4.44
 Vsr4	Green (opaque) [NCS S 5030-G30Y]	54.13	-9.99	17.51	 Vc8	Green (opaque) [NCS S 3040-G]	48.46	-13.16	13.37
 V5	Green (opaque) [NCS S 4030-G30Y]	43.93	-18.27	17.66	 Vc9	Green (opaque) [NCS S 3065-G40Y]	49.86	-15.42	17.43

Tessera	Colour			Tessera	Colour		
 Ga10	Green (opaque) [NCS S 1510-G]			 G/V13	Yellow (translucent) [NCS S 6030-Y20R]		
	L*	a*	b*		L*	a*	b*
 Am/Au11	Yellow (translucent) [NCS S 4050-Y10R]			 Am14	Yellow (translucent) [NCS S 2060-Y]		
	L*	a*	b*		L*	a*	b*
 Am12	Yellow (translucent) [NCS S 6030-Y20R]			 A15	Blue (translucent) [NCS S 0515-B20G]		
	L*	a*	b*		L*	a*	b*

Tab.5.2. Tesserae from Khirbat al-Mafjar selected for this study. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

5.2 The assemblage from the Great Mosque of Damascus

The Great Mosque of Damascus is one of the largest and oldest mosques in the world, whose construction was commissioned by the Umayyad caliph al-Walid I (r. 705–715). Started in 706, the mosque was completed in 715, shortly after al-Walid's death, by his successor, Sulayman ibn Abd al-Malik (r. 715–717). (Creswell 1969; Flood 2001; Grafman and Rosen-Ayalon 1999; Sauvaget 1947).

Fig.5.3 The Great Mosque of Damascus.

Conceived as a large congregational mosque for the citizens of Damascus and as a tribute to the new capital of the Umayyad caliphate, the structure was built inside the former enclosure of the 1st century temple dedicated to Jupiter Damascenus, rebuilt as the cathedral of St. John the Baptist, which was then demolished for the erection of the Mosque (Creswell 1969; Ettinghausen et al. 2001).

The structure of the Mosque reminds, therefore, of a basilical church, with three 'aisles' of equal size running lengthwise along it, separated by arcades supported by columns with Corinthian capitals with small arcades above.

When the Great Mosque was erected, all of the walls and arcades of its court and prayer hall were decorated with mosaics on both the inside and outside, above marble paneling[56]. The decorative program consisted of a combination of architectural (both monumental buildings and small palaces), and naturalistic motives, like trees, acanthus scrolls, vegetal friezes and plant candelabra used in all-over decoration (Gautier-van Berchem 1969; McKenzie 2007; McKenzie 2013). Large areas of the surviving mosaics date to the original construction of the building. Repairs are mentioned in inscriptions, including those of the late 11th century under the Seljuq Tutush and in 1159 under the Zengid sultan Nur al-Din, and those in 1269 by the Mamluk sultan Baibars (Gautier-van Berckem 1969).

The repairs generally copy mosaics located elsewhere in the mosque and so are distinguished by their style rather than content. The most recent and extensive ones, completed in the 1960s, are easily distinguishable from their bright gold background and more angular style. They are located on the façade of the prayer hall transept, and on the Dome of the Treasury (McKenzie 2013).

Tesserae selected for this study were collected from the warehouses of the Mosque and, therefore, their belonging to the original Umayyad decoration of the building cannot be ascertained through archaeological evidence.

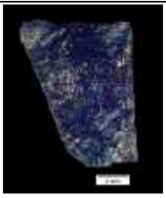
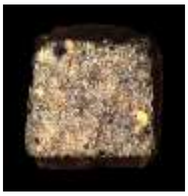
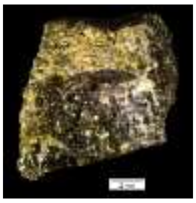
It is, however, reported in the literature that some mosaic fragments ascribable to the original Umayyad decoration of the building were stored in the warehouses of the Mosque itself. More specifically, in the paper *Les mosaïques de la Mosquée des Omayyades a Damas*, published in 1931 (de Lorey 1931), the restorer Eustache de Lorey, who collaborated on the conservation intervention of the mosaics occurred in the 1920s, states:

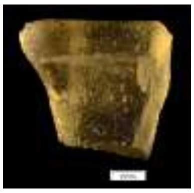
"[…] *En effet, il y a quelques années, il ne paraissait plus subsister de cette décoration que quelques fragments, très détériorés et peu importants, visibles sur le fronton, à l'extrémité du transept et sur les douelles du portique ouest. Cependant, divers sondages pratiqués sous l'enduit de chaux qui recouvrait les murs, m'avaient convaincu qu'il était possible, comme le pensait déjà Dickie, de*

[56] For an extensive discussion on hypotheses and theories concerning the gathering of materials and craftsmen for the mosaic decoration of the Great Mosque of Damascus, see chapter 3.

retrouver une partie des mosaïques décorant la colonnade de la porte d'entrée et le portique ouest.
Dès 1922, j'avais attiré l'attention des autorités compétentes sur la nécessité de commencer, le plus tôt possible, les travaux de consolidation et de dégagement; mais je nie pus obtenir les crédits nécessaires. En 1924, à l'occasion d'une réparation de la mosquée, je fis procéder, de mon propre chef, à la dépose de deux fragments, particulièrement menacés, qui se trouvaient sur le mur du portique (côte est). Ils sont conservés, depuis cette date, dans la réserve de la Grande Mosquée […]".

De Lorey clearly refers to mosaics located on the western portico (*le portique oust*), the place where the largest area of mosaics dating back to the Umayyad period is still on site (Gautier-van Berckem 1969). Furthermore, he reports having detached two fragments of this mosaic decoration and stored them into the warehouse of the Mosque (*la réserve de la Grande Mosquée*).
According to this reference, it cannot be excluded (and it is, conversely, highly probable) that the tesserae under study could belong to the original Umayyad mosaic decoration of the Mosque.
A set of 22 coloured (17 opaque and 5 translucent) and 2 colourless tesserae was selected for the analyses (Tab.5.3). The opaque sub-group encompasses 10 green (1Aa, 1Ab, 3C, 5Ea, 5eb, 11M, 13nv, 16Qa, 17R, 20U), 5 yellow (2Ba, 2Bb, 7G, 9I, 14O), 1 blue (10L) and 1 "black" (13Ngr) tesserae, while the translucent sub-group comprises 1 green (8H), 3 yellow (6Fs, 18S, 19T) and 1 blue (4D). Tesserae 6Fc and 15P are colourless and transparent.

Tessera	Colour	L*	a*	b*	Tessera	Colour	L*	a*	b*
 DMS_1_Aa	Green (opaque) [NCS S 4040-G]	41.16	-24.35	16.32	 DMS_4_D	Blue (translucent) [NCS S 7020-R80B]			
 DMS_1_Ab	Green (opaque) [NCS S 4040-G]	32.98	-12.91	6.49	 DMS_5_Ea	Green (opaque) [NCS S 5020-B90G]	33.01	-7.56	0.05
 DMS_2_Ba	Yellow (opaque) [NCS S 2030-G70Y]				 DMS_5_Eb	Green (opaque) [NCS S 5020-B90G]	40.23	-17.90	4.68
 DMS_2_Bb	Yellow (opaque) [NCS S 2030-G70Y]	51.51	-9.22	30.56	 DMS_6_Fs	Yellow (translucent) [NCS S 8502-Y]			
 DMS_3_C	Green (opaque) [NCS S 3040-G20Y]	46.10	-21.84	19.66	 DSM_6_Fc	Colourless […]			
 DMS_7_G	Yellow (opaque) NCS S 1020-Y]	70.78	1.72	28.34	 DMS_13_Nv	Green (opaque) [NCS S 8502-G]	25.06	-0.03	1.95
 DMS_8_H	Green (translucent) [NCS S 3020-B90G]				 DMS_13_Ngr	Black (opaque) [NCS S 8502]	21.28	-0.59	-1.22

Sample	Colour	L*	a*	b*	Sample	Colour	L*	a*	b*
 DMS_9_I	Yellow (opaque) [NCS S S3020-G70Y]	40.23	-17.90	4.68	 DMS_14_O	Yellow (opaque) [NCS S 6020-Y10R]	36.78	2.35	11.63
 DMS_10_L	Blue (opaque) [NCS S 4050-B20G]				 DMS_15_P	Colourless […]			
 DMS_11_M	Green/Yellow (opaque) [NCS S 4020-G50Y]	45.52	-3.70	10.58	 DMS_16-Qa	Green (opaque) [NCS S 0907-B80G]	67.68	-1.04	12.63
 DMS_17_R	Green (opaque) [NCS S 4550-B90G]	30.60	-14.56	3.44	 DMS_18_S	Yellow (translucent) [NCS S 2030-Y]			
 DMS_19_T	Yellow (translucent) [NCS S 3040-Y10R]				 DMS_20_U	Green/Blue (opaque) [NCS S 2050-B50G]			

Tab.5.3. Tesserae from the Great Mosque of Damascus selected for this study. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

5.3 The assemblage from the Dome of the Rock

The Dome of the Rock (Qubbat al-Ṣakhrah) in Jerusalem was built by caliph ʻAbd al-Malik, presumably started in 684/5 and completed in 691/2 (Creswell 1969; Grabar 1996; Grabar 2006; Nuseibeh & Grabar 1996).
The Dome is located on the Haram al-Sharif, an open-air platform of a peculiar significance for both Jews and Christians as it was the site of the Temple of Abraham's sacrifice and of Adam's creation.


Fig.5.4 The Dome of the Rock.

Positioned at the centre of a wide raised platform, the structure is composed of an octagonal base topped by a gilded wooden central dome. This architectural conception was probably adapted from Roman and Late Antique examples, inspired by models like the Church of the Ascension in Jerusalem and the great Golden Octagon of Antioch.
Commonly used for baptisteries in the West, the octagonal plan was more common for churches in Egypt and Syro-Palestine. It is, for instance, the case of the 5th century Kathisma church in Jerusalem, whose design consists of an octagonal structure with an internal colonnade built around a rock. The church of St John the Baptist in Alexandria and the church of Theotokos in Tyre also

seem to have been octagonal. The Church of the Ascension in Jerusalem and the great Golden Octagon of Antioch also had an octagonal plan (McKenzie 2007).

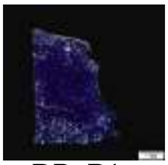
The original function and significance of the Dome of the Rock are uncertain and, therefore, source of debate among scholars. The building was (almost certainly) not a mosque and does not fit easily into other categories of Muslim religious structures.

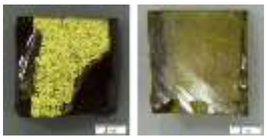
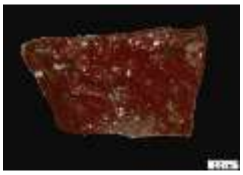
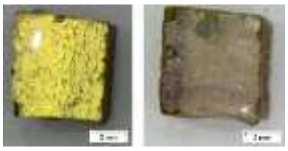
After the advent of the ʿAbbāsid dynasty, some Muslim historians began to report that ʿAbd al-Malik built the Dome of the Rock as a substitute for the Kaʿbah to relocate the site of the Muslim *hajj* from Mecca to Jerusalem. Another theory states that the Dome commemorates the *Miʿrāj*, the Prophet Muhammad's ascension into heaven. It has also been argued that ʿAbd al-Malik built the Dome to proclaim the emergence of Islam as a supreme new faith linked to biblical tradition yet distinct from the religions of the conquered people, especially Christianity (Goiten 1950).

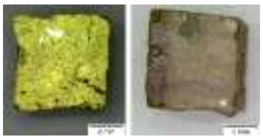
The Dome of the Rock was originally decorated with mosaics inside and outside. While those on the outside were replaced by tiles by 1552 (which have, since then, been replaced more than once to some extent), the interior mosaics are still largely 7^{th} century, despite some repairs that are clearly indicated by inscriptions (Gautier-van Berchem 1969).

The mosaics are all aniconic, and the variety of ornaments is amazing. Trees, fruits and garlands proliferate, mixed with leaves, shells, vases, scrolls, cornucopia, and a broad range of decorative borders and decorative elements like rosettes and palmettes. The palette of colours is rich as well: tones of blues and greens dominate on the golden background, while red, silver and mother-of-pearl are used as highlights.

A set of 31 coloured tesserae (23 opaque and 8 translucent) was selected for the analyses (Tab.5.4). The opaque sub-group encompasses 8 green (A1, G2, G3, G4, G5, G6, G7, GR1), 2 yellow (GY1, GY2), 5 blue (B1, T1, T2, T3, T4), 1 green/blue (LB1), 2 red (R1, R2) and 5 black (BK1, BK2, BK3, BK4, BK5) tesserae; the translucent sub-group is formed by 7 yellow (Am1_Au, Am2_Au, Am3_Au, Am4_Ag, Am5_Ag, Am6_Au) and 1 green (G1_Au) tesserae, all with either gold or silver foils.

Tessera	Colour				Tessera	Colour			
		L*	a*	b*			L*	a*	b*
 DR_A1	Green (opaque) [NCS S 3040-B80G]	43.88	-12.6	-2.25	 DR_G2	Green (opaque) [NCS S 2060-G30Y]	47.65	-11.95	15.5
 DR_B1	Blue (opaque) [NCS S 7020-R80B]	28.8	0.34	-7.83	 DR_G3	Green (opaque) [NCS S 3060-G20Y]	44.93	-22.83	15.34
 DR_BK1	Black (opaque) [NCS S 9000-N]	24.15	0.01	-1.1	 DR_G4	Green (opaque) [NCS S 3060-G]	40.88	-13.11	5.55
 DR_BK2	Black (opaque) [NCS S 9000-N]	24.7	0.01	0.6	 DR_G5	Green (opaque) [NCS S 2555-B80G]	32.2	-11.95	2.29
 DR_BK3	Black (opaque) [NCS S 8550-N]	27.6	-0.33	0.3	 DR_G6	Green (opaque) [NCS S 4040-B90G]	44.11	-11.95	3.72
 DR_BK4	Black (opaque) [NCS S 8500-N]	24.4	0.97	0.42	 DR_G7	Green (opaque) [NCS S 2050-G20Y]	36.2	-4.44	9.75
 DR_BK5	Black (opaque) [NCS S 9000-N]	24.28	0.73	0.38	 DR_GR1	Green (opaque) [NCS S 4010-G10Y]	58.74	-6.32	2.5

Tessera	Colour				Tessera	Colour			
 DR_GY1	Yellow (opaque) [NCS S 1050-G60Y]	L*	a*	L*	 DR_T2	Blue (opaque) [NCS S 4550-B20G]	L*	a*	b*
		56.35	-7.48	29.22			42.35	-15.19	-9.36
 DR_GY2	Yellow (opaque) [NCS S 1050-G70Y]	L*	a*	L*	 DR_T3	Blue (opaque) [NCS S 2555-B20G]	L*	a*	b*
		61.35	-7.28	37.16			50.26	-13.07	-7.24
 DR_LB1	Blue/Green (opaque) [NCS S 1515-B50G]	L*	a*	b*	 DR_T4	Blue (opaque) [NCS S 3060-B10G]	L*	a*	b*
		57.55	-7.07	0.92					
 DR_R1	Red (opaque) [NCS S 6030-Y90R]	L*	a*	b*	 DR_Am1_Au	Yellow (with golden leaf) (translucent) [NCS S 2060-G90Y]	L*	a*	b*
		34.33	23.81	14.45					
 DR_R2	Red (opaque) [NCS S 4550-Y80R]	L*	a*	L*	 DR_Am2_Au	Yellow (with golden leaf) (translucent) [NCS S 0530-Y20R]	L*	a*	b*
		34.42	23.85	15.24					
 DR_T1	Blue (opaque) [NCS S 2055-B10G]	L*	a*	L*	 DR_Am3_Au	Yellow (with golden leaf) (translucent) [NCS S 0515-G90Y]	L*	a*	b*
		47.3	-11.8	-8.79					

Tessera	Colour				
 DR_Am4_Ag	Yellow (with silver leaf) (translucent) [NCS S 0540-G90Y]				
	L*	a*	b*		
 DR_Am5_Ag	Yellow (with silver leaf) (translucent) [NCS S 0530-G90Y]				
	L*	a*	b*		
 DR_Am6_Au	Yellow (with golden leaf) (translucent) [NCS S 0570-G90Y]				
	L*	a*	b*		
	.				
 DR_G1_Au	Green (with golden leaf) (translucent) [NCS S 4550-G20Y]				
	L*	a*	b*		
 DR_Y1_Au	Yellow (with golden leaf) (translucent) [NCS S 4050-G90Y]				
	L*	a*	b*		

Tab.5.4. Tesserae from the Dome of the Rock selected for this study. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

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Chapter 6

Results and discussion

This chapter is aimed at illustrating and discussing the results obtained from the analyses carried out on the assemblages under study.

In order to (hopefully) help the reading and make the argument easier to be followed, the discussion will be carried out site by site.

For each assemblage, data concerning the characterisation of the base glass will be shown first, followed by what emerged from the archaeometric study of the micro-structure of the tesserae, with specific focus on colouring and opacifying agents.

Although in chapter 4 the importance of an in-depth characterisation of the micro-texture and micro-structure of the tesserae before that of the base glass has been highlighted, it is appropriate that, when the results are discussed, the base glass is addressed as starting point. It is, in fact, implicit that raw glass was always produced before the actual coloured tesserae.

In the discussion on the base glass, please refer to chapter 2 for a thorough examination of the compositional categories mentioned.

At the end of each section, a comprehensive table will be provided, aimed at summarising all achieved data on samples under study.

Then, in the next chapter, data obtained from all assemblages will be put together, in order to outline a framework that will be compared with information reported in the historical sources (discussed in chapter 3) and, then, contextualised in the broader scenario of understanding the relationship between Byzantine and Umayyad mosaics.

6.1 The assemblage from Khirbat al-Mafjar

The glass assemblage from the *qasr* of Khirbat al-Mafjar (Jericho, Palestine) encompasses both naturally coloured vessels and coloured tesserae (opaque and translucent).

Samples were collected in the so-called Red Building and they are ascribable to the Umayyad occupational phase of the complex according to archaeological evidence (see chapter 5)[57].

Detailed description and documentation of studied samples is provided in Tables 5.1 and 5.2.

6.1.1 Base glass

For the analysed vessels and tesserae from the *qasr* of Khirbat al-Mafjar, major and minor oxides, obtained by EPMA, are reported in Tab.6.1a. LA-ICP-MS data for trace elements are shown in Tab.6.2.

To compare the base glass composition of the opaque tesserae with the categories reported in the literature for naturally coloured glass, EPMA compositional data were recalculated according to the method discussed in chapter 4. The subtracted oxides were CuO, SnO_2, PbO and MnO. Sb_2O_3 and CoO were not subtracted since their values were negligible (respectively ranging up to 0.04 wt% and 0.09 wt%). For the opaque tesserae, discussion upon the base glass is made by taking EPMA reduced compositional data into account (Tab.6.1b).

Analysed samples are all of natron type glass, being MgO and K_2O contents below 1.5 wt%, (Fig.6.1). Tessera A15 is the only sample showing higher MgO and K_2O (respectively 2.23 wt% and 1.68 wt%), though below the value of 2.5 wt%, unequivocally referable to the use of plant ash as flux (Lyliquist & Brill 1993).

[57] The set of samples was provided by Dr. Enrico Cirelli (University of Bologna), participating in the Jericho-Mafjar Project; their study was authorised by Prof. Donald Whitcomb (University of Chicago) and Prof. Hadam Taha (Palestinian Department of Antiquities), Directors of the aforementioned Project.

The higher MgO (2.23 wt%) and K_2O (1.67 wt%) contents, together with slightly higher P_2O_5 (0.38 wt%), can be presumably linked to the occurrence of a contamination during the production process (Paynter 2008).

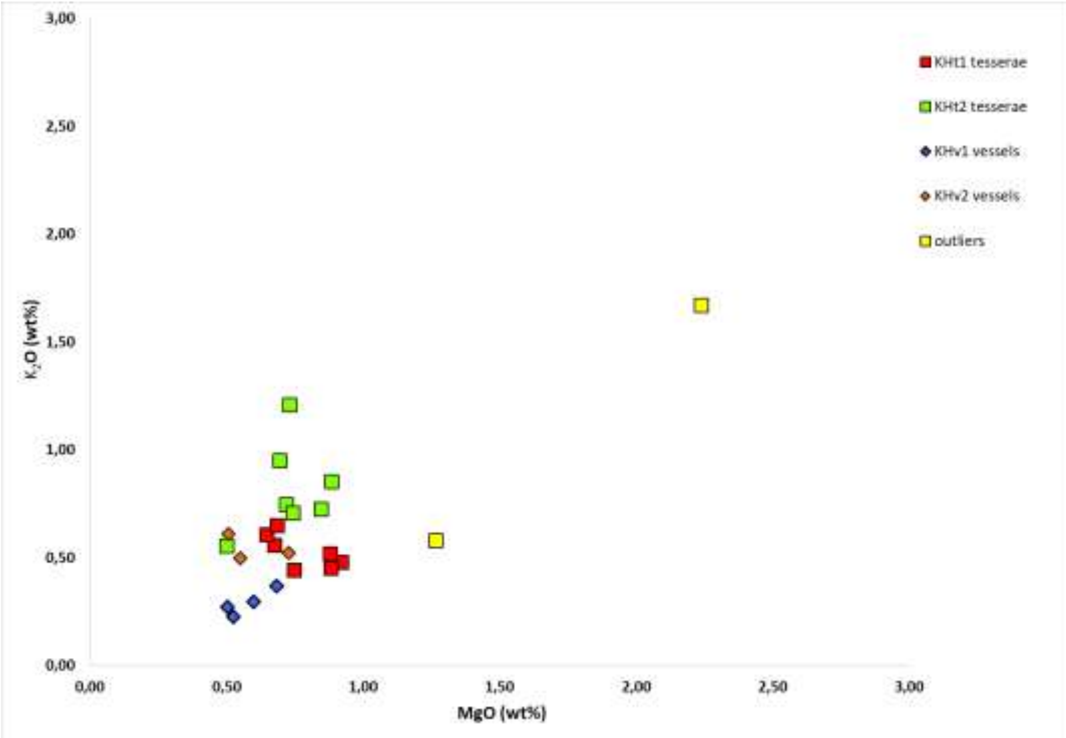


Fig.6.1 K_2O versus MgO bi-plot
(for the opaque tesserae, reduced wt% contents are used).

Taking first vessels into account, trace element patterns show that KH01, KH03 and KH05 exhibit lower strontium and higher heavy elements, like titanium, vanadium (associated to iron), chromium, zirconium, niobium (associated to titanium) and hafnium (Fig.6.2). Contrariwise, KH04 and KH06 are characterised by higher strontium together with relatively lower contents of heavy elements[58].

[58] Due to scarcity of available material, no LA-ICP-MS data are available for sample KH02 and KH07; therefore, they will only be discussed according to their major and minor oxides values.

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	CoO	CuO	SnO_2	Sb_2O_3	PbO	Total
KH01	Vessel	Egypt II	KHv1	Translucent	Weak green	**Mean**	14.19	0.52	2.32	70.35	0.09	0.1	1.53	0.23	10.25	0.31	0.01	0.02	0.88	nd	0.01	0.01	nd	0.05	100.86
						StDev	0.50	0.02	0.13	0.31	0.02	0.04	0.02	0.13	0.05	0.02	0.01	0.03	0.04	0.00	0.01	0.01	0.00	0.02	
KH02	Vessel	Egypt II	KHv1	Translucent	Weak green	**Mean**	15.09	0.68	2.63	69.42	0.1	0.06	1.32	0.37	10.01	0.27	0.01	0.07	0.88	nd	nd	0.02	nd	0.08	101.01
						StDev	0.30	0.02	0.09	0.37	0.032	0.02	0.02	0.05	0.11	0.01	0.01	0.01	0.04	0.00	0.00	0.01	0.00	0.07	
KH03	Vessel	Egypt II	KHv1	Translucent	Weak green	**Mean**	14.36	0.5	2.22	71.26	0.08	0.19	1.37	0.28	9.43	0.27	0.01	0.02	0.81	nd	0.01	0.03	nd	0.04	100.87
						StDev	0.37	0.02	0.15	0.42	0.02	0.03	0.03	0.04	0.11	0.03	0.01	0.01	0.01	0.00	0.01	0.03	0.00	0.05	
KH05	Vessel	Egypt II	KHv1	Translucent	Weak turquois	**Mean**	14.84	0.6	2.43	69.95	0.07	0.13	1.58	0.3	10.5	0.33	0.02	0.03	0.91	0.01	0.01	0.01	nd	0.04	101.76
						StDev	0.34	0.01	0.09	0.43	0.01	0.02	0.04	0.06	0.11	0.02	0.01	0.01	0.03	0.01	0.01	0.01	0.00	0.04	
KH04	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak olive	**Mean**	14.29	0.72	3.41	71.17	0.12	0.07	0.95	0.53	8.71	0.18	nd	0.04	0.83	0.01	0.01	nd	nd	0.05	101.09
						StDev	0.31	0.02	0.18	0.43	0.02	0.03	0.04	0.05	0.11	0.01	0.00	0.01	0.04	0.01	0.01	0.00	0.00	0.04	
KH07	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak turquois	**Mean**	15.06	0.5	3.28	72.27	0.06	0.11	1.27	0.62	7.7	0.07	0.01	0.02	0.42	0.01	0.01	nd	nd	0.04	101.46
						StDev	0.31	0.02	0.11	0.54	0.02	0.02	0.02	0.08	0.05	0.01	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.04	
KH06	Vessel	Bet Eli'ezer-type Levantine II	KHv2	Translucent	Weak turquois	**Mean**	12.89	0.54	3.32	75.44	0.07	0.04	1.05	0.5	6.63	0.1	0.02	0.02	0.46	0.01	0.01	0.01	0.01	0.03	101.15
						StDev	0.18	0.01	0.16	0.35	0.02	0.03	0.02	0.03	0.07	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.03	
R1	Tessera	Egypt I	KHt1	Opaque	Red	**Mean**	16.86	0.88	4.11	67.83	0.08	0.04	1.29	0.47	2.66	0.49	0.02	0.04	1.72	0.01	2.58	0.37	nd	0.85	100.3
						StDev	0.40	0.03	0.19	1.56	0.02	0.02	0.04	0.05	0.05	0.02	0.01	0.01	0.33	0.01	0.29	0.25	0.00	0.26	
G/V3	Tessera	Egypt I	KHt1	Opaque	Yellow	**Mean**	13.84	0.7	2.64	55.61	0.09	0.06	1.17	0.37	2.86	0.33	0.01	0.72	1.06	nd	0.01	1.99	nd	17.94	99.41
						StDev	0.44	0.03	0.12	1.54	0.02	0.01	0.04	0.05	0.11	0.02	0.01	0.06	0.04	0.00	0.01	0.40	0.00	1.77	
Vsr4	Tessera	Egypt I	KHt1	Opaque	Green	**Mean**	14.47	0.77	3.71	63.67	0.08	0.05	1.21	0.47	2.48	0.46	0.02	0.11	1.41	nd	1.82	1.16	nd	8.63	100.51
						StDev	0.34	0.01	0.18	0.93	0.01	0.03	0.04	0.06	0.07	0.02	0.02	0.01	0.04	0.00	0.07	0.08	0.00	0.61	
V5	Tessera	Egypt I	KHt1	Opaque	Green	**Mean**	16.36	0.58	2.87	60.05	0.09	0.1	1.28	0.49	2.67	0.23	0.01	0.04	0.81	0.01	1.47	0.82	0.04	10.89	98.8
						StDev	0.28	0.02	0.14	0.85	0.02	0.03	0.03	0.05	0.04	0.01	0.01	0.01	0.01	0.01	0.04	0.06	0.01	0.25	
A6	Tessera	Egypt I	KHt1	Opaque	Blue	**Mean**	16.73	0.72	3.36	69.13	0.58	0.07	1.48	0.44	3.28	0.41	0.01	0.56	1.35	0.01	2.42	0.16	nd	0.53	101.23
						StDev	0.41	0.02	0.16	1.15	0.12	0.02	0.04	0.07	0.09	0.02	0.01	0.02	0.03	0.02	0.05	0.05	0.00	0.07	
Vc9	Tessera	Egypt I	KHt1	Opaque	Green	**Mean**	16.27	0.56	3.15	60.66	0.14	0.14	1.41	0.53	2.77	0.24	0.01	0.04	0.95	0.09	1.12	0.81	nd	11.53	100.34
						StDev	0.32	0.02	0.12	0.44	0.01	0.03	0.03	0.06	0.05	0.02	0.01	0.01	0.01	0.10	0.04	0.07	0.00	0.41	
Ga10	Tessera	Egypt I	KHt1	Opaque	Green	**Mean**	18.18	0.68	3.58	69.81	0.9	0.15	1.59	0.66	4.6	0.32	0.01	0.04	1.13	0.00	0.01	0.01	0.01	0.04	101.71
						StDev	0.37	0.02	0.13	0.91	0.45	0.02	0.05	0.06	0.33	0.02	0.01	0.01	0.03	0.12	0.01	0.01	0.01	0.04	
G2	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Yellow	**Mean**	11.1	0.61	1.98	50.24	0.06	0.05	0.8	0.53	5.65	0.07	0.01	0.03	0.35	0.01	0.39	2.3	nd	24.87	99.03
						StDev	0.25	0.03	0.09	0.91	0.02	0.03	0.04	0.09	0.08	0.01	0.02	0.01	0.02	0.01	0.02	0.27	0.00	0.93	
A7	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	**Mean**	13.97	0.71	2.82	67.19	0.35	0.07	0.99	1.19	9.59	0.09	0.01	0.34	0.57	0.03	1.77	0.1	nd	0.4	100.16
						StDev	0.63	0.05	0.15	0.52	0.03	0.02	0.04	0.13	0.18	0.01	0.01	0.02	0.01	0.04	0.06	0.03	0.00	0.07	
A7bis	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	**Mean**	13.26	0.7	3.11	67.78	0.2	0.13	1.1	0.74	10.14	0.1	0.01	0.05	0.5	0.05	1.7	0.12	nd	0.26	99.9
						StDev	0.38	0.01	0.08	0.52	0.01	0.05	0.03	0.06	0.08	0.01	0.01	0.01	0.02	0.06	0.10	0.02	0.00	0.06	
Vc8	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Green	**Mean**	12.88	0.73	1.83	58.18	0.24	0.12	0.95	0.71	6.00	0.07	nd	0.37	0.4	0.07	0.7	1.47	nd	14.56	99.23
						StDev	0.21	0.02	0.10	0.46	0.02	0.04	0.04	0.07	0.05	0.01	0.00	0.02	0.02	0.08	0.03	0.09	0.00	0.42	
G/V13	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	**Mean**	13.71	0.69	3.01	71.01	0.17	0.06	1.18	0.96	9.3	0.07	0.01	0.02	0.42	0.17	0.02	nd	nd	0.05	100.69
						StDev	0.53	0.01	0.18	0.52	0.02	0.02	0.03	0.08	0.08	0.01	0.01	0.01	0.01	0.18	0.01	0.00	0.00	0.04	
Am14	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	**Mean**	14.62	0.74	3.11	69.1	0.08	0.19	1.06	0.72	8.93	0.1	0.01	2.58	0.45	0.19	nd	0.02	0.01	0.02	101.72
						StDev	0.46	0.02	0.08	0.42	0.02	0.03	0.02	0.04	0.08	0.02	0.01	0.01	0.02	0.20	0.00	0.02	0.01	0.03	
Am/Au11	Tessera	Bet Eli'ezer-type Levantine II	KHt2	Translucent	Yellow	**Mean**	12.09	0.49	3.17	74.32	0.05	0.11	0.95	0.56	6.68	0.1	0.01	1.87	0.43	0.13	0.01	0.01	nd	0.03	100.9
						StDev	0.60	0.02	0.08	0.32	0.02	0.02	0.02	0.05	0.06	0.01	0.01	0.01	0.02	0.14	0.01	0.01	0.00	0.03	
Am12	Tessera	outlier	outlier	Translucent	Yellow	**Mean**	16.28	1.26	2.55	66.07	0.1	0.28	1.13	0.59	8.63	0.18	nd	0.1	1.41	0.15	nd	0.01	0.01	0.04	98.65
						StDev	0.32	0.02	0.12	0.83	0.02	0.03	0.04	0.04	0.08	0.01	0.00	0.03	0.04	0.16	0.00	0.01	0.01	0.04	
A15	Tessera	outlier	outlier	Translucent	Blue	**Mean**	16.28	2.23	2.26	63.17	0.37	0.31	0.7	1.68	7.74	0.24	0.01	nd	1.83	0.21	0.01	0.01	nd	0.02	96.85
						StDev	0.50	0.02	0.13	0.31	0.02	0.04	0.02	0.13	0.05	0.02	0.01	0.00	0.04	0.22	0.01	0.01	0.00	0.02	

Tab.6.1a Chemical compositions of the glassy matrices of vessels and tesserae, obtained by EMPA.
All data are expressed as percentage concentrations of element oxides (wt%); n.d. is for not detected.

Sample	Typology	Compositional category	Group	Opacity	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	FeO	CoO	Sb_2O_3
R1	Tessera	Egypt I	KHt1	Opaque	Red	17.48	0.91	4.26	70.32	0.09	0.04	1.34	0.49	2.75	0.51	0.02	1.78	0.01	nd
G/V3	Tessera	Egypt I	KHt1	Opaque	Yellow	17.58	0.89	3.35	70.63	0.12	0.07	1.49	0.47	3.63	0.42	0.01	1.35	nd	nd
Vsr4	Tessera	Egypt I	KHt1	Opaque	Green	16.29	0.87	4.18	71.71	0.09	0.05	1.36	0.52	2.80	0.51	0.02	1.58	nd	nd
V5	Tessera	Egypt I	KHt1	Opaque	Green	19.12	0.68	3.35	70.17	0.10	0.11	1.49	0.57	3.12	0.27	0.01	0.94	0.01	0.04
A6	Tessera	Egypt I	KHt1	Opaque	Green	17.15	0.74	3.44	70.85	0.59	0.08	1.52	0.45	3.36	0.42	0.01	1.39	0.01	nd
Vc9	Tessera	Egypt I	KHt1	Opaque	Green	18.74	0.64	3.63	69.86	0.16	0.16	1.63	0.61	3.19	0.27	0.01	1.10	0.09	nd
Ga10	Tessera	Egypt I	KHt1	Opaque	Green	17.89	0.67	3.52	68.70	0.89	0.15	1.56	0.65	4.53	0.31	0.01	1.11	0.00	0.01
G2	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Yellow	15.53	0.85	2.77	70.32	0.08	0.07	1.12	0.74	7.91	0.09	0.02	0.49	0.01	nd
A7	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	14.32	0.73	2.89	68.88	0.36	0.07	1.02	1.22	9.83	0.09	0.01	0.58	0.03	nd
A7bis	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	13.56	0.71	3.18	69.33	0.21	0.13	1.12	0.75	10.37	0.10	0.01	0.52	0.05	nd
Vc8	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Green	15.68	0.89	2.22	70.84	0.29	0.14	1.16	0.87	7.31	0.09	nd	0.49	0.07	nd

Tab.6.1b Reduced percentage concentrations of major and minor oxides analysed by EMPA, calculated for the opaque tesserae.

Sample	Typology	Compositional category	Group	Opacity	Colour	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Sn	Sb	Ba	La
KH01	Vessel	Egypt II	KHv1	Translucent	Weak green	5.59	1405	17.22	18.21	2.46	5.44	2.41	17.09	2.41	3.64	146.85	6.31	129.05	3.21	0.37	0.09	124.48	7.45
KH02	Vessel	Egypt II	KHv1	Translucent	Weak green																		
KH03	Vessel	Egypt II	KHv1	Translucent	Weak green	6.09	1271.25	17.4	23.51	5.12	7.11	33.95	28.33	2.85	4.55	209.2	6.16	143.98	2.97	10.83	1.55	154.2	7.58
KH05	Vessel	Egypt II	KHv1	Translucent	Weak turquoise	6.47	1665.5	21.09	27.23	2.67	6.48	2.86	15.96	2.77	4.38	180.73	7.92	258.4	4.01	0.43	0.08	150.02	8.74
KH04	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak olive green	6.54	939.33	16.82	17.01	2.39	6.05	36.65	21.01	2.88	8.46	321.93	7.34	63.95	2.22	4.32	1.56	186.25	8.25
KH07	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak turquoise																		
KH06	Vessel	Bet Eli'ezer-type Levantine II	KHv2	Translucent	Weak turquoise	5.62	470.08	9.18	13.72	1.43	4.19	2.75	7.4	3.31	9.43	305.47	4.95	35.3	1.53	0.6	0.04	193.52	6.16
R1	Tessera	Egypt I	KHt1	Opaque	Red	9.92	2716.2	38.1	52.15	7.57	32.19	12178	1528.2	4.45	8.4	203.02	9.8	150.5	4.26	1002.86	23.4	213.18	10.24
G/V3	Tessera	Egypt I	KHt1	Opaque	Yellow	7.58	1872.33	26.13	36.94	4.71	10.19	192.32	56.87	3.53	5.69	168.15	7.93	141.52	3.4	17000	82.03	217.53	8.09
Vsr4	Tessera	Egypt I	KHt1	Opaque	Green	9.14	2482.17	34.62	53.91	6.56	24.67	11116.67	877.35	4.63	7.42	211.58	9.81	176.4	4.47	7881	57.85	206.17	10.41
V5	Tessera	Egypt I	KHt1	Opaque	Green	8.64	1387.67	21.53	33.89	5.55	17.45	8308.17	1003.12	3.3	7.26	219.28	6.91	94.06	2.72	5049.17	68	157.4	7.49
A6	Tessera	Egypt I	KHt1	Opaque	Blue	8.42	2253.83	29.82	45.27	6.96	28.69	14640	996.22	4.12	6.17	193.52	8.62	144.47	4.2	1034.63	21.54	245.62	9.41
Vc9	Tessera	Egypt I	KHt1	Opaque	Green	7.2	1363.83	22.23	32.44	5.49	16.42	6778.5	658.53	3.53	7.53	213.03	6.57	85.21	2.75	5776.5	95.68	173.15	7.32
Ga10	Tessera	Egypt I	KHt1	Opaque	Green	7.95	1649.33	24.87	37.92	3.59	7.19	14.61	27.59	3.59	8.36	238.93	7.71	111.6	3.18	2.3	0.09	182.58	8.28
G2	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Yellow	4.59	400.63	6.83	9.84	1.9	8.2	2355.67	154.18	2.31	5.78	298.18	6.04	41.85	1.27	16715	194.38	163.83	5.87
A7	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	6	525.6	13.26	17.21	10.57	20.81	9692	37.63	3	12.04	467.55	7.65	54.06	1.73	606.5	22.43	238.93	8.06
A7bis	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	6.73	480.7	9.72	12.54	18.07	39.5	8780.83	47.77	3.16	10.27	474.43	7.55	47.01	1.61	662	7.15	231.73	8.17
Vc8	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Green	5.66	434.85	11.92	12.54	8.74	14.08	4226.33	364.68	2.31	5.3	413.3	5.77	49.47	1.34	10906.5	188.5	188.37	6
G/V13	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	8.15	372.84	9.33	12.32	5.95	4.7	39.21	18.91	2.76	12.19	322.72	5.2	29.77	1.06	7.89	5.14	192.86	5.87
Am14	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	8.08	427.57	10.1	10.7	1.33	3.53	4.53	9.57	2.71	10.75	326.13	5.35	34.07	1.15	0.71	0.24	186.73	6.06
Am/Au11	Tessera	Bet Eli'ezer-type Levantine II	KHt2	Translucent	Yellow	9.79	398	8.23	14.28	1.31	4.05	2.75	9.42	3.05	10.04	293.05	4.2	28.33	1.28	0.61	0.03	180.72	5.36
Am12	Tessera		outlier	Translucent	Yellow	9.7	852.8	39.11	15	11.94	15.85	56.85	31.07	3.29	6.21	715.3	9.93	86.55	2.73	5.9	142.27	394.5	11.96
A15	Tessera		outlier	Translucent	Blue	9.16	1273.33	46.53	22.85	26.96	50.57	59.55	68.5	3.58	7.82	822.28	11.02	120.83	3.27	1.63	15.68	410.35	14.56

Tab.6.2 Trace element data obtained by LA-ICP-MS, expressed in ppm.
KH02 and KH07 were not analysed due to the scarcity of available material.

Sample	Typology	Compositional category	Group	Opacity	Colour	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	Th
KH01	Vessel	Egypt II	KHv1	Translucent	Weak green	13.09	1.73	5.86	1.14	0.32	1.1	0.19	1.06	0.29	0.64	0.11	0.64	0.13	3.05	0.24	0	3.37	1.48
KH02	Vessel	Egypt II	KHv1	Translucent	Weak green																		
KH03	Vessel	Egypt II	KHv1	Translucent	Weak green	14.28	1.73	6.08	1.25	0.35	1.13	0.21	1.11	0.28	0.63	0.12	0.65	0.13	3.31	0.22	0.01	320	1.62
KH05	Vessel	Egypt II	KHv1	Translucent	Weak turquoise	15.32	1.95	7.24	1.51	0.33	1.26	0.27	1.38	0.34	0.82	0.15	0.88	0.19	6.15	0.3	0	4.18	2.15
KH04	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak olive green	12.94	1.9	5.52	1.1	0.31	0.98	0.19	0.95	0.24	0.52	0.09	0.58	0.1	1.6	0.15	0	128.32	1.17
KH07	Vessel	Apollonia-type Levantine I	KHv2	Translucent	Weak turquoise																		
KH06	Vessel	Bet Eli'ezer-type Levantine II	KHv2	Translucent	Weak turquoise	12.88	1.46	5.04	1	0.31	0.84	0.17	0.84	0.21	0.46	0.08	0.42	0.08	0.88	0.1	0	6.2	0.81
R1	Tessera	Egypt I	KHt1	Opaque	Red	17.36	2.47	8.08	1.68	0.49	1.61	0.29	1.5	0.39	0.84	0.16	0.88	0.17	3.54	0.3	0.03	4306.4	1.87
G/V3	Tessera	Egypt I	KHt1	Opaque	Yellow	14.53	1.94	7.29	1.57	0.41	1.4	0.28	1.39	0.36	0.81	0.15	0.84	0.16	3.54	0.28	0.06	165866.67	1.77
Vsr4	Tessera	Egypt I	KHt1	Opaque	Green	18.83	2.46	9.37	2.01	0.61	1.93	0.37	1.81	0.47	1.07	0.19	1.09	0.21	4.51	0.37	0.65	69925	2.3
V5	Tessera	Egypt I	KHt1	Opaque	Green	12.88	1.72	6.61	1.43	0.43	1.34	0.26	1.29	0.32	0.73	0.13	0.73	0.14	2.5	0.22	0.43	104133.33	1.43
A6	Tessera	Egypt I	KHt1	Opaque	Blue	17.61	2.28	8.35	1.76	0.5	1.59	0.31	1.6	0.42	0.95	0.17	0.97	0.19	3.77	0.32	0.78	4667	2.07
Vc9	Tessera	Egypt I	KHt1	Opaque	Green	13.28	1.71	6.39	1.38	0.41	1.29	0.25	1.2	0.3	0.69	0.12	0.66	0.12	2.19	0.22	0.39	102541.67	1.36
Ga10	Tessera	Egypt I	KHt1	Opaque	Green	14.76	1.9	7.03	1.51	0.46	1.4	0.28	1.4	0.35	0.81	0.14	0.81	0.15	2.9	0.26	0	30.47	1.64
G2	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Yellow	9.96	1.33	5.21	1.08	0.3	1.01	0.2	1	0.27	0.58	0.1	0.54	0.1	1.08	0.11	0.08	188216.67	0.91
A7	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	13.44	1.76	6.84	1.43	0.42	1.26	0.26	1.28	0.33	0.75	0.13	0.7	0.12	1.44	0.14	0.37	3065	1.21
A7bis	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Blue	14.55	1.84	6.82	1.36	0.45	1.31	0.25	1.24	0.31	0.69	0.12	0.63	0.12	1.2	0.12	0.2	2235.33	1.08
Vc8	Tessera	Apollonia-type Levantine I	KHt2	Opaque	Green	9.54	1.3	4.91	1.02	0.31	1	0.2	0.95	0.25	0.57	0.09	0.54	0.1	1.29	0.11	0.66	139966.67	1.01
G/V13	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	11.14	1.38	4.41	0.88	0.29	0.78	0.15	0.74	0.19	0.44	0.07	0.4	0.07	0.75	0.08	0	113.6	0.66
Am14	Tessera	Apollonia-type Levantine I	KHt2	Translucent	Yellow	11.14	1.45	4.37	0.82	0.27	0.77	0.15	0.73	0.2	0.45	0.07	0.41	0.08	0.87	0.08	0	11.48	0.71
Am/Au11	Tessera	Bet Eli'ezer-type Levantine II	KHt2	Translucent	Yellow	12.14	1.32	4.29	0.82	0.3	0.73	0.14	0.7	0.18	0.39	0.06	0.36	0.07	0.7	0.08	0	6.91	0.68
Am12	Tessera		outlier	Translucent	Yellow	16.19	2.55	9.09	1.85	0.55	1.77	0.34	1.68	0.44	1.01	0.17	0.92	0.17	2.12	0.2	0	91.99	1.6
A15	Tessera		outlier	Translucent	Blue	17.38	2.94	10.72	2.22	0.57	2.12	0.4	2.03	0.52	1.21	0.21	1.16	0.21	2.85	0.25	0	26.14	1.96

Tab.6.2 (continuing) Trace element data obtained by LA-ICP-MS, expressed in ppm.
KH02 and KH07 were not analysed due to the scarcity of available material.

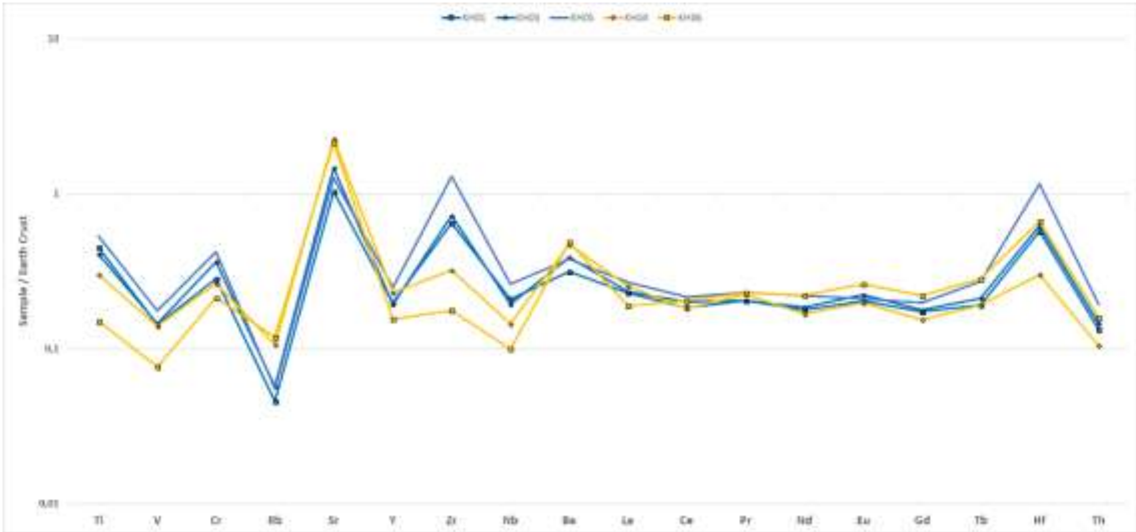


Fig.6.2 Trace elements patterns and of the vessels (LA-ICP.MS data). Averages are normalised to the mean values in the continental crust (Kamber et al. 2005). Blue lines are used for samples of group KHv1, orange lines one for those of group KHv2.

From now on, the first group of vessel samples (KH01, KH03, KH05) will be referred to as KHv1, whilst the second group (KH04, KH06) will be named KHv2.

CaO/Al_2O_3:Na_2O/SiO_2, TiO_2/Al_2O_3:Al_2O_3/SiO_2 and FeO/TiO_2:FeO/Al_2O_3 bi-plots (Fig.6.3-6.5) further enhance the distinctive features showed by the vessels under study: KHv1 vessels have higher CaO/Al_2O_3 than KHv2, whilst Na_2O/SiO_2 does not show significant shifts; KHv1 vessels also show consistently higher TiO_2/Al_2O_3 and FeO/Al_2O_3 ratios when compared to KHv2 vessels. Sample KH06 is characterised by lower Na_2O/SiO_2 and CaO/Al_2O_3 than the other vessels belonging to KHv2 group. Vessel KH02 shows features comparable to KHv1 group, while the behaviour of KH07 is consistent with KH04.

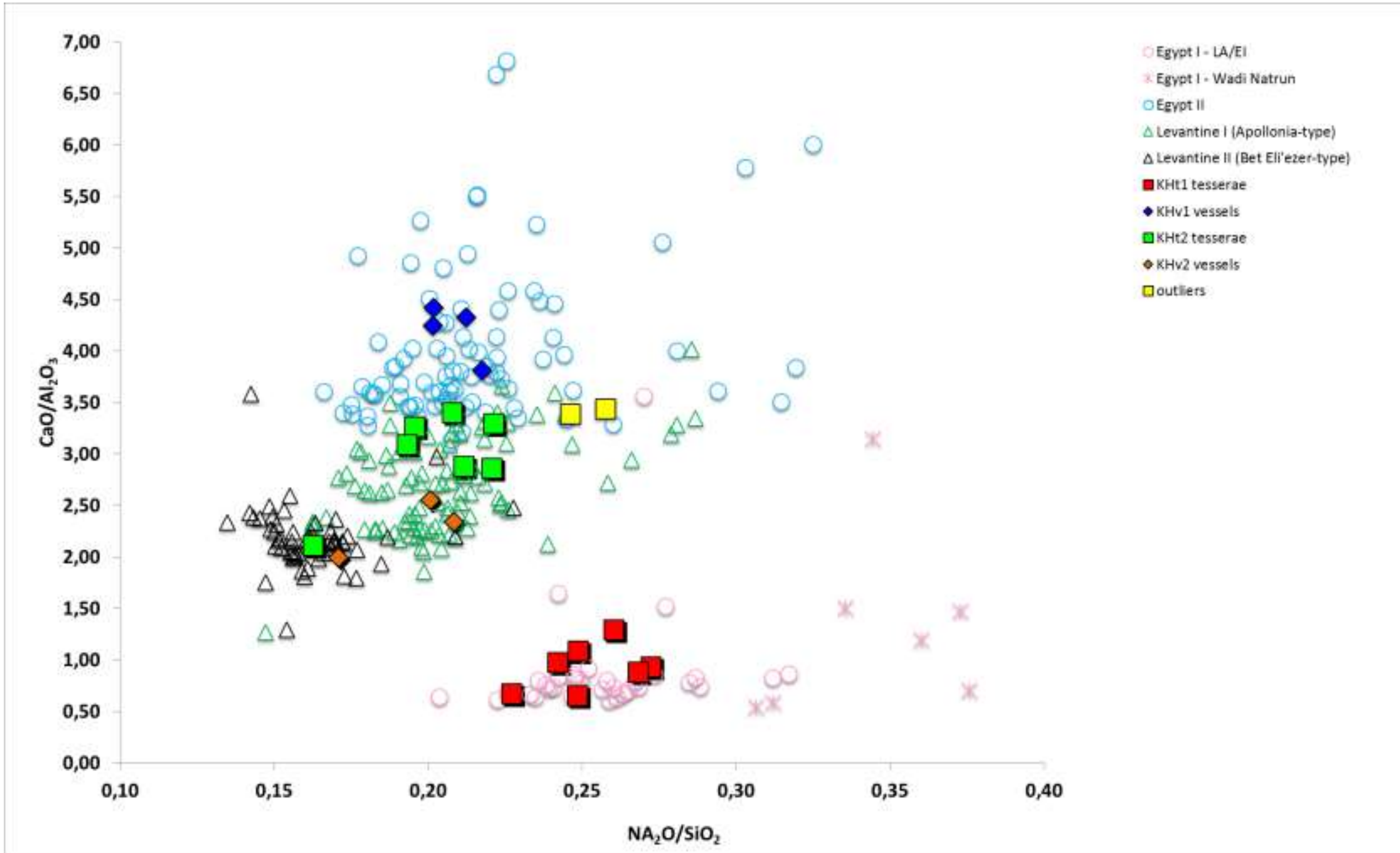


Fig.6.3 CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Bet Eli'ezer-type: Freestone et al. 2000; Freestone et al. 2015; Phelps et al. 2016; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Egypt II: Bimson & Freestone 1985; Foy, Picon & Vichy 2003; Freestone et al. 2015; Gratuze & Barrandon 1990; Phelps et al. 2016.

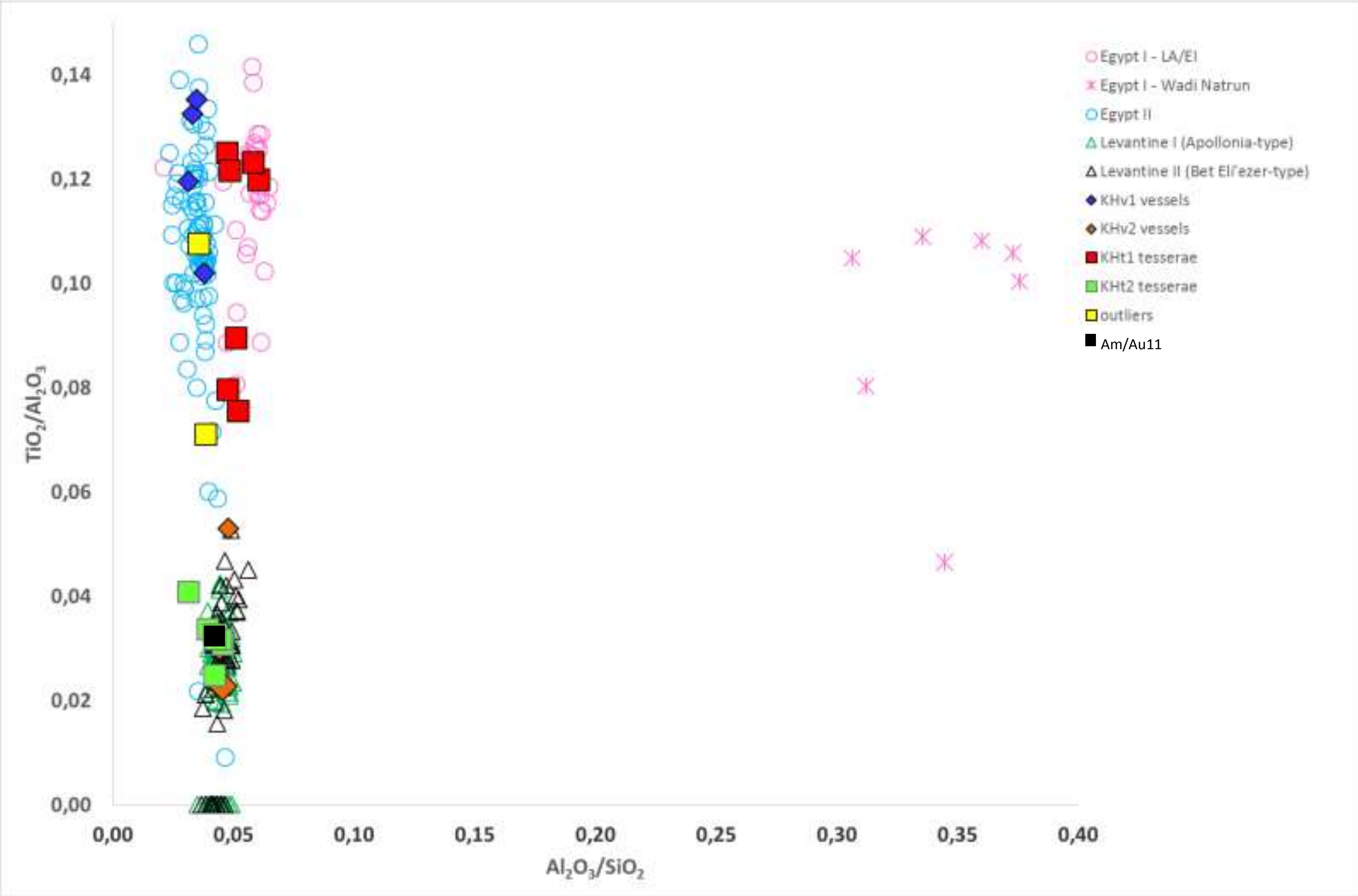


Fig.6.4 TiO_2/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Bet Eli'ezer-type: Freestone et al. 2000; Freestone et al. 2015; Phelps et al. 2016; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Egypt II: Bimson & Freestone 1985; Foy, Picon & Vichy 2003; Freestone et al. 2015; Gratuze & Barrandon 1990; Phelps et al. 2016.

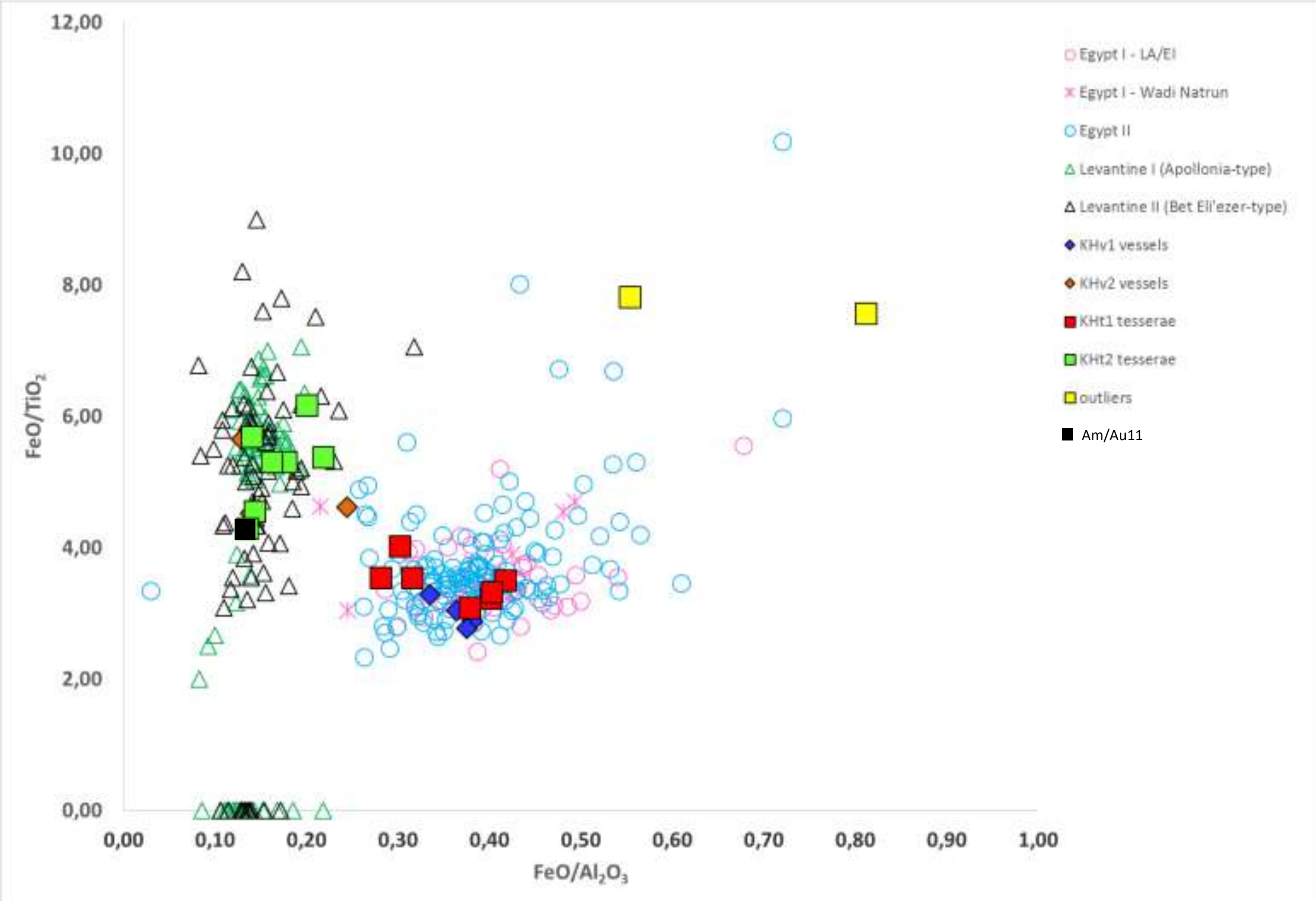


Fig.6.5 FeO/TiO_2 versus FeO/Al_2O_3 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Bet Eli'ezer-type: Freestone et al. 2000; Freestone et al. 2015; Phelps et al. 2016; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Egypt II: Bimson & Freestone 1985; Foy, Picon & Vichy 2003; Freestone et al. 2015; Gratuze & Barrandon 1990; Phelps et al. 2016.

Moving to tesserae, it can be observed that trace element patterns allow a first well-defined separation of the analysed samples in two main groups. R1, G/V3, Vsr4, V5, A6, Vc9 and Ga10, from now on referred to as KHt1, show lower strontium and higher heavy elements contents (Ti, V, Cr, Zr, Nb, Hf) when compared to G2, A7, A7bis, Vc8, Am/Au11, G/V13 and Am14, from now on labelled KHt2 (Fig.6.6).

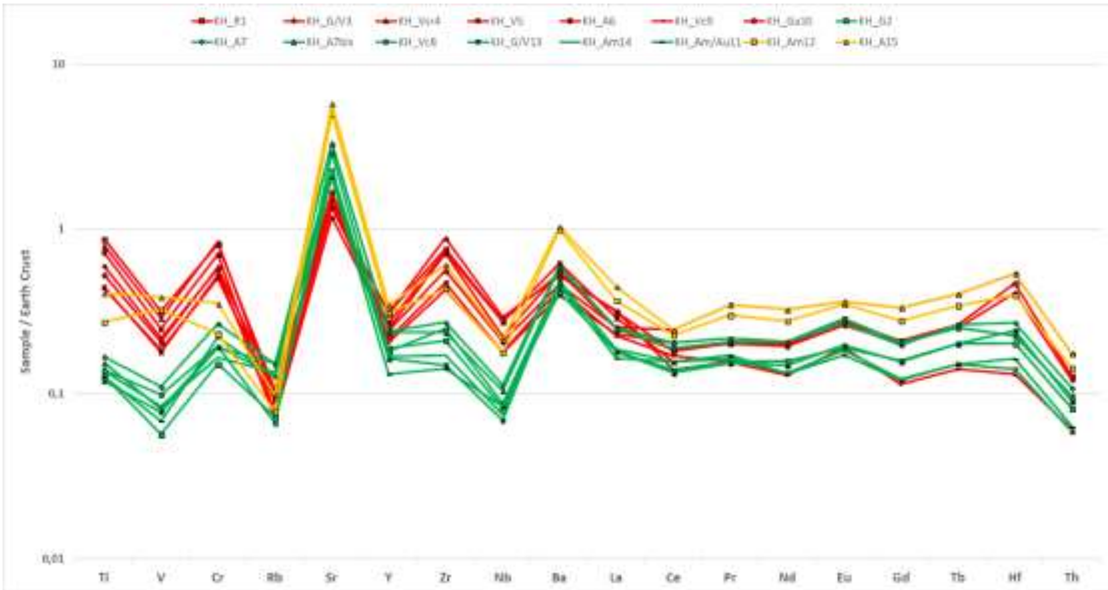


Fig.6.6 Trace elements patterns of the tesserae (LA-ICP-MS data). Averages are normalised to the mean values in the continental crust (Kamber et al. 2005). Red lines are used for samples of group KHt1, green lines for samples belonging to group KHt2; orange lines indicate the outliers.

KHt1 tesserae also have lower lime (2.75-4.53 wt%), higher alumina and slightly higher iron oxides contents (0.94-1.78 wt%) contents (3.35-4.26 wt%) compared to KHt2 samples (lime ranging from 6.68 to 10.37 wt% and alumina ranging from 2.22 to 3.18 wt%); moreover, the two groups differ in terms of soda contents, KHt1 tesserae containing higher soda (16.29-18.74 wt%) compared to KHt2 (12.09-15.68 wt%). The above differences are clearly displayed in CaO/Al_2O_3:Na_2O/SiO_2, TiO_2/Al_2O_3:Al_2O_3/SiO_2 and FeO/TiO_2:FeO/Al_2O_3 bi-plots (Fig.6.3-6.5), also highlighting a separation of Am/Au11 from the other KHt2 tesserae especially due to its lower CaO/Al_2O_3 and Na_2O/SiO_2 ratios.

Am12 and A15 translucent tesserae can be considered as outliers, since they show a less definite behaviour that cannot allow unequivocally including them into neither the KHt1 nor the KHt2 group, although they have some common features with KHt2 samples.

6.1.1a KHv1 and KHt1 groups: Egyptian production

Vessels and tesserae belonging to groups KHv1 (KH01, KH02, KH03, KH05) and KHt1 (R1, G/V3, Vsr4, V5, A6, Vc9, Ga10) have been manufactured by using sands richer in the heavy accessory minerals and low in strontium contents (Fig.6.2, 6.6). These features, as well as the high soda contents, are typical of Egyptian glasses (Foy, Picon & Vichy 2003; Nenna 2014; Phelps et al. 2016).

However, even though they are linked by an Egyptian origin, KHv1 and KHt1 are separate glass groups: KHv1 vessels are made of Egypt II glass, whilst KHt1 tesserae correspond to Egypt I compositional category.

KHv1 vessels show high lime, low alumina, lower soda and a high CaO/Sr ratio, suggesting that lime is derived from a limestone source (Freestone et al. 2003; Phelps et al. 2016). CaO/Sr ratios reported in the literature for natron glass produced with limestone in Middle Egypt El-Ashmunein (Freestone et al. 2003) are, indeed, of circa 616. CaO/Sr ratios measured for raw materials have been reported by Wedepohl and co-workers (Wedepohl et al. 2011) and follow the same trend observed for the glass: low ratios for the marine carbonates, like shells (CaO/Sr=212) and higher ratios for limestone (CaO/Sr=870). CaO/Sr ratios measured for KHv1 samples range from 450 to 690, compatible with the use of an inland sand source.

At this point, a comparison between compositional features and previously discussed chrono-typological study of the analysed vessels[59] needs to be addressed. Concerning KHv1 vessels, it should be noted that KH02 and KH03 are two wall fragments of weak green glass, showing a decorative motif with trails of the same colour of the body, frequently attested from Roman to Umayyad period; the weak green loop handle with pinched thumb-rest (KH01) and the weak turquoise small neck with infolded rim (KH05) show precise comparisons with some published materials and can be attributed to vessel types datable to the Umayyad period and, more precisely, to the 8th CE.

[59] See chapter 5.

Here, analyses have demonstrated that these vessels are made of Egypt II glass, perfectly consistent with the majority of produced and consumed glass vessels of 8th CE falling within this compositional category in the Near East as attested in the literature (Freestone et al. 2015; Greiff & Keller 2014; Kato et al. 2009; Phelps et al. 2016).

Tesserae belonging to KHt1 group are consistent with Egypt I compositional category as they show lower lime, higher alumina and higher soda when compared to KHv1 vessels (Fig.6.3-6.5). Contrarily from what observed for the KHv1 vessels, CaO/Sr ratios found for KHt1 tesserae are low (on average 150) and the two elements show positive correlation (Fig.6.7).

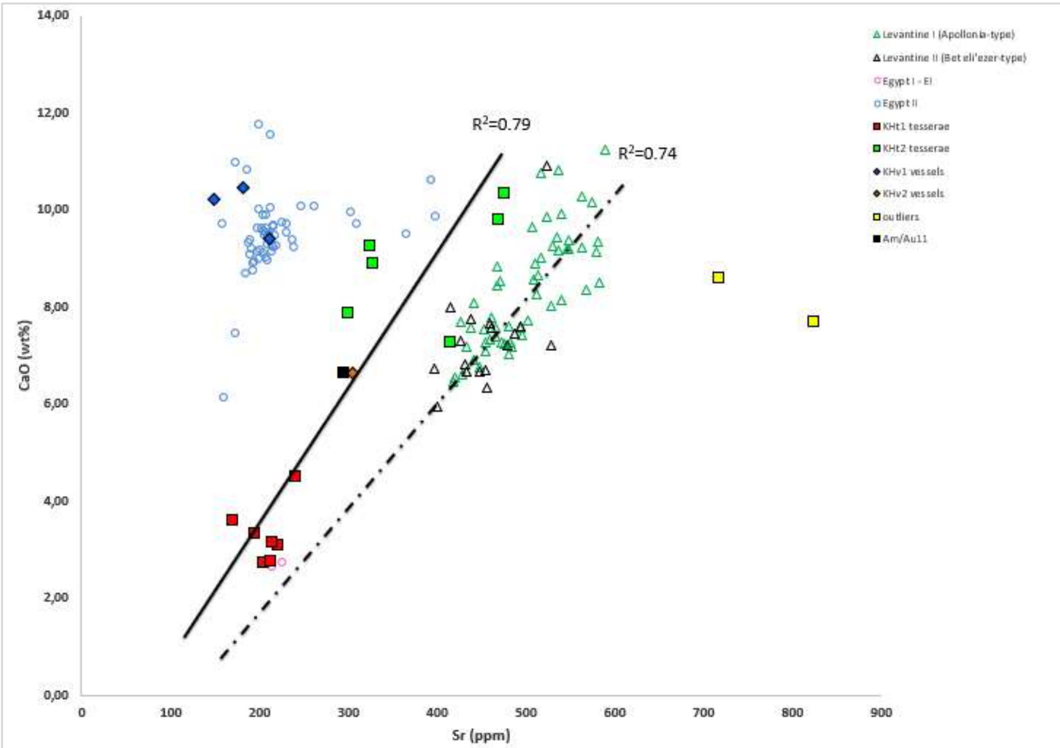


Fig.6.7 CaO (wt%) versus Sr (ppm) bi-plot (for the opaque tesserae, reduced wt% contents are used). The black and the dotted lines show, respectively, the correlation between CaO and Sr contents for samples from this study and from the literature (Phelps et al. 2016).

These data are consistent with the use of a shell-containing coastal sand, as recently also stated by Phelps and co-workers regarding early Islamic Egypt I glasses (Phelps et al. 2016). Data of major and minor oxides and trace elements here reported indicate, thus, the use of different sands for the production of vessels and tesserae of Egyptian manufacture, in particular with reference to the distribution of REE: though the two sample sets (KHv1 and KHt1) show the same relative patterns, a relatively higher depletion of REE is observed for the KHv1 vessels, linkable to the use of a purer sand (Fig.6.8).

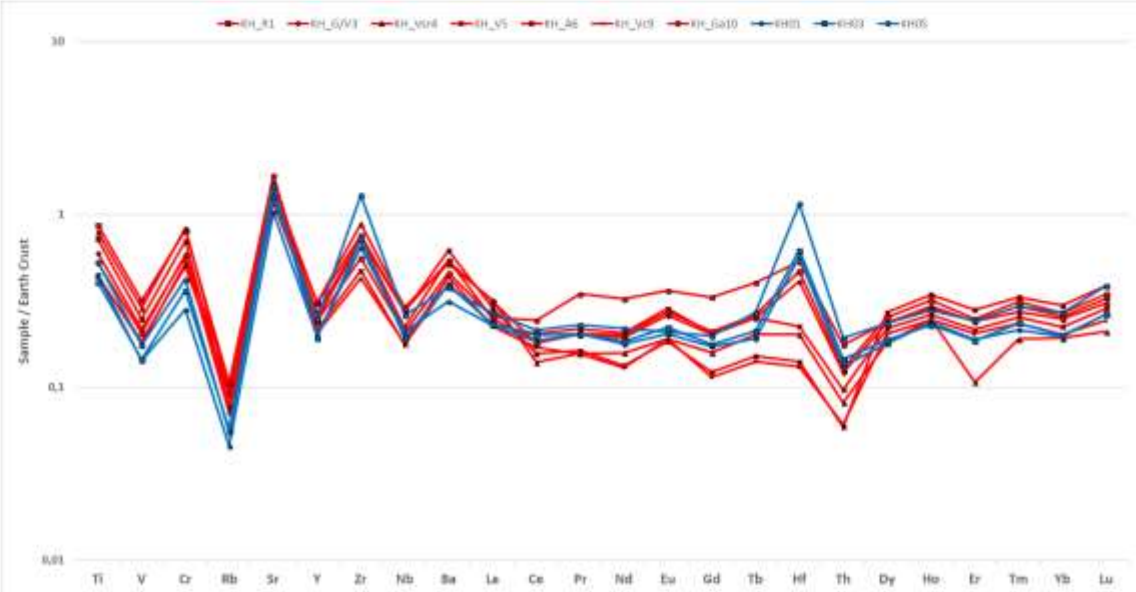


Fig.6.8 Comparison between KHv1 and KHt1 trace elements patterns.
Averages are normalised to the mean values in the continental crust (Kamber et al. 2005).
A red line is used for KHt1 tesserae, a blue one for KHv1 vessels.

CaO/Al_2O_3:Na_2O/SiO_2 and TiO_2/Al_2O_3:Al_2O_3/SiO_2 bi-plots (Fig.6.3,6.4) show that KHt1 tesserae match Egypt I compositional category and, even more precisely, late antique/early Islamic Egypt I. Data reported in the scatter plots highlight, indeed, a differentiation between late antique/early Islamic Egypt I (Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Kato et al. 2009; Phelps et al. 2016) and earlier Egypt I (Picon, Thirion-Merle & Vichy 2008), whose primary production site was identified at Wadi Natrun with furnaces operating up to the 3rd CE. These differences are clearly revisable in the compositional features, with late antique/early Islamic Egypt I glass showing lower soda, higher silica, higher alumina and slightly higher lime compared to earlier Egypt I (Tab.6.3).

Egypt I-late antique/early Islamic	**Egypt I-Wadi Natrun**
Higher Al_2O_3 (3.8-4.5 wt%)	Lower Al_2O_3 (1.8-2.9 wt%)
Lower Na_2O (16-19 wt%)	Higher Na_2O (20-25 wt%)
Higher CaO (2.5-4.0 wt%)	Lower CaO (1.8-3.0 wt%)

Tab.6.3 Comparison between Egypt I groups. For late Byzantine/early Islamic Egypt I, data are from this study, Phelps et al. 2016, Kato et al. 2009, Foy, Picon & Vichy 2003, Gratuze and Barrandon 1990. For earlier Egypt I, data are from Picon, Thirion-Merle & Vichy 2008.

Compositional features seem, therefore, to imply the use of different batch recipes and, presumably, different sands. Nevertheless, no production evidence for the late antique and Islamic periods has yet been uncovered in Egypt (Nenna 2014; Nenna 2015). Production in the Egyptian Delta is a possibility, with a coastal location being suggested by the CaO/Sr ratio. LA-ICP-MS data from this study also support, in fact, the theory recently proposed by Phelps and colleagues (Phelps et al. 2016) about the use of an Egyptian shell-containing coastal sand in the manufacture of early Islamic Egypt I glass.

Whilst the production and consumption of Egypt II glass has been frequently documented in the 8^{th} CE Umayyad glass industry, having found an assemblage of Egypt I type (low lime – high alumina) represents a novelty. To date, research has underpinned evidence of Egypt I compositional category only playing a marginal role in glass production and consumption in the Umayyad period: for instance, within more than 500 glassware fragments analysed from Raya (Kato et al. 2009), less than 5% accounts for N2-a2 type; another example is represented by the small number of Umayyad lamps and vessels remains from the monastery of St Aaron on Jabal Harun (near Petra, Jordan), datable to the mid-7^{th} to the mid-8^{th} CE, corresponding to the Egypt I group (Greiff and Keller 2014).

Nevertheless, what makes these results remarkable is the fact that we are discussing upon base used in the manufacture of tesserae, not vessels: it is the first time that evidence is provided of the occurrence of an Egypt-made base glass in the manufacture glass tesserae datable back to the Umayyad period.

6.1.1b KHv2 and KHt2 groups: Levantine production

Vessels and tesserae belonging to groups KHv2 (KH04, KH06, KH07) and KHt2 (G2, A7, A7bis, Vc8, Am/Au11, G/V13, Am14) have been manufactured by using sands low in the heavy accessory minerals and showing a greater REE depletion (Fig.6.2, 6.6). In addition, the relatively high alumina suggests the use of a mature sand, and the positive correlation between high lime and high strontium indicates a coastal sand containing shells (Fig.6.7) (Freestone et al. 2003; Phelps et al. 2016).

As in the case of the Egyptian samples, even if they show a common Levantine origin, KHv2 and KHt2 are distinct glass groups.

Concerning the vessels, patterns elaborated on the basis of LA-ICP-MS data markedly distinguish KH04 and KH06 samples from the Egyptian set (Fig.6.2). KH04 and KH06 are characterised by higher strontium together with relatively lower titanium, vanadium (associated to iron), chromium, zirconium, niobium (associated to titanium) and hafnium. Furthermore, these samples show low CaO/Sr ratios, respectively being 270 and 217; these values are comparable with those found by Freestone and co-workers (Freestone et al. 2003) for Bet Eli'Ezer and Bet She'an glasses and compatible with the use of a Levantine coastal sand. Glass of Levantine origin is generally made by using pure sand, as confirmed by the low levels of all the analysed trace elements and by the strongly depleted REE patterns. Major oxides demonstrate that samples KH04 and KH07 seem to better correspond to Apollonia-type (Levantine I) glass, being characterised by high lime (7.70 – 8.71 wt%), high soda (14.29 – 15.06 wt%) and low silica (71.17 – 72.27 wt%) contents (Fig.6.3-6.5). Whilst KH07 lacks a precise typological identification, the light olive green fragment KH04 is referable to a straight rim with wall folded towards the outside, belonged to a small bottle probably similar to the n. 126 of the Bet Shean's catalogue, dated to the Umayyad period (Hadad 2005). Sample KH06 has lower lime (6.63 wt%), lower soda (12.89 wt%) and higher silica (75.44 wt%) contents, consistent with an attribution to Bet Eli'ezer-type (Levantine II) group (Fig.6.3-6.5); this hypothesis is further enhanced by the chrono-typological data, since this fragment of a flat bottom, probably belonged to a globular bottle, is similar to some types documented in the catalogue of the glass findings from Al-Hadir (northern Syria) (Foy 2012), dated from the 8^{th} CE onward, therefore of a slightly later time.

Concerning KHt2 tesserae, trace element patterns show low heavy elements contents together with high strontium (also correlated to CaO), these features being consistent with the use of a Levantine coastal sand (Fig.6.6). Major oxides soda, silica, lime and alumina (Fig.6.3-6.5) demonstrate that the majority of samples (opaque G2, A7, A7bis, Vc8 and translucent G/V13, Am14) show a close match with Apollonia-type glass. The only exception is represented by Am/Au11tessera, showing compositional features more similar to the ones of Bet Eli'ezer-type glass, being characterised by higher silica (74.32 wt%), lower soda (12.09 wt%), lower lime (6.68 wt%) and higher alumina (3.17 wt%) contents.

6.1.2 Colourants and opacifiers

6.1.2a Copper-based phases

R1 opaque red tessera was coloured and opacified by means of copper-based phases.

According to EPMA and LA-ICP-MS data, this sample is made of a natron-based glass, characterised by low lime, high alumina and high soda contents, as well as by a sand source high in the heavy accessory minerals, showing considerable amounts of iron oxide, titanium and zirconium. Thus, compositional features match those identified for early Islamic Egypt I category (KHt1).

BSE images show a dispersion of nanometric rounded particles in the glassy matrix, and EDS spot analyses demonstrated that they are made of copper (Fig.6.9).

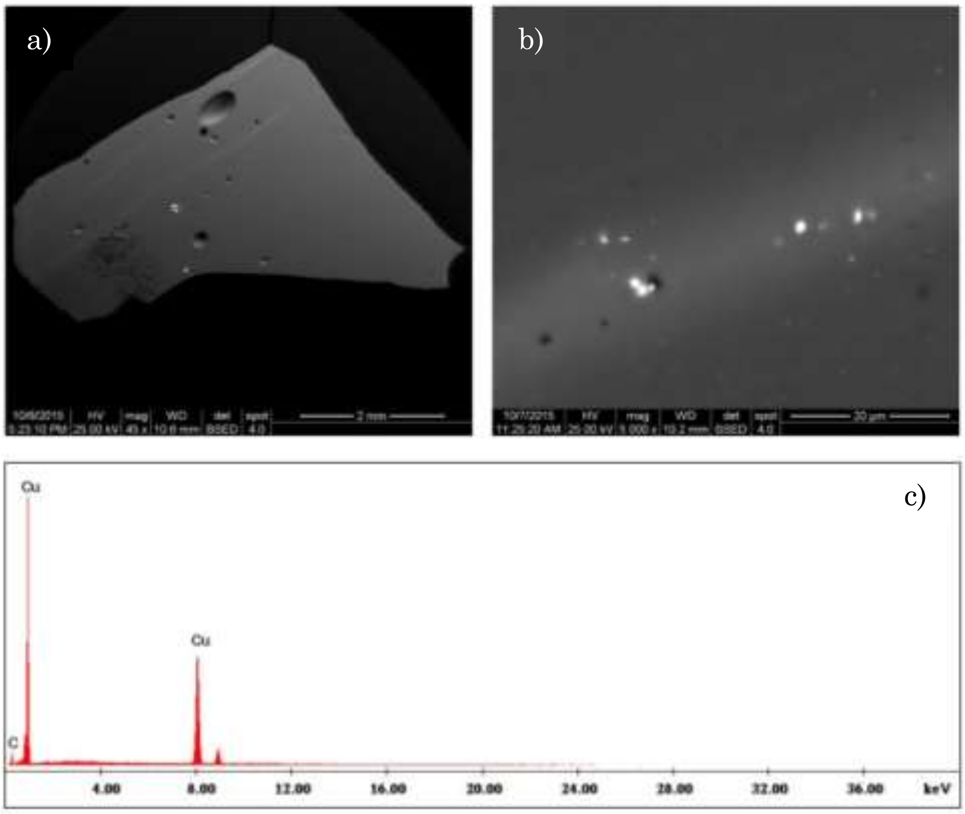
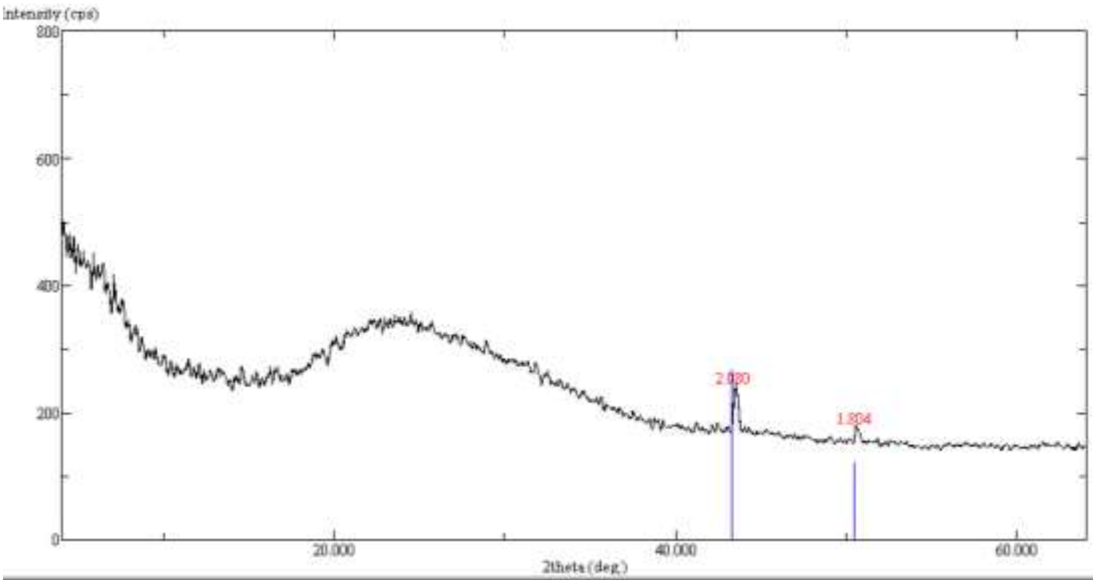


Fig.6.9 a) BSE image of R1 tessera; b) detail of nanometric metallic copper inclusions; c) example of EDS spectrum collected on the inclusions (Fiorentino et al. 2017).

It was not possible to characterize the crystalline phase of these inclusions by micro-Raman measurements, due to the extremely small dimensions of the particles dispersed into the glassy matrix, that make them almost impossible to be detected at the magnifications obtainable when a Raman microscope is used[60].

XRPD analysis was, thus, carried out, and the diffraction pattern allowed identifying the crystalline phase as metallic copper (Fig.6.10).



No	2theta(Orig)	2theta(Edit)	d-value(Orig)	d-value(Edit)	Intensity(Orig)	Intensity(Edit)	Specif.
1	43.460	43.460	2.08046	2.08046	242	242	No
2	50.560	50.560	1.80370	1.80370	179	179	No

No	Card No.	Chemical formula	Mineral name	Mark	Match	Refi.	Specif.
1	4-0836	Cu	Copper, syn	*	2/2	1000	No

Fig.6.10 XRPD pattern of R1 tessera (Fiorentino et al. 2017).

R1 tessera shows low copper (2.58 wt%) dispersed into the glassy matrix as sub-micron droplets (diameter less than 1 μm) and very low lead (0.85 wt%). These features are consistent with “dullish red glass” (Freestone, Stapleton & Rigby 2003). Opaque red glass can be, in fact, divided in two main technological variants: the former, of a brightest red and known as “sealing-wax red glass”, is a high-lead high-copper glass coloured and opacified by dendritic crystals of Cu_2O; its use is predominantly attested from the 8th century BC to the 1st AD

[60]Another difficulty was due to the available laser, a red one: as attested in the literature, Raman spectroscopy can be able to reveal the presence of Cu^0 nanoparticles only if a green or blue laser as excitation source is employed (Basso et al. 2014), responsible for the modification of the polymerization degree of silica network around the metallic particles (Colomban & Schreiber 2005; Ricciardi et al. 2009).

(Brill 1970), since when it started to occur less frequently (Hughes 1972); the latter is known as “dullish red glass” and is a low-lead low-copper glass coloured and opacified by nanometric droplets of metallic copper. Dullish red glass can also be characterized by variable amounts of potassium and magnesium oxides, since it is either linked to the practice of introducing wood charcoals and/or fuel ash in the crucibles to aid the reduction (Henderson 2013; Vandini et al. 2014), or plant ash was used as an alkali source (Boschetti et al. 2016).

Moreover, it can be interesting to notice that similarly low PbO amounts as found in R1 sample have occasionally been found. We can quote, for instance, the case of Egyptian glasses from Tell al Amarna, as well as that of an Egyptian inlay head probably datable to the 7th-5th centuries BC (Brill & Cahill 1988); two opaque red mosaic tesserae from the Basilica of St. Severus in Classe, Ravenna (Vandini et al. 2014) and the Parthenon (Barber et al. 2010) also show very low lead contents. Furthermore, in India and the Far East copper-based reds were often lead-free (Freestone, Stapleton & Rigby 2003). When occurring at such low concentrations, it is unlikely that lead oxide had been intentionally added to the molten glass in order to gain the well-known advantages linked to its addition, as increasing the refractive index, lowering the melting temperature and reducing the predisposition to devitrify. The low lead contents could be linked to the use of metal slags or debris employed as copper-bearing material.

R1 tessera also shows magnesium and potassium oxides both below 1 wt%, denoting the only use of natron as alkali source. The relatively low content of SnO (0.37 wt%) suggests that it could have been incorporated as a component of the scale deposits produced when heating a copper alloy in air (Freestone, Stapleton & Rigby 2003).

The microstructure of R1 tessera is also characterised by the presence of light zoned bands in BSE (Fig.6.9b), slightly richer in PbO (bands: 5 wt%; matrix: 2 wt%), FeO (bands: 5 wt%; matrix: 2 wt%) and CuO (bands: 6 wt%; matrix: 4 wt%) when compared to the surrounding glass. The presence of iron could be consistent with the deliberate addition of Fe-bearing materials to the melt, acting as a reducing agent (Arletti et al. 2006; Arletti, Vezzalini et al. 2011; Barber et al. 2010; Croveri et al. 2010; Di Bella et al. 2014).

As demonstrated by previous studies (Arletti, Quartieri & Vezzalini 2006; Barber et al. 2010; Boschetti et al. 2016; Di Bella et al. 2014; Santagostino Barbone et al. 2008; Shugar 2000), sub-micrometric copper particles acting as opacifier are also responsible for the dullish red colour of R1 tessera. VIS-RS spectrum of R1 tessera (Fig.6.11) shows a very flat behaviour in the wavelength range 400-580 nm with an increase of reflectance intensity for the wavelength above 580 nm (Mirti et al. 2002).

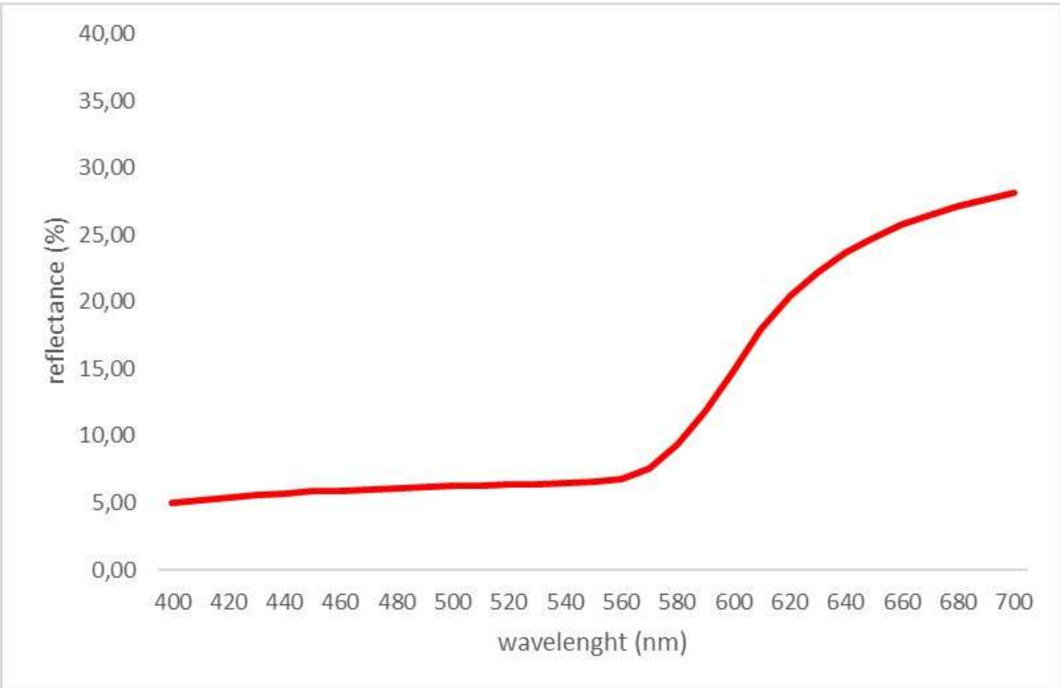


Fig.6.11 RS curve of R1 tessera (Fiorentino et al. 2017).

6.1.2b Tin-based phases

All opaque yellow (G2, G/V3) and the majority of opaque green (Vsr4, V5, Vc8, Vc9) tesserae were opacified by the addition of tin-based phases, regardless the different compositional categories they belong to.

EMPA and LA-ICP-MS data demonstrated, indeed, that the above tesserae fall within two distinctive compositional categories: on the one hand, samples G/V3, Vsr4, V5 and Vc9 match Egypt I (KHt1), show analogous features to those discussed for R1 tessera; on the other hand, samples G2 and Vc8 are of a Levantine origin, KHt2 (more precisely, they match the Apollonia-type glass), characterised by sands low in oxides from heavy accessory minerals (titanium, iron oxide and zirconium), but relatively high in alumina, and high lime and strontium showing a strong correlation suggesting the use of marine sands containing shells.

These opaque yellow- and green-shaded tesserae show an inhomogeneous micro-texture, the matrix being characterised by lighter bands in BSE containing higher lead than the darker areas (Fig.6.12a). Aggregates formed by the opacifying agent have different shapes and sizes. The majority show an anhedral crystalline habit with a mean size of about 2-3 μm, mainly containing lead and tin (Fig.6.12b-d). Tiny acicular crystals (mean thickness less than 1 μm) were also found in the glassy matrix, either forming aggregates or surrounding the anhedral phases (Fig.6.13a-c); these acicular crystals are mainly composed of tin (Fig.6.13d), even though their precise chemical composition could not be measured by EDS due to their small sizes.

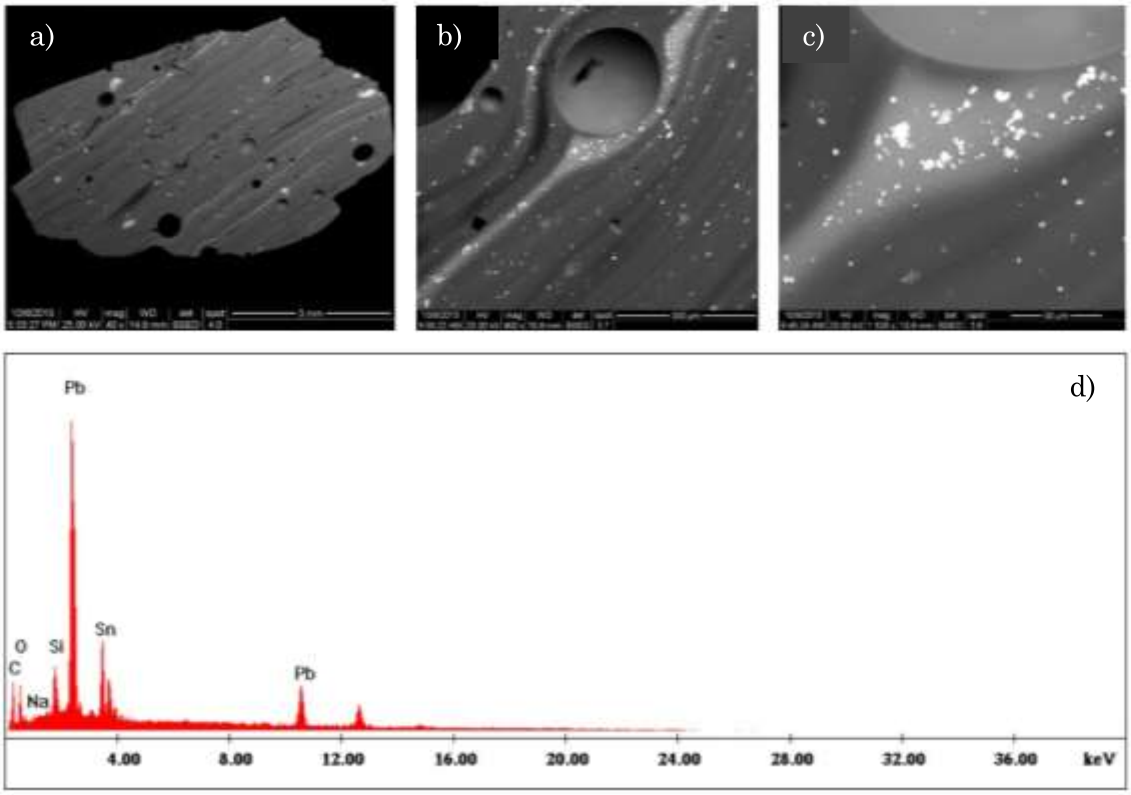


Fig.6.12 a) BSE image of G/V3 tessera; b) detail of diffusion stripes into the glassy matrix; c) detail of anhedral lead-tin based inclusions; d) EDS spectrum collected on an anhedral inclusion (Fiorentino et al. 2017).

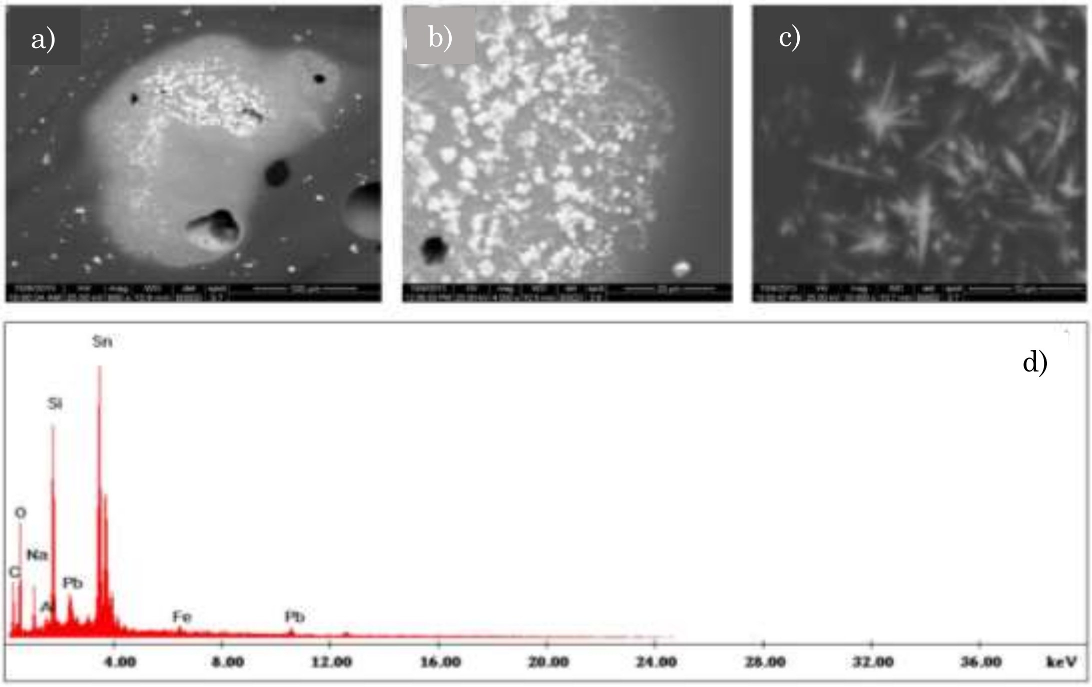


Fig.6.13 a) and b) details of a mixed inclusion detected in G/V3 tessera; c) detail of acicular inclusions; d) EDS spectrum collected on an acicular inclusion (Fiorentino et al. 2017).

SEM-EDS analyses suggest, therefore, that tin-based phases were used to opacify yellow, greenish-yellow and green-tesserae. Basically, lead stannate and cassiterite form the category of tin-based phases, whose production and use in glass manufacture has exhaustively been discussed in several studies (Arletti et al. 2008; Arletti, Vezzalini et al. 2011; Arletti, Conte et al. 2011; Bayley & Wilthew 1986; Fiori et al. 2004; Henderson 2000; Mason 2004; Mason & Tite 1997; Matin et al. 2018; Silvestri et al. 2014; Tite et al. 2008; Turner & Rooksby 1959; Uboldi & Verità 2003; Verità 2000).
According to the literature, tin-based phases were employed to produce yellow glass as a cubic $PbSnO_3$ phase, since the orthorhombic Pb_2SnO_4 (also called "lead tin yellow type I") is not chromophorous.
Production process of tin-based phases involved the use of a lead-tin calx, obtained by heating a mixture of lead and tin up to temperatures above 600°C. When a mixture of PbO and SnO_2 is heated to temperatures between 700 and 900°C, orthorhombic Pb_2SnO_4 occurs; if SiO_2 is, then, added to Pb_2SnO_4 and the mixture is then heated again at 850°C, the orthorhombic phase is converted into the cubic $PbSnO_3$, as demonstrated by experiments undertaken by Tite and co-workers (Tite et al. 2008) and confirmed by Matin and colleagues (Matin et al. 2018). This procedure is in accordance with the textual source *Manoscritto Bolognese*, dated to the 15th CE (Merrifield 1849), and an analogous process has been proposed for Venetian manufacturing of the 18th-19th CE to produce the so-called "lead-tin yellow anime", then powdered and added to the molten glass (Moretti & Hreglich 2005; Tite et al. 2008).
Experiments undertaken by Tite and co-workers (Tite et al. 2008) and Matin and colleagues (Matin et al. 2018) also demonstrated that the persistence of $PbSnO_3$ crystals mainly depends on the temperature. By increasing the temperature between 850 and 950°C, lead-tin crystals decompose and re-crystallise as SnO_2, turning the colour from yellow to white.
Micro-Raman analyses were, therefore, carried out on both anhedral and acicular inclusions dispersed into the glassy matrix, to ascertain their crystalline phases and verify the presence of cassiterite. Micro-Raman spectra acquired on the anhedral inclusions display bands at 67, 136, 326 and 456 cm^{-}

^{1} (Fig.6.14), matching those reported in the literature for the so-called “Lead Tin Yellow type II” (Šefců et al. 2015; Welter et al. 2007; Zhao et al. 2013).

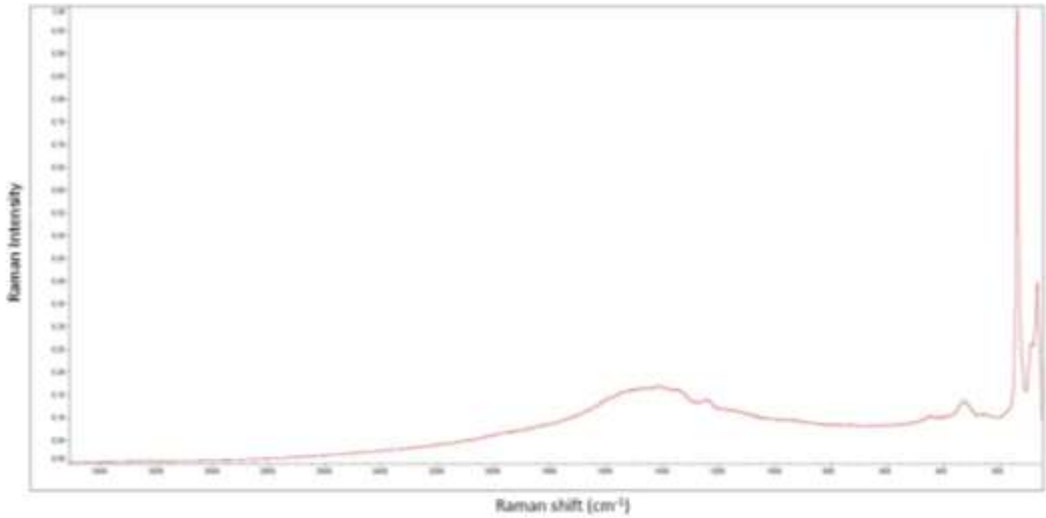


Fig.6.14 Raman spectrum collected on an anhedral inclusion in tessera G/V3 (Fiorentino et al. 2017).

Lead Tin Yellow type II ($PbSn_{1-x}Si_xO_3$) is a cubic-structured lead tin silicon oxide that can show a variable stoichiometry: it can be either $PbSnO_3$, $Pb(Sn,Si)O_3$ or $PbSn_2SiO_3$. Research concerning its formation suggests that the process is still unclear. According to Eastaugh and colleagues (Eastaugh et al. 2008), it probably involves the growth of an intermediate lead silicate at around 690°C before that lead-tin-silicon compound is formed at about 750°C.

Matin and co-workers undertook replication experiments to investigate the conversion of Lead Tin Oxide type I to type II (Matin et al. 2018), demonstrating that this conversion takes place if SiO_2 is added to Lead Tin Oxide type I and the mix is heated up to between 800°C and 950°C.

For the analysed tesserae, it was not possible to make a direct comparison between Raman signatures of pure $PbSnO_3$ and $PbSn_{1-x}Si_xO_3$, since a spectrum of $PbSnO_3$ cannot be found in the literature. XRPD was, therefore, also performed, in attempt to provide a more precise characterisation of the mineralogical phase. Though diffraction patterns of lead-tin based compounds show very close similarity, those acquired on the yellow and green tesserae seem to compare best to $PbSnO_3$ (Fig.6.15). The presence of SnO_2 was also detected by XRPD analyses for samples G/V3 and Vsr4 (Fig.6.16).

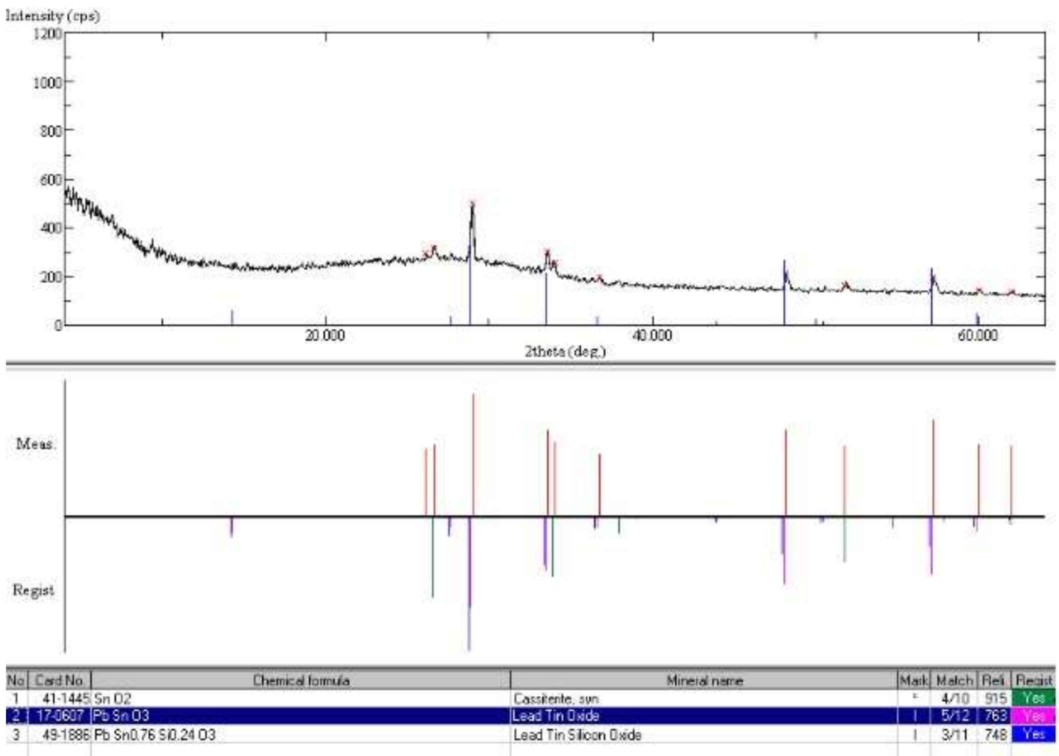


Fig.6.15 XRPD pattern of G/V3 tessera, showing the presence of $PbSnO_3$ (Fiorentino et al. 2017).

Concerning acicular-shaped crystals, Raman spectra acquired are highly affected by fluorescence, probably also due to their very exiguous dimensions (Fig.6.17). A band at about 634 cm^{-1} is always observed, being the one related to cassiterite (SnO_2). Though, a univocal characterisation cannot be stated due to the lack of the two other main bands of SnO_2: 471 and 773 cm^{-1} (Bouchard & Smith 2003; Welter et al. 2007; Zhao et al. 2013).

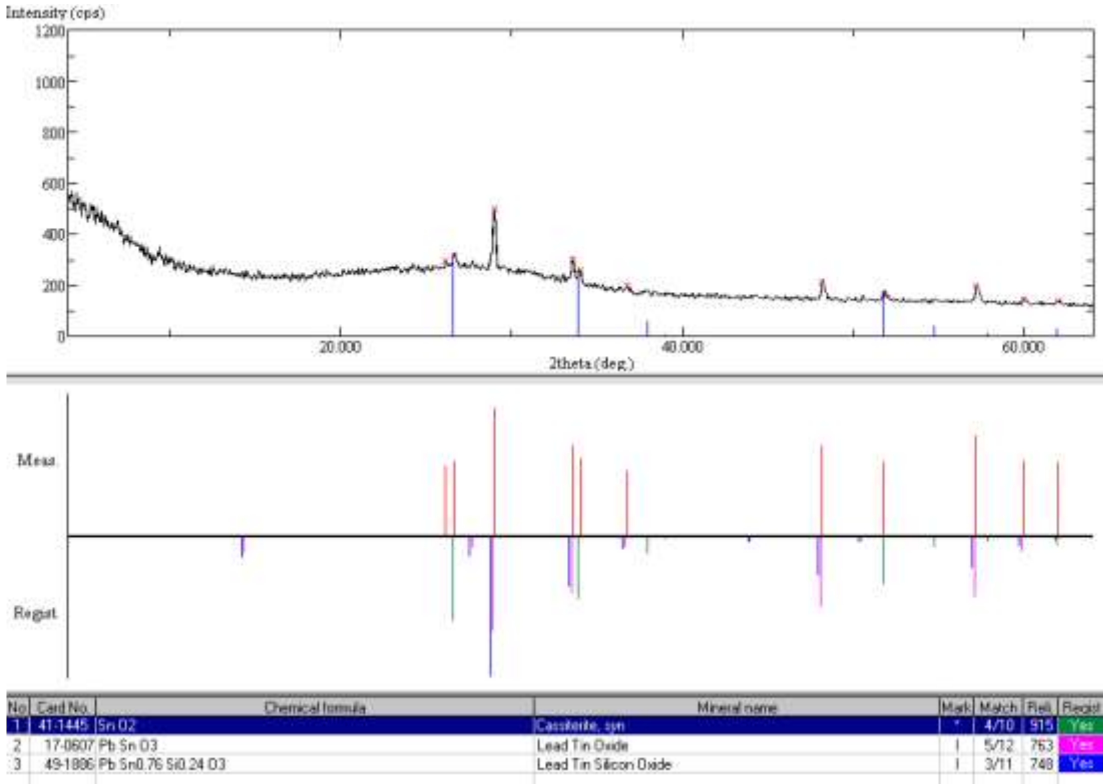


Fig.6.16 XRPD pattern of G/V3 tessera, also showing the presence of SnO_2 (Fiorentino et al. 2017).

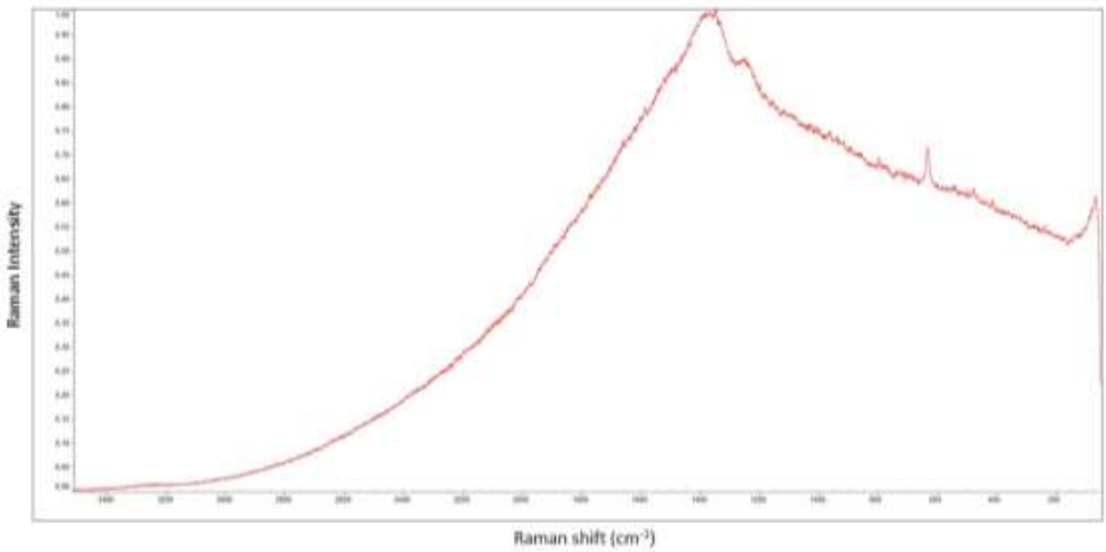


Fig.6.17 Raman spectrum collected on an acicular inclusion (tessera G/V3). (Fiorentino et al. 2017).

Yellow tesserae (G2 and G/V3) owe their colour to the addition of Lead Tin Yellow type II, acting as both colouring agent and opacifier. The presence of a considerable amount of differently shaped crystals precipitated into the glassy matrix is, in fact, also responsible for the opacity of the tesserae.
Concerning Vsr4, V5, Vc8, Vc9 green tesserae, the blue hue conferred by copper-based cations dispersed in the glassy matrix, combined with the yellow colour due to Lead Tin Yellow type II, is responsible for the observed shades. A slightly higher copper content can also be observed for the yellow tessera G/V3, responsible for its greenish-yellow shade.
Figures 6.18 and 6.19 show reflectance curves in the visible region of the electromagnetic spectrum acquired by VIS-RS on opaque yellow and green tesserae.

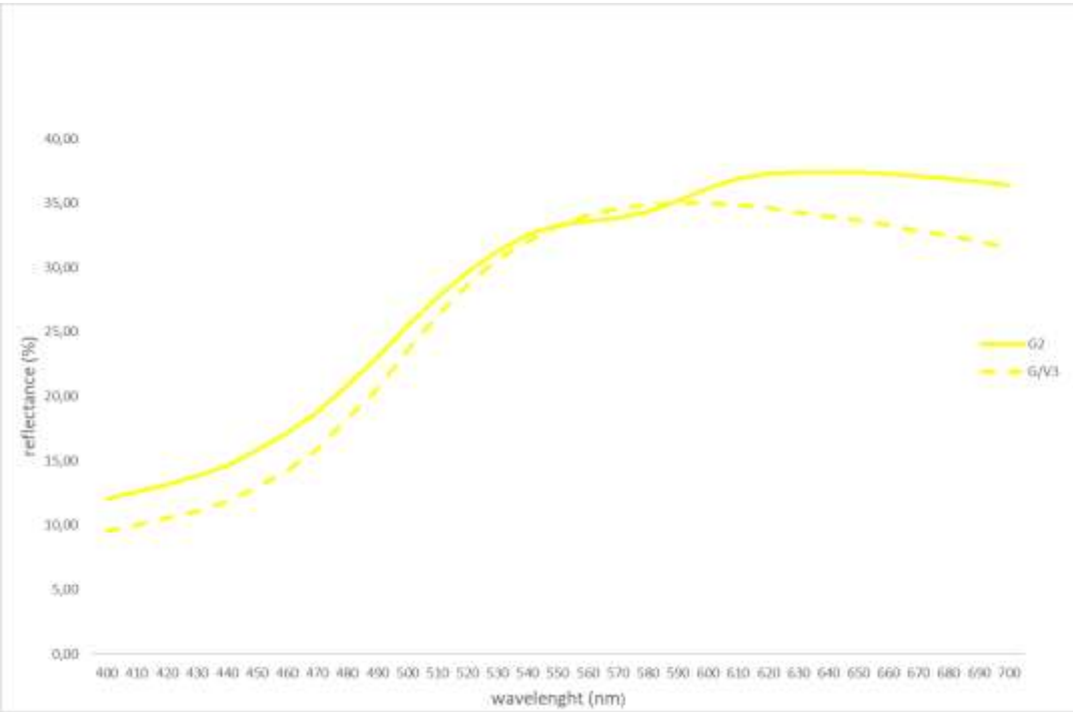


Fig.6.18 Reflectance curves acquired on opaque yellow tesserae.

The curve shapes of yellow tesserae (Fig.6.18) are comparable to the ones reported by Cloutis and colleagues for powdered lead-tin oxides-based yellow pigments (Cloutis et al. 2016). More precisely, the closest similarity occurs with standard PIG818, a Lead-Tin Yellow type II. Though all lead-tin oxides-based yellow pigments have broadly similar reflectance spectra, consistent with their similar compositions, PIG818 shows the shallowest absorption edge, closely resembling the profiles of the curve acquired on opaque yellow tesserae.

Green tesserae display characteristic bell-shaped RS curves (Fig.6.19), ascribable to the presence of copper as colouring agent. According to the literature, copper compounds show reflectance peaks between 440 and 540 nm, without absorptions in the visible region (Galli et al. 2007). For the green tesserae, a decrease of the overall reflectance intensity can also be noticed when the copper content increases.

Last, it can be perceived that A6 tessera shows a slightly different RS curve, probably due to a contribution of the different opacifier detected in this tessera (discussed in the next paragraph).

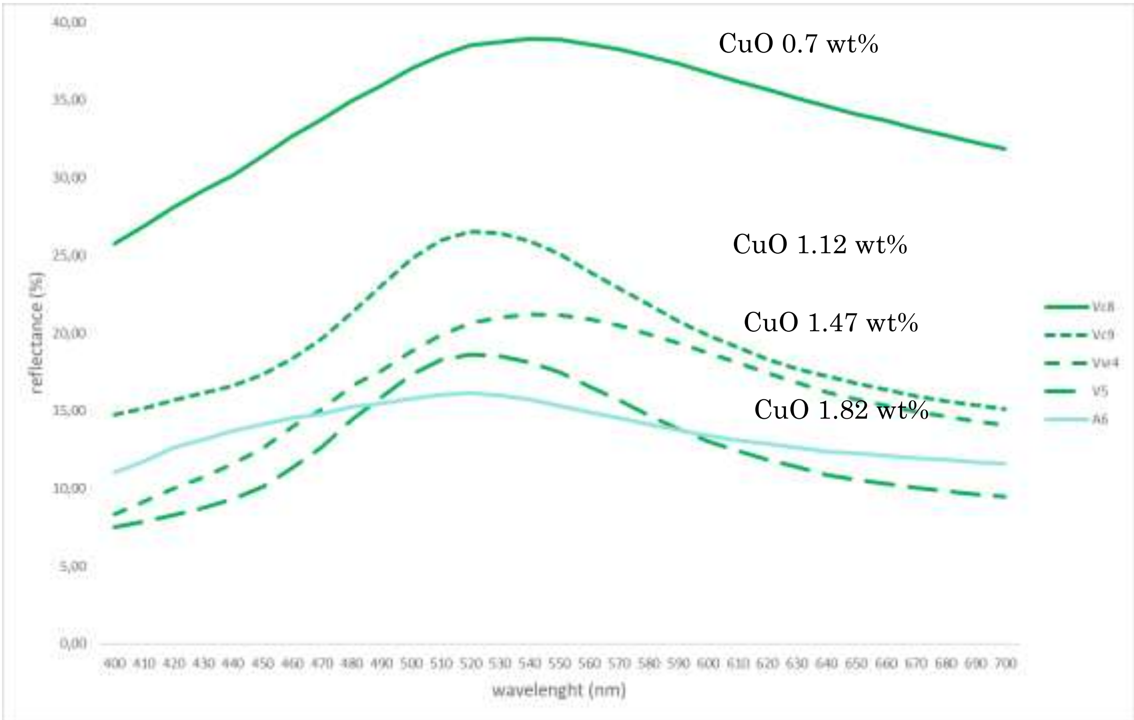


Fig.6.19 Reflectance curves acquired on opaque green tesserae.

6.1.2c Phosphorus-based phases

Phosphorus-based phases were detected in 2 bluish green (A6, Ga10) and 2 light blue (A7, A7bis) tesserae. Once again, the same opacifier was found inside tesserae belonging to diverse compositional categories and different provenance.

EMPA and LA-ICP-MS analyses showed that the above tesserae fall within two different compositional categories: samples A6 and Ga10 match Egypt I compositional category (KHt1), whilst A7 and A7bis are made of an Apollonia-type glass (KHt2).

SEM-BSE images show that the inclusions found in the tesserae have dimensions ranging from about 60 to 500 µm; they exhibit an irregular shape and are characterized by a number of small vacuoles (Fig.6.20a,b).

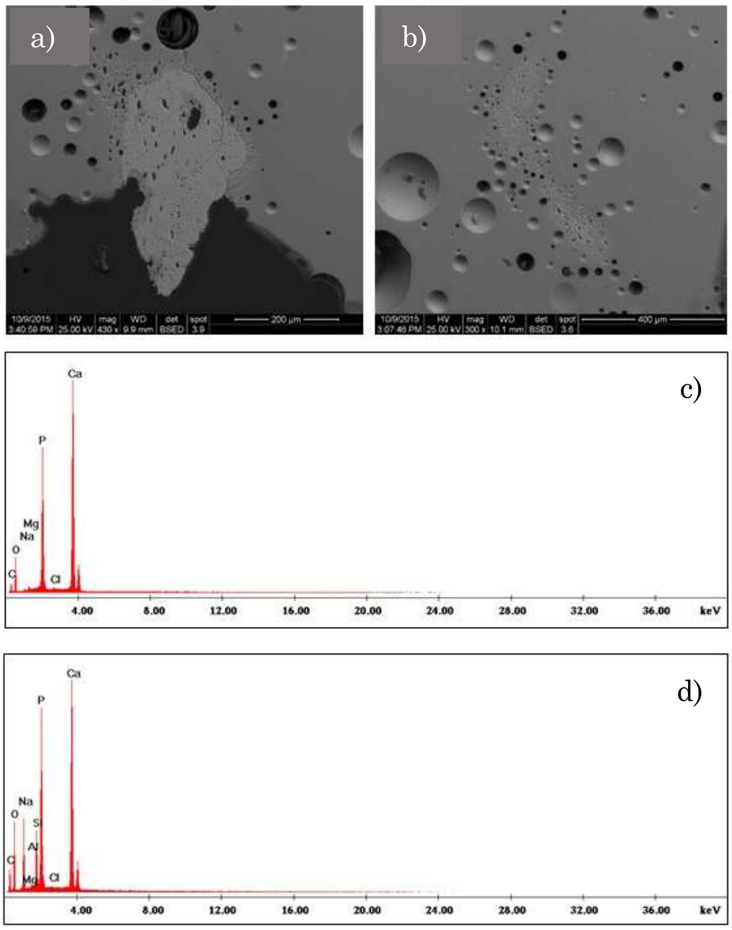


Fig.6.20 a) Tessera A6, detail of phosphorus-based inclusion with reaction rims; b) tessera A6, detail of phosphorus-based inclusion without reaction rims; c) EDS spectrum collected on the core of the phosphorus-based inclusion; d) EDS spectrum collected on the rim of the phosphorus-based inclusion (Fiorentino et al. 2017).

Furthermore, the larger inclusions (>100 μm) generally have a reaction rim, slightly darker than the core in BSE images (Fig.6.20a). EDS data demonstrate that these inclusions are mainly composed of calcium and phosphorus (Fig.6.20c); the rim is generally characterised by sodium and silicon enrichment, presumably coming from the surrounding glass (Fig.6.20d).
To provide a more precise characterization of the phosphorus-based opacifiers, micro-Raman measurements were carried out. For the larger inclusions (>100 μm), Raman spectra of the cores (Fig.6.21) are consistent with that of hydroxyapatite (Penel et al. 2003): the band positions are in the region from 400 to 1100 cm^{-1}, where vibrational modes within the phosphate tetrahedra of the apatite are located (Silvestri et al. 2016).

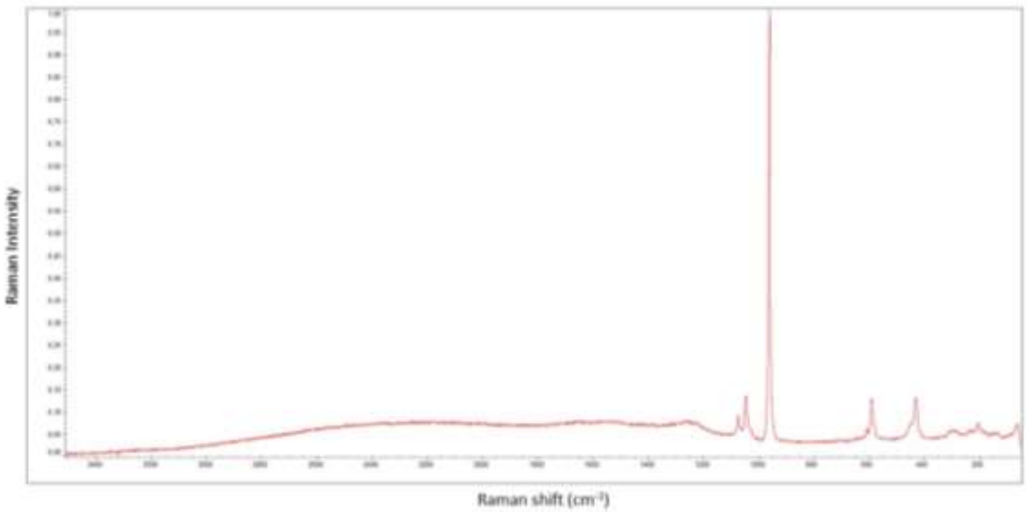


Fig.6.21 Raman spectrum acquired on the core of the P-based inclusion shown in Fig.5.19a (Fiorentino et al. 2017).

For Raman spectra acquired on the rims, a different situation can be observed: band positions in the region from 430 to 1046 cm^{-1} occur together with other shifts located between ~1206 and 1645 cm^{-1} (Fig.6.22 and Tab.6.4).

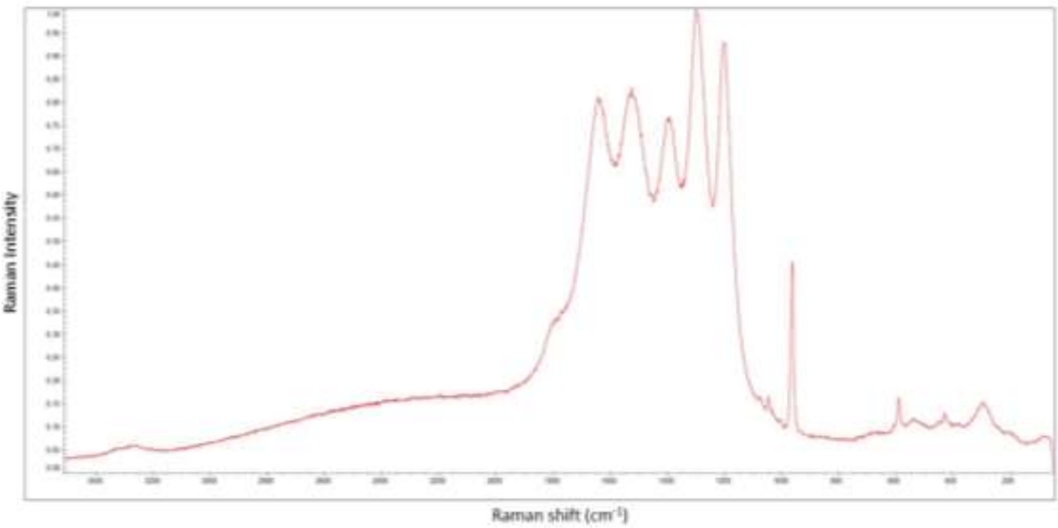


Fig.6.22 Raman spectrum acquired on the rim of the P-based inclusion shown in Fig.5.19a (Fiorentino et al. 2017).

	Core (cm^{-1})	Rim (cm^{-1})
ν_2PO_4	430	428
	444	449
ν_4PO_4	580	590
	590	
	609	
ν_1PO_4	962	965
ν_3PO_4	1027	1027
	1045	1046
	1073	
		1203
		1300
		1400
		1527
		1642

Tab.6.4. Raman shifts observed for phosphorus-based inclusions

Raman bands located between 430 and 1046 cm^{-1} are comparable to those of ß-rhenanite (ß-$NaCaPO_4$), a newly formed crystalline (Silvestri et al. 2016). The occurrence of ß-rhenanite provides useful insights on the working temperature of the analysed samples, as its phase transition has been observed at about 650°C (Suchanek et al. 1997).

Concerning the other Raman bands between ~1206 and 1645 cm^{-1}, no precise comparison was found in the literature so as to allow a univocal assignment.

By performing micro-Raman measurements on synthetic and natural apatites, Antonakos and co-workers (Antonakos et al. 2007) noticed that some forms of hydroxyapatite show, after heating at 840°C, bands at ~1412 and ~1642 cm^{-1}, attributable to the presence of carbonate impurities in channel sites.
Hence, the presence of the above cited bands could be interpreted as a result of modifications of hydroxyapatite structure happened when powdered bone was added to the molten transparent glass at high temperatures.
All the smaller phosphorus-based inclusions (<100 μm) do not show the presence of any reaction feature (Fig.6.20b): although in some cases we cannot exclude that this lack could be due to sample cut, it is highly unlikely that all of them present an artificial effect. The acquired Raman spectra of the smaller inclusions are highly comparable to those of the rims of the larger grains (Fig.6.23). As a consequence, it can be stated that the modification of hydroxyapatite reached a higher degree in the crystals with smaller dimensions.

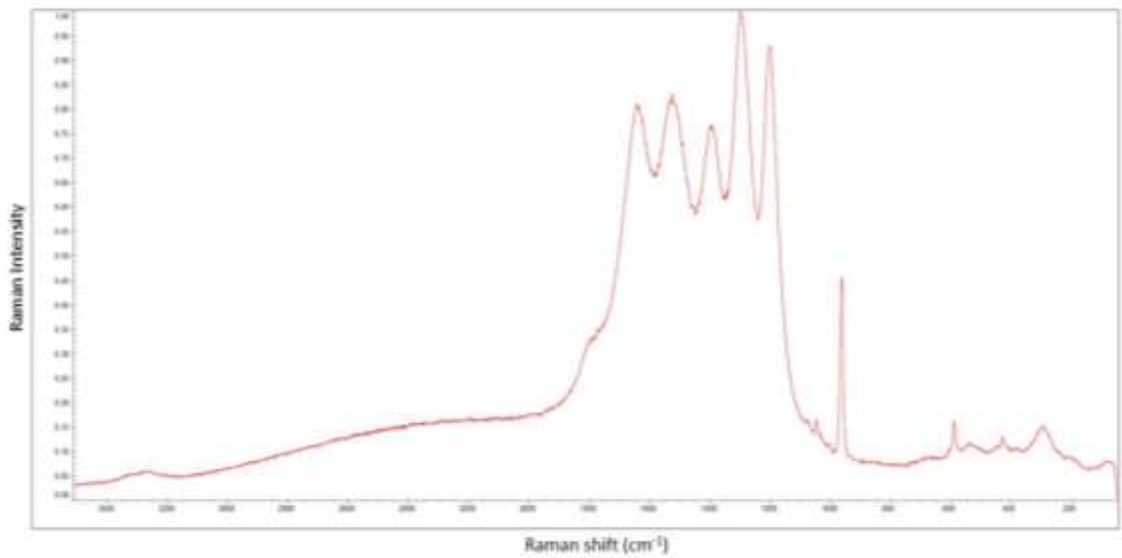


Fig.6.23 Raman spectrum acquired on the the P-based inclusion shown in Fig.5.19b (Fiorentino et al. 2017).

All tesserae opacified by calcium phosphate also show a high number of gas bubbles in the glassy matrix (Fig.6.20a,b), probably ascribable to the decomposition of hydroxyapatite during the melting step. These bubbles also play an important role in contributing to increase the opacity. A7bis tessera also contains small sporadic inclusions of SnO_2.

Concerning the colour, opaque light blue A7 and A7bis, as well as A6 opaque green tesserae due their tint to the presence of copper dispersed into the glassy matrix (EMPA data performed on the glassy matrix show CuO ranging from 1.70 to 2.42 wt%). Copper was, indeed, among the mostly used colouring agents in the ancient glass industry, as attested by a number of studies regarding glasses from the Bronze Age until the Medieval period (Hatton et al. 2008; van der Werf et al. 2009; Verità et al. 2002). RS curves of A6 green and A7bis light blue tesserae have a bell-shaped morphology with a weak reflectance peak between 440 and 540 nm, ascribable to the presence of copper (Fig.6.24).
Ga10 tessera does not show the presence of copper used as colouring agent, and EMPA data demonstrate that a slightly higher FeO content, if compared to A6, A7 and A7bis characterises this sample. Iron is normally found in glass batches as a contaminant of sand, thus being the most common colouring agent in ancient glasses (Mirti et al. 2002). VIS-RS was not performed on this sample, due to its small and irregular surfaces.

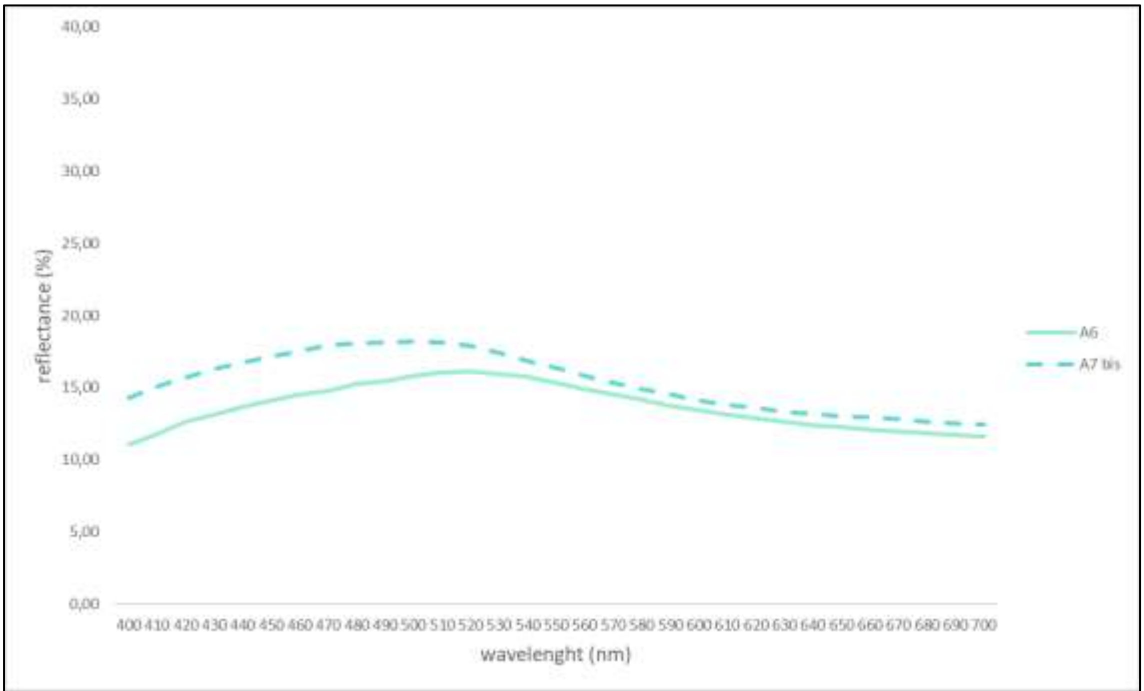
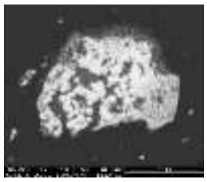
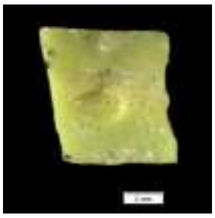
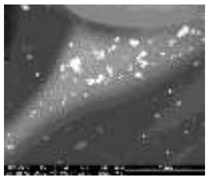
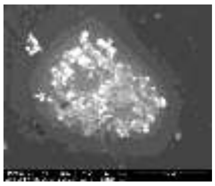
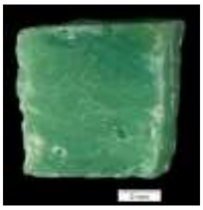
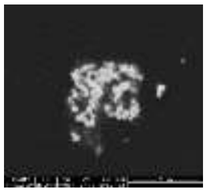
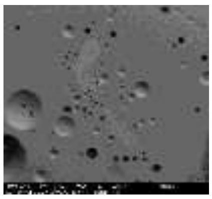


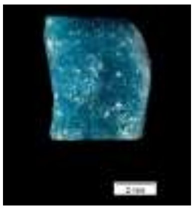
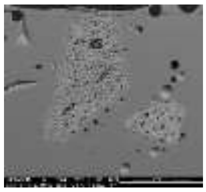
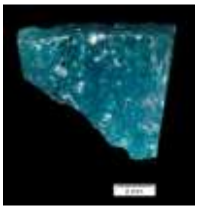
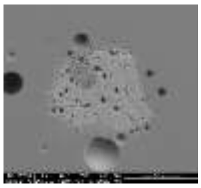
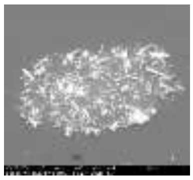
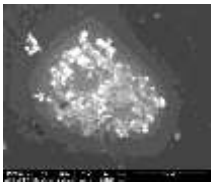
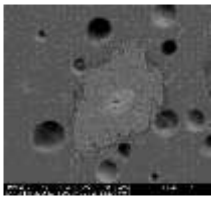
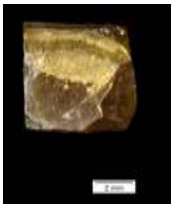
Fig.6.24 Reflectance curves acquired on A6 (opaque green) and A7bis (opaque light blue) tesserae, opacified by means of P-based phases.

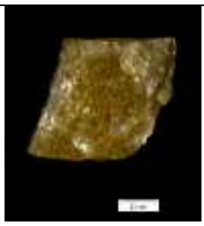
6.1.2d Translucent and transparent tesserae

Am/Au11 and Am14 translucent yellow tesserae show relatively high MnO contents of 1.87 and 2.58 wt%, this indicating its intentional addition as colouring agent. Translucent yellow tesserae G/V13 and Am12 do not show considerable MnO contents, as well as any other metal oxides whose contents could imply a deliberate addition to the base glass in order to achieve the desired colour shade; it can only be noticed that Am12 tessera has a slightly higher FeO content (1.41 wt%), presumably responsible for the yellowish hue.

Translucent light blue tessera A15 does not show relevant CoO or CuO contents which could have been responsible for its colour; again, a slightly higher FeO content can be observed (1.83 wt%), presumably impacting on the glass colour.

Sample	Base glass	Compositional category	Colour	L*	a*	b*	Colouring agent	Opacity
 R1	Soda-silica-lime Natron-based	Egypt I	Red [NCS S 5040-Y80R]	34.21	23.81	14.39	Cu nano-particles	 Cu nano-particles
 G2	Soda-silica-lime Natron-based	Apollonia-type	Yellow [NCS S 2040-G90Y]	65.79	-0.81	44.28	Lead Tin Yellow II	 Lead Tin Yellow II
 G/V3	Soda-silica-lime Natron-based	Egypt I	Yellow [NCS S 2040-G80Y]	60.98	-3.95	43.13	Lead Tin Yellow II	 Lead Tin Yellow II
 Vsr4	Soda-silica-lime Natron-based	Egypt I	Green [NCS S 5030-G30Y]	54.13	-9.99	17.51	Lead Tin Yellow II + copper	 Lead Tin Yellow II
 V5	Soda-silica-lime Natron-based	Egypt I	Green [NCS S 4030-G30Y]	43.93	-18.27	17.66	Lead Tin Yellow II + copper	 Lead Tin Yellow II
 A6	Soda-silica-lime Natron-based	Egypt I	Green [NCS S 5040-B80G]	31.69	-12.45	-1.59	Copper	 Calcium Phosphate

Sample	Base glass	Colour	Opacity
 A7	Soda-silica-lime Natron-based Compositional category Apollonia-type	Blue [NCS S 4040-B20G] L* - ; a* - ; b* - Copper	 Calcium Phosphate
 A7bis	Soda-silica-lime Natron-based Compositional category Apollonia-type	Blue [NCS S 4055-B40G] L* 29.86 ; a* -13.33 ; b* -4.44 Copper	 Calcium Phosphate and SnO_2
 Vc8	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 3040-G] L* 48.46 ; a* -13.16 ; b* 13.37 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 Vc9	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 3065-G40Y] L* 49.86 ; a* -15.42 ; b* 17.43 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 Ga10	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 1510-G] L* - ; a* - ; b* - Iron (?)	 Calcium Phosphate
 Am/Au11	Soda-silica-lime Natron-based Compositional category Beth Eli'ezer-type	Yellow [NCS S 4050-Y10R] L* - ; a* - ; b* - Manganese	Translucent

Sample	Base glass	Colour	Opacity
 Am12	Soda-silica-lime Natron-based Compositional category outlier	Yellow [NCS S 6030-Y20R] L* - ; a* - ; b* - Iron	Translucent
 G/V13	Soda-silica-lime Natron-based Compositional category Apollonia-type	Yellow [NCS S 2050-Y] L* - ; a* - ; b* - Iron	Translucent
 Am14	Soda-silica-lime Natron-based Compositional category Apollonia-type	Yellow [NCS S 2060-Y] L* - ; a* - ; b* - Manganese	Translucent
 A15	Soda-silica-lime Natron-based Compositional category outlier	Blue [NCS S 0515-B20G] L* - ; a* - ; b* - Iron	Translucent

Tab.6.5 Summary of results obtained by analyses carried out on tesserae from Khirbat al-Mafjar. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

6.2 The assemblage from the Great Mosque of Damascus

The assemblage from the Great Mosque of Damascus consists of coloured mosaic glass tesserae, opaque, ranslucent and some transparent.

Samples were collected from the warehouses of the Mosque and their belonging to the original Umayyad mosaic decoration of the building stands as a concrete possibility for the reasons explained in chapter 5[61].

Detailed description and documentation of all tesserae is provided in Table 5.3.

6.2.1 Base glass

For the analysed tesserae from the Great Mosque of Damascus, major and minor oxides, obtained by EPMA, are reported in Tab.6.6a. LA-ICP-MS data for trace elements are shown in Tab.6.7.

EPMA compositional data were recalculated according to the method discussed in chapter 4. The reduced composition was obtained by subtracting the oxides of the elements ascribable to additives, and by normalising to 100 the remaining data (Tab.6.6b). In particular, the subtracted oxides were CuO, SnO_2, PbO and MnO. Sb_2O_3 and CoO were not subtracted since their values were negligible (respectively ranging up to 0.04 wt% and 0.09 wt%).

The analysed samples are all of natron type glass, being MgO and K_2O contents below the value of 1.5 wt%, (Fig.6.25) (Lyliquist and Brill 1993).

Trace element patterns allow a first well-defined separation of the analysed tesserae in three main groups. The first group, from now on referred to as DMSt1, encompasses samples 1Aa, 1Ab, 2Bb, 10L, 17R and 20U. DMSt1 tesserae show lower strontium and higher heavy elements contents (titanium, vanadium, chromium, zirconium, niobium and hafnium) compared to other samples. (Fig.6.26). Moreover, DMSt1 tesserae show lower lime (2.95-3.73 wt%), as well as slightly higher soda (17.65-18.01 wt%), alumina (2.23-3.64 wt%) and iron oxide (0.90-1.20 wt%) contents. These features are clearly

[61] Tesserae under study were provided by Mr. Paolo Racagni and collected on the occasion of a mosaic restoration training course for conservators held in 2007-2008 with the collaboration and involvement of *Ravennantica* Foundation and CNR-ISTEC.

displayed in CaO/Al_2O_3:Na_2O/SiO_2, TiO_2/Al_2O_3:Al_2O_3/SiO_2 and FeO/TiO_2:FeO/Al_2O_3 bi-plots (Fig.6.27-6.29).

Sample	Typology	mpositional catego	Group	Opacity	Colour	Value	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	CoO	CuO	SnO_2	Sb_2O_3	PbO	Total
DMS-1-Aa	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	16.20	0.64	3.06	58.00	0.14	0.18	1.44	0.54	2.91	0.24	0.00	0.05	0.93	0.02	1.60	0.75	0.00	12.72	99.42
						StDev	0.42	0.03	0.17	0.30	0.02	0.04	0.02	0.07	0.05	0.01	0.00	0.03	0.03	0.01	0.04	0.04	0.00	0.29	
DMS-1-Ab	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	17.89	0.92	3.24	66.16	0.12	0.16	1.44	0.41	3.09	0.31	0.00	0.05	1.00	0.01	1.26	0.38	0.00	4.74	101.19
						StDev	0.55	0.01	0.12	0.42	0.02	0.03	0.04	0.03	0.04	0.01	0.00	0.01	0.04	0.01	0.04	0.03	0.00	0.29	
DMS-2-Bb	Tessera	Egypt I	DMSt1	Opaque	Yellow	Mean	16.61	0.69	3.13	60.26	0.03	0.26	1.18	0.41	2.55	0.32	0.00	0.14	1.03	0.01	0.29	1.01	0.01	11.73	99.65
						StDev	0.86	0.05	0.20	1.31	0.02	0.04	0.05	0.05	0.13	0.02	0.00	0.02	0.06	0.01	0.06	1.08	0.02	1.81	
DMS-10-L	Tessera	Egypt I	DMSt1	Opaque	Yellow	Mean	17.68	0.77	3.55	71.63	0.14	0.14	1.42	0.40	3.04	0.30	0.00	0.04	1.11	0.01	1.66	0.09	0.00	0.56	102.52
						StDev	0.35	0.02	0.15	1.35	0.05	0.05	0.03	0.06	0.10	0.02	0.00	0.02	0.04	0.02	0.82	0.06	0.00	0.36	
DMS-17-R	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	17.69	0.65	3.23	61.89	0.19	0.19	1.50	0.57	2.93	0.25	0.00	0.06	0.95	0.00	1.98	0.49	0.00	8.32	100.88
						StDev	0.28	0.03	0.16	0.70	0.02	0.02	0.04	0.08	0.04	0.02	0.00	0.04	0.04	0.01	0.10	0.08	0.01	0.98	
DMS-20-U	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	17.45	0.55	2.16	69.74	0.22	0.22	1.32	0.45	3.61	0.27	0.01	0.03	0.86	0.01	1.75	0.15	0.01	1.35	100.16
						StDev	0.22	0.02	0.16	2.43	0.04	0.04	0.05	0.04	0.32	0.01	0.02	0.02	0.04	0.01	0.37	0.04	0.01	0.12	
DMS-2-Ba	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	10.59	0.56	2.26	48.63	0.04	0.07	0.80	0.48	7.64	0.06	0.00	0.05	0.36	0.00	0.71	1.45	0.00	25.36	99.09
						StDev	0.50	0.01	0.23	1.01	0.03	0.04	0.05	0.07	0.24	0.02	0.00	0.02	0.03	0.00	0.05	0.13	0.00	1.58	
DMS-3-C	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	14.26	0.61	2.32	60.47	0.08	0.14	1.10	0.64	7.25	0.07	0.01	0.15	0.37	0.00	1.53	0.74	0.01	11.14	100.88
						StDev	0.30	0.03	0.11	0.68	0.03	0.02	0.03	0.05	0.14	0.02	0.02	0.03	0.03	0.01	0.06	0.16	0.01	1.04	
DMS-5-Ea	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	17.47	0.80	2.65	66.95	0.19	0.20	1.36	0.82	9.04	0.11	0.01	0.49	0.50	0.01	0.80	0.09	0.01	0.41	101.91
						StDev	0.33	0.02	0.10	1.09	0.03	0.02	0.03	0.06	0.05	0.02	0.03	0.03	0.06	0.01	0.05	0.03	0.02	0.08	
DMS-5-Eb	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	15.27	0.76	2.66	66.88	0.09	0.12	1.27	0.74	9.61	0.08	0.00	0.08	0.45	0.00	2.53	0.40	0.00	0.58	101.52
						StDev	0.45	0.04	0.20	0.97	0.05	0.03	0.04	0.07	0.08	0.01	0.00	0.01	0.02	0.01	0.23	0.12	0.00	0.12	
DMS-6-FC	Tessera	Apollonia-type Levantine I	DMSt2	Transparent	Colourless	Mean	14.10	0.78	3.09	64.46	0.18	0.10	0.80	0.92	10.86	0.12	0.00	5.21	0.78	0.01	0.02	0.02	0.00	0.12	101.57
						StDev	0.48	0.02	0.08	0.39	0.04	0.02	0.02	0.08	0.09	0.02	0.00	0.09	0.04	0.02	0.02	0.03	0.01	0.09	
DMS-6-FS	Tessera	Apollonia-type Levantine I	DMSt2	Translucent	Yellow	Mean	14.99	0.76	3.01	66.23	0.12	0.12	0.97	0.82	9.54	0.10	0.01	4.04	0.67	0.01	0.03	0.02	0.01	0.16	101.62
						StDev	0.25	0.03	0.13	0.47	0.03	0.03	0.04	0.09	0.07	0.02	0.01	0.11	0.04	0.01	0.03	0.02	0.02	0.09	
DMS-8-H	Tessera	Apollonia-type Levantine I	DMSt2	Translucent	Green	Mean	15.79	1.14	3.25	68.28	0.14	0.14	1.24	0.58	11.17	0.11	0.00	0.05	0.62	0.00	0.01	0.01	0.00	0.04	102.57
						StDev	0.21	0.04	0.14	0.77	0.01	0.01	0.04	0.06	0.13	0.03	0.00	0.02	0.03	0.01	0.02	0.02	0.01	0.04	
DMS-9-I	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	11.60	0.64	2.52	54.38	0.06	0.06	0.89	0.50	8.16	0.08	0.00	0.05	0.48	0.01	0.93	1.36	0.00	17.19	98.88
						StDev	0.41	0.03	0.10	0.91	0.04	0.04	0.03	0.06	0.14	0.02	0.00	0.02	0.03	0.01	0.05	0.38	0.00	1.06	
DMS-11-M	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green/Yellow	Mean	16.90	0.74	2.67	68.22	0.22	0.22	1.48	0.63	7.71	0.08	0.00	1.36	0.48	0.01	0.55	0.03	0.20	0.77	102.28
						StDev	0.34	0.03	0.10	0.43	0.03	0.03	0.02	0.04	0.12	0.01	0.01	0.10	0.04	0.02	0.05	0.03	0.04	0.15	
DMS-13-Nv	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	15.19	0.70	2.83	66.26	0.08	0.08	1.02	1.00	9.80	0.09	0.00	0.31	4.53	0.01	0.03	0.00	0.00	0.06	102.00
						StDev	0.34	0.02	0.21	0.38	0.03	0.03	0.05	0.08	0.12	0.01	0.00	0.03	0.11	0.01	0.03	0.00	0.00	0.05	
DMS-14-O	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	15.19	0.73	2.97	68.09	0.11	0.11	1.11	1.07	10.17	0.08	0.01	0.33	0.60	0.02	0.01	0.01	0.00	0.04	100.62
						StDev	0.22	0.02	0.12	1.52	0.05	0.05	0.06	0.10	0.13	0.02	0.01	0.03	0.08	0.02	0.01	0.01	0.00	0.04	
DMS-16-Qa	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	14.41	0.90	2.69	65.16	0.07	0.07	1.04	1.10	10.42	0.09	0.00	0.20	0.56	0.01	0.04	0.13	0.01	2.33	99.23
						StDev	0.54	0.03	0.14	0.83	0.03	0.03	0.02	0.07	0.05	0.01	0.00	0.01	0.03	0.02	0.02	0.03	0.03	0.14	
DMS-19-T	Tessera	Apollonia-type Levantine I	DMSt2	Translucent	Yellow	Mean	15.31	0.81	3.09	66.75	0.13	0.13	0.86	0.83	10.32	0.09	0.00	2.55	0.64	0.01	0.00	0.02	0.00	0.08	101.65
						StDev	0.49	0.02	0.23	0.42	0.03	0.03	0.03	0.07	0.12	0.01	0.01	0.05	0.02	0.01	0.02	0.02	0.00	0.06	
DMS-4-D	Tessera	Foy-2	DMSt3	Translucent	Blue	Mean	20.43	0.82	2.15	65.16	0.04	0.35	1.50	0.58	7.66	0.12	0.00	1.14	1.06	0.08	0.13	0.03	0.01	0.36	101.62
						StDev	0.36	0.02	0.16	0.88	0.01	0.05	0.03	0.07	0.07	0.02	0.00	0.07	0.07	0.01	0.01	0.02	0.03	0.06	
DMS-7-G	Tessera	Foy-2	DMSt3	Opaque	Yellow	Mean	13.18	0.81	1.78	47.31	0.26	0.26	0.80	0.47	5.54	0.13	0.00	1.25	0.67	0.01	0.03	2.02	0.00	26.08	100.59
						StDev	0.47	0.03	0.15	2.32	0.05	0.05	0.05	0.06	0.12	0.02	0.00	0.07	0.03	0.01	0.03	0.76	0.00	1.53	
DMS-13-Ngr	Tessera	Foy-2	DMSt3	Opaque	Black	Mean	16.67	0.88	2.34	64.69	0.19	0.19	1.34	0.72	7.65	0.13	0.00	1.24	6.31	0.01	0.18	0.02	0.03	0.15	102.73
						StDev	0.33	0.04	0.12	1.15	0.03	0.03	0.07	0.07	0.28	0.03	0.00	0.13	1.37	0.01	0.05	0.03	0.03	0.08	
DMS-15-P	Tessera	Foy-2	DMSt3	Transparent	Colourless	Mean	20.18	0.80	1.96	68.56	0.41	0.41	1.16	0.47	6.84	0.11	0.01	1.17	0.56	0.01	0.03	0.01	0.00	0.02	102.71
						StDev	0.44	0.02	0.12	0.55	0.04	0.04	0.02	0.05	0.05	0.02	0.02	0.03	0.04	0.01	0.02	0.01	0.00	0.03	
DMS-18-S	Tessera	Foy-2	DMSt3	Translucent	Yellow	Mean	19.38	1.52	2.46	64.81	0.41	0.41	1.21	0.85	8.22	0.16	0.01	2.12	0.89	0.01	0.03	0.01	0.01	0.06	102.56
						StDev	0.35	0.05	0.17	0.74	0.03	0.03	0.04	0.07	0.05	0.01	0.02	0.07	0.04	0.01	0.02	0.02	0.02	0.07	

Tab.6.6a Chemical compositions of the glassy matrices of tesserae, obtained by EMPA.
All data are expressed as percentage concentrations of element oxides.

Sample	Typology	mpositional catego	Group	Opacity	Colour	Value	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	FeO	CoO
DMS-1-Aa	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	19.22	0.76	3.64	68.81	0.16	0.22	1.71	0.64	3.45	0.29	0.00	1.12	0.02
DMS-1-Ab	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	18.88	0.98	3.42	69.82	0.13	0.17	1.52	0.44	3.26	0.33	0.00	1.06	0.01
DMS-2-Bb	Tessera	Egypt I	DMSt1	Opaque	Yellow	Mean	19.21	0.80	3.63	69.69	0.03	0.31	1.36	0.47	2.95	0.37	0.00	1.20	0.01
DMS-10-L	Tessera	Egypt I	DMSt1	Opaque	Yellow	Mean	17.65	0.78	3.55	71.51	0.14	0.14	1.41	0.40	3.04	0.30	0.00	1.12	0.01
DMS-17-R	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	19.65	0.73	3.59	68.74	0.21	0.21	1.67	0.63	3.26	0.28	0.00	1.06	0.00
DMS-20-U	Tessera	Egypt I	DMSt1	Opaque	Green	Mean	18.01	0.58	2.23	71.99	0.23	0.23	1.36	0.47	3.73	0.28	0.01	0.90	0.01
DMS-2-Ba	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	14.82	0.79	3.17	68.01	0.06	0.10	1.12	0.68	10.69	0.08	0.00	0.51	0.00
DMS-3-C	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	16.33	0.70	2.66	69.26	0.09	0.16	1.26	0.73	8.30	0.08	0.01	0.43	0.00
DMS-5-Ea	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	17.45	0.80	2.65	66.88	0.19	0.20	1.36	0.82	9.03	0.11	0.01	0.50	0.01
DMS-5-Eb	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	15.60	0.78	2.72	68.30	0.09	0.12	1.30	0.75	9.81	0.08	0.00	0.47	0.00
DMS-9-I	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	14.62	0.81	3.18	68.52	0.07	0.07	1.12	0.63	10.28	0.10	0.00	0.61	0.01
DMS-11-M	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green/Yellow	Mean	17.01	0.74	2.69	68.66	0.22	0.22	1.49	0.63	7.76	0.08	0.00	0.48	0.01
DMS-13-Nv	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	14.95	0.70	2.79	65.23	0.08	0.08	1.01	0.98	9.65	0.09	0.00	4.48	0.01
DMS-14-O	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Yellow	Mean	15.16	0.73	2.96	67.95	0.11	0.11	1.11	1.07	10.14	0.08	0.01	0.61	0.02
DMS-16-Qa	Tessera	Apollonia-type Levantine I	DMSt2	Opaque	Green	Mean	14.93	0.94	2.79	67.52	0.08	0.08	1.07	1.14	10.80	0.09	0.00	0.58	0.01
DMS-7-G	Tessera	Foy-2	DMSt3	Opaque	Yellow	Mean	18.51	1.13	2.51	66.44	0.36	0.36	1.13	0.65	7.79	0.18	0.00	0.93	0.01
DMS-13-Ngr	Tessera	Foy-2	DMSt3	Opaque	Black	Mean	16.49	0.86	2.32	63.98	0.19	0.19	1.32	0.71	7.56	0.13	0.00	6.22	0.01

Tab.6.6b Reduced percentage concentrations of element oxides detected by EMPA, calculated for the opaque tesserae.

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Sn	Sb	Ba	La
DMS-1-Aa	Tessera	Egypt I	DMSt1	opaque	Green	Mean	3.42	1393.89	20.61	32.81	5.63	22.13	12909.62	950.86	3.05	6.99	175.46	5.51	69.59	2.73	6464.43	83.84	161.27	5.18
DMS-1-Ab	Tessera	Egypt I	DMSt1	opaque	Green	Mean	4.00	1704.67	22.41	35.80	5.12	14.01	9275.12	52.87	3.73	6.27	205.07	6.57	87.96	2.99	2441.62	39.32	177.27	6.24
DMS-2-Bb	Tessera	Egypt I	DMSt1	opaque	Yellow	Mean	3.94	1831.48	22.55	40.03	4.82	10.78	2218.82	45.21	3.63	6.14	193.07	6.49	91.43	3.27	4694.31	68.51	184.61	6.23
DMS-10-L	Tessera	Egypt I	DMSt1	opaque	Yellow	Mean	5.28	2026.39	27.00	45.42	5.04	14.37	12263.56	528.93	4.71	7.44	218.07	8.03	109.40	3.72	774.98	16.90	215.35	7.78
DMS-17-R	Tessera	Egypt I	DMSt1	opaque	Green	Mean	4.31	1724.63	27.15	38.31	8.51	26.28	17312.23	1222.30	3.88	8.80	233.87	7.25	88.38	3.13	5270.32	73.77	223.17	6.47
DMS-20-U	Tessera	Egypt I	DMSt1	opaque	Green	Mean	3.45	1900.89	20.34	31.24	5.01	11.94	9926.89	314.07	2.85	5.18	142.09	6.81	124.32	3.53	1165.28	13.20	149.40	6.49
DMS-2-Ba	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	1.08	350.43	6.49	10.68	4.60	19.46	4699.98	49.82	2.15	5.62	327.42	5.15	29.04	1.24	15791.20	75.19	155.03	4.12
DMS-3-C	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	1.44	472.19	9.60	14.10	3.93	22.22	13793.52	41.09	2.45	8.68	386.24	6.25	41.60	1.48	8973.16	88.22	207.82	5.47
DMS-5-Ea	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	1.74	679.29	11.26	17.62	5.25	14.12	5832.63	145.88	2.94	10.60	480.06	7.61	58.22	1.75	414.18	7.86	266.89	6.15
DMS-5-Eb	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	1.80	573.05	10.91	18.68	5.02	60.11	18167.27	218.64	3.29	10.84	497.20	7.92	47.63	1.69	2507.50	17.19	251.18	6.84
DMS-6-FC	Tessera	Apollonia-type Levantine I	DMSt2	transparent	Colourless	Mean	2.78	896.88	21.41	22.99	7.99	15.65	188.71	40.51	4.14	11.05	538.97	9.12	57.22	2.56	116.54	20.01	611.39	8.12
DMS-6-FS	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Yellow	Mean	2.51	768.29	19.62	18.40	9.08	11.76	228.84	36.88	3.86	10.75	551.41	8.95	56.90	2.24	77.73	18.71	502.00	7.48
DMS-8-H	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Green	Mean	2.77	741.21	14.29	86.87	3.38	12.45	5.48	14.39	4.14	8.57	617.01	8.76	48.05	2.19	≤ DL	≤ DL	269.51	7.78
DMS-9-I	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	1.78	554.71	10.38	14.43	8.02	30.44	7045.43	192.36	3.09	6.60	439.23	7.25	38.33	1.75	17607.06	102.61	218.98	6.14
DMS-11-M	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green/Yellow	Mean	2.49	556.11	22.25	11.96	10.17	10.26	4317.86	43.11	3.38	13.40	554.77	8.07	45.82	2.29	318.51	1971.14	413.00	7.46
DMS-13-Nv	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	1.81	620.63	13.96	16.00	5.12	15.66	145.01	24.65	3.52	14.27	558.05	8.83	49.71	1.82	20.17	12.95	321.28	7.35
DMS-14-O	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	2.28	577.15	13.63	13.28	5.29	7.59	73.74	29.46	3.41	14.24	572.58	8.85	48.19	1.88	≤ DL	10.43	335.76	7.46
DMS-16-Qa	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	2.36	594.75	11.38	16.52	6.65	8.83	248.41	42.40	3.23	10.60	466.62	7.62	48.34	1.78	1164.38	110.94	270.52	6.70
DMS-19-T	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Yellow	Mean	2.58	750.31	18.75	25.61	6.50	14.36	77.52	35.66	3.99	13.10	562.08	8.96	60.65	2.29	18.74	12.52	433.87	7.93
DMS-4-D	Tessera	Foy-2	DMSt3	translucent	Blue	Mean	1.97	771.35	26.52	14.84	630.87	155.97	1176.79	46.36	3.38	6.98	486.05	6.98	64.58	1.98	106.40	19.87	297.29	6.43
DMS-7-G	Tessera	Foy-2	DMSt3	opaque	Yellow	Mean	1.93	727.43	23.54	12.11	7.32	17.46	262.11	28.09	2.13	6.23	538.17	6.05	62.10	2.09	26178.77	454.90	287.82	5.88
DMS-13-Ngr	Tessera	Foy-2	DMSt3	opaque	Black	Mean	2.84	1205.38	27.01	24.24	19.06	30.36	1977.49	130.41	3.68	11.65	489.12	8.85	75.16	2.79	324.92	405.79	384.02	8.66
DMS-15-P	Tessera	Foy-2	DMSt3	transparent	Colourless	Mean	2.19	726.69	27.40	12.66	6.24	8.76	19.05	19.59	2.63	7.00	541.18	7.48	67.92	2.07	2.67	18.83	324.30	6.76
DMS-18-S	Tessera	Foy-2	DMSt3	translucent	Yellow	Mean	2.87	1097.76	34.79	17.86	7.98	15.59	58.99	40.14	3.26	8.83	852.66	8.55	103.51	3.13	8.32	91.22	395.09	8.07

Tab.6.7 Trace element composition of the tesserae obtained by LA-ICP-MS. All data are expressed in ppm.

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th
DMS-1-Aa	Tessera	Egypt I	DMSt1	opaque	Green	Mean	10.38	1.41	5.55	1.08	0.38	1.07	0.17	1.00	0.20	0.56	0.08	0.59	0.09	1.71	0.18	92331.86	0.94
DMS-1-Ab	Tessera	Egypt I	DMSt1	opaque	Green	Mean	12.97	1.55	6.52	1.33	0.37	1.31	0.18	1.18	0.24	0.73	0.11	0.66	0.11	2.18	0.20	38018.03	1.21
DMS-2-Bb	Tessera	Egypt I	DMSt1	opaque	Yellow	Mean	12.98	1.62	6.63	1.34	0.40	1.30	0.20	1.22	0.26	0.73	0.10	0.70	0.10	2.40	0.24	91289.48	1.33
DMS-10-L	Tessera	Egypt I	DMSt1	opaque	Yellow	Mean	13.58	2.18	7.47	1.72	0.47	1.55	0.27	1.39	0.30	0.84	0.14	0.92	0.12	2.68	0.29	3282.71	1.49
DMS-17-R	Tessera	Egypt I	DMSt1	opaque	Green	Mean	13.56	1.66	6.80	1.48	0.45	1.38	0.21	1.31	0.25	0.74	0.11	0.74	0.11	2.17	0.22	73487.32	1.21
DMS-20-U	Tessera	Egypt I	DMSt1	opaque	Green	Mean	13.31	1.65	6.31	1.37	0.38	1.23	0.19	1.15	0.24	0.68	0.10	0.69	0.11	3.02	0.24	10483.13	1.36
DMS-2-Ba	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	8.03	1.14	4.17	0.90	0.27	0.85	0.12	0.80	0.17	0.48	0.07	0.44	0.06	0.74	0.10	174736.86	0.57
DMS-3-C	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	10.02	1.24	5.33	1.17	0.32	1.09	0.16	1.04	0.20	0.58	0.08	0.56	0.08	1.05	0.13	97994.29	0.78
DMS-5-Ea	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	12.19	1.88	6.24	1.33	0.41	1.20	0.19	1.20	0.25	0.71	0.10	0.70	0.09	1.50	0.13	2270.00	0.93
DMS-5-Eb	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	12.92	1.63	6.83	1.46	0.43	1.40	0.21	1.36	0.27	0.73	0.10	0.70	0.10	1.21	0.12	3285.60	0.95
DMS-6-FC	Tessera	Apollonia-type Levantine I	DMSt2	transparent	Colourless	Mean	15.91	1.93	7.73	1.74	0.47	1.53	0.24	1.42	0.29	0.86	0.12	0.84	0.11	1.40	0.17	938.55	1.23
DMS-6-FS	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Yellow	Mean	14.93	1.85	7.50	1.64	0.46	1.53	0.25	1.48	0.29	0.84	0.11	0.76	0.10	1.40	0.15	746.71	1.14
DMS-8-H	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Green	Mean	15.73	1.81	7.69	1.47	0.61	1.56	0.23	1.39	0.33	0.94	≤ DL	1.03	0.12	1.25	0.15	15.88	0.89
DMS-9-I	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	11.25	1.56	5.90	1.34	0.37	1.25	0.19	1.17	0.24	0.67	0.09	0.60	0.09	0.98	0.15	171213.20	0.84
DMS-11-M	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green/Yellow	Mean	13.79	1.88	7.06	1.47	0.40	1.33	0.22	1.28	0.28	0.76	0.11	0.77	0.10	1.18	0.12	5625.99	1.18
DMS-13-Nv	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	13.99	1.78	7.20	1.50	0.59	1.56	0.23	1.38	0.29	0.81	0.11	0.74	0.10	1.28	0.12	291.71	0.98
DMS-14-O	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Yellow	Mean	14.05	1.77	7.12	1.58	0.52	1.58	0.23	1.46	0.30	0.84	0.11	0.80	≤ DL	1.25	0.14	206.14	1.05
DMS-16-Qa	Tessera	Apollonia-type Levantine I	DMSt2	opaque	Green	Mean	13.03	1.68	6.47	1.69	0.50	1.30	0.21	1.26	0.26	0.75	0.11	0.76	0.14	≤ DL	0.15	21067.64	1.02
DMS-19-T	Tessera	Apollonia-type Levantine I	DMSt2	translucent	Yellow	Mean	15.16	1.86	7.50	1.65	0.44	1.55	0.23	1.46	0.30	0.85	0.12	0.83	0.11	1.47	0.14	114.69	1.04
DMS-4-D	Tessera	Foy-2	DMSt3	translucent	Blue	Mean	10.91	1.26	6.17	1.28	0.35	1.20	0.19	1.15	0.24	0.71	0.10	0.67	0.09	1.56	0.14	2445.80	1.08
DMS-7-G	Tessera	Foy-2	DMSt3	opaque	Yellow	Mean	10.16	1.39	5.76	1.20	0.29	1.14	0.17	1.02	0.22	0.63	0.09	0.60	0.09	1.54	0.13	256380.00	1.03
DMS-13-Ngr	Tessera	Foy-2	DMSt3	opaque	Black	Mean	16.05	2.12	7.87	1.68	0.45	1.60	0.25	1.50	0.32	0.88	0.12	0.81	0.11	1.90	0.19	1070.70	1.38
DMS-15-P	Tessera	Foy-2	DMSt3	transparent	Colourless	Mean	11.71	1.59	6.25	1.33	0.35	1.24	0.21	1.17	0.25	0.73	0.10	0.67	0.10	1.65	0.14	20.24	1.12
DMS-18-S	Tessera	Foy-2	DMSt3	translucent	Yellow	Mean	14.73	1.93	7.45	1.63	0.43	1.48	0.21	1.42	0.29	0.86	0.13	0.80	0.13	2.57	0.22	55.90	1.45

Tab.6.7 (continuing) Trace element composition of the tesserae obtained by LA-ICP-MS. All data are expressed in ppm.

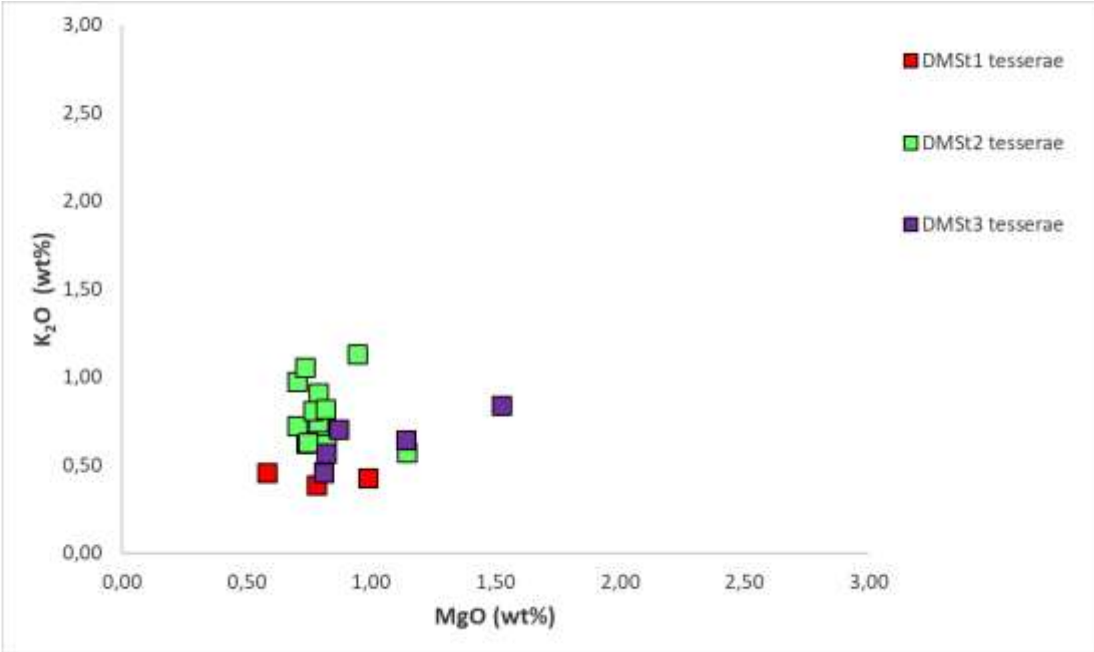


Fig.6.25 K_2O versus MgO bi-plot
(for the opaque tesserae, reduced wt% contents are used).

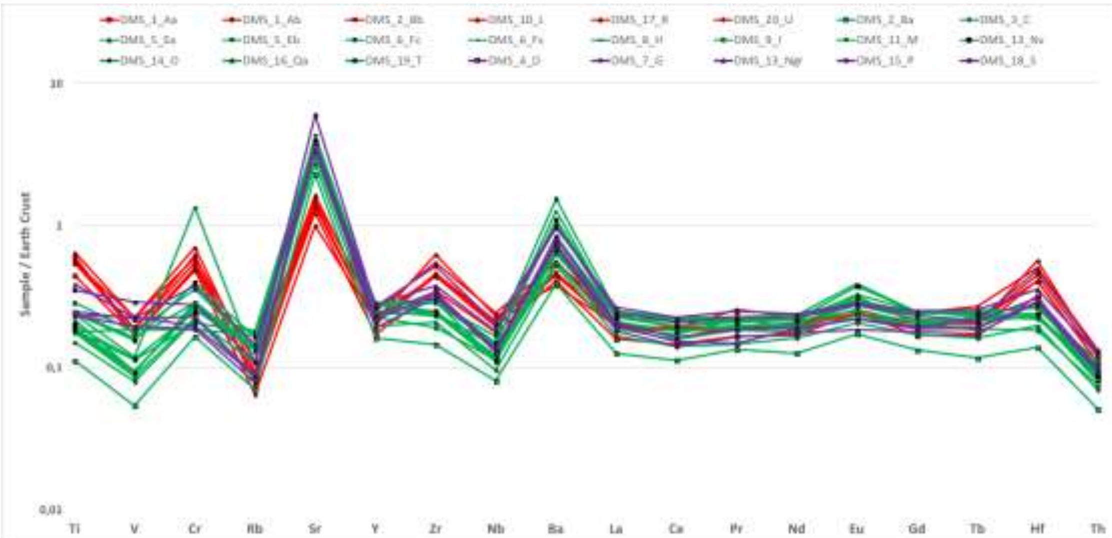


Fig.6.26 Trace elements patterns of the tesserae (LA-ICP-MS data). Averages are normalised to the mean values in the continental crust (Kamber et al. 2005). Red lines are used for samples of group DMSt1, green lines for samples belonging to group DMSt2, purple lines for samples of group DMSt3.

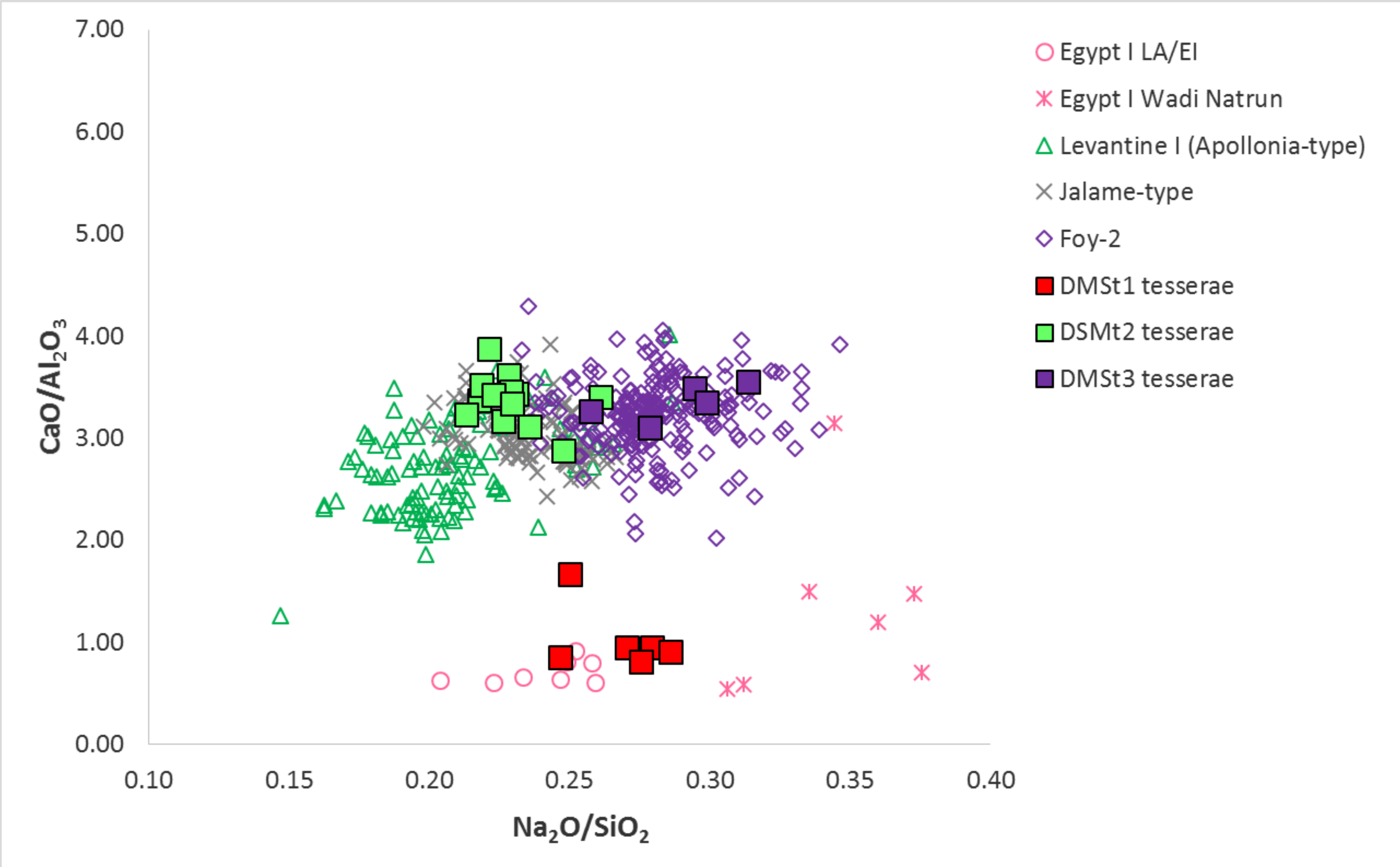


Fig.6.27 CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004; Jalame-type: Brill 1988; Silvestri 2008; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017.

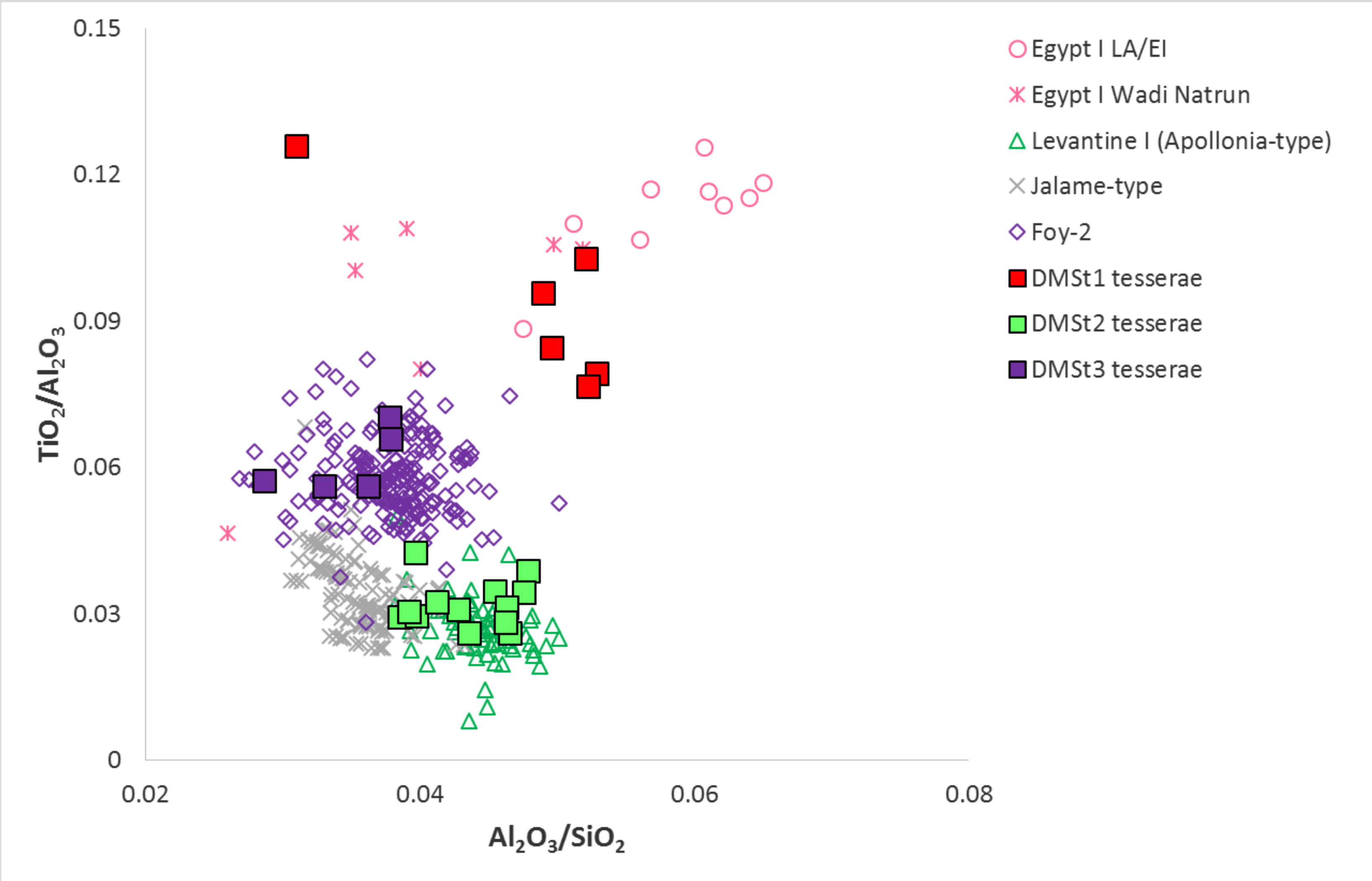


Fig.6.28 TiO_2/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004; Jalame-type: Brill 1988; Silvestri 2008; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017.

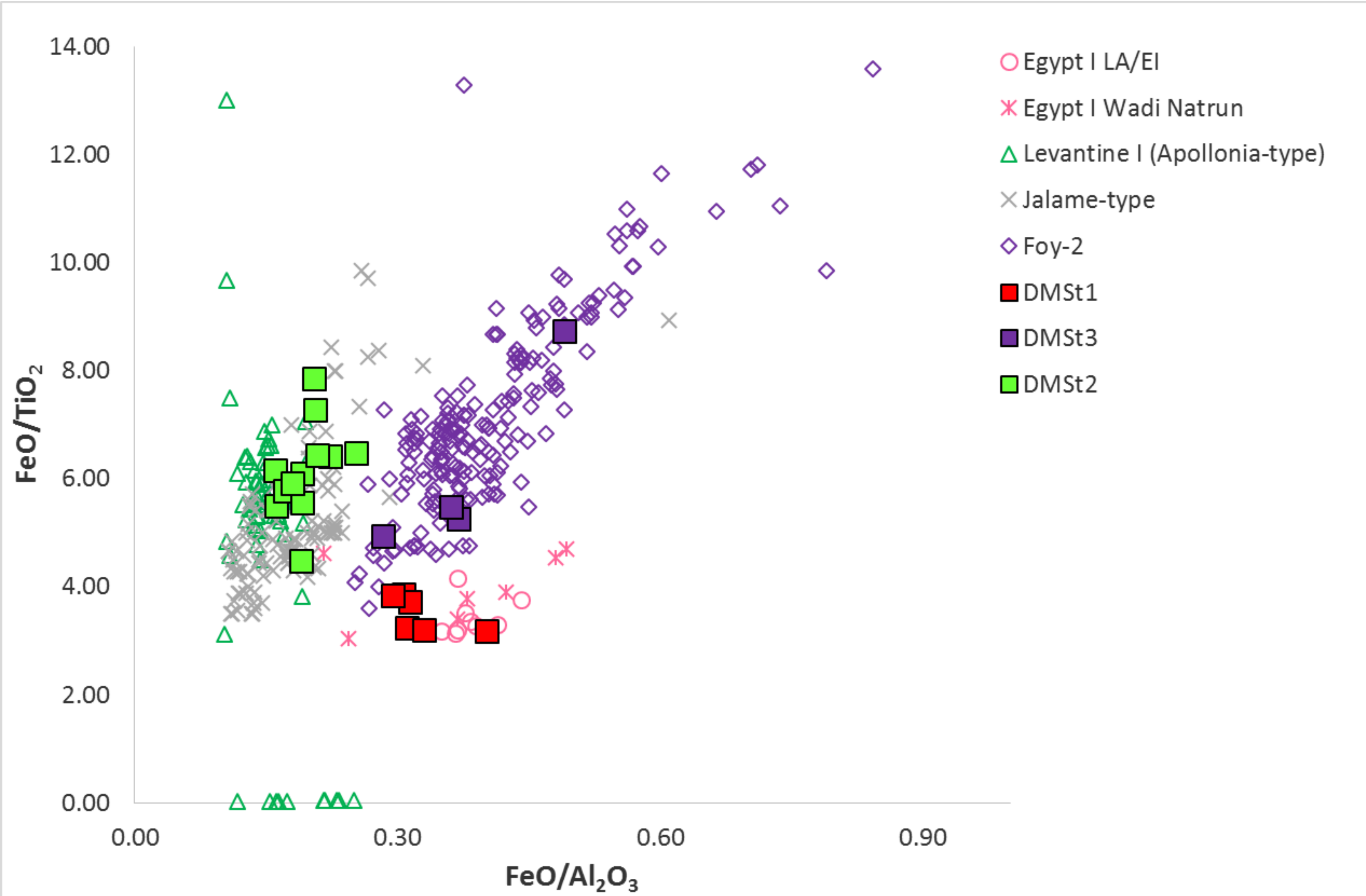


Fig.6.29 FeO/TiO_2 versus FeO/Al_2O_3 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004; Jalame-type: Brill 1988; Silvestri 2008; Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017.

Tesserae belonging to group **DMSt1** have been manufactured by using a sand rich in heavy elements and low in strontium contents. These features, together with the relatively high soda contents, are typical of Egyptian glasses (Foy, Picon & Vichy 2003; Nenna 2014; Phelps et al. 2016; Picon, Thirion-Merle & Vichy 2008). More precisely, compositional data show that DMSt1 tesserae match Egypt I compositional category. If a closer look is given to CaO/Al_2O_3:Na_2O/SiO_2 and TiO_2/Al_2O_3:Al_2O_3/SiO_2 bi-plots (Fig.6.27-6.29), it will also be noticed that DMSt1 tesserae show more affinities with late antique/early Islamic Egypt I than with earlier Egypt I, referable to Wadi Natrun furnaces.

Fig.6.30 allows to hypothesise the use of a coastal rather than an inland sand for DMSt1 tesserae: though strontium and calcium oxide contents are lower compared to DMSt2 group (see below), they are equally correlated, and their ratios are low, with a mean of 175.

The second cluster, from now on named **DMSt2**, comprises tesserae 2Ba, 3C, 5Ea, 5Eb, 6Fc, 6Fs, 8H, 9I, 11M, 13Nv, 14O, 16Qa and 19T. They are characterised by higher strontium and lower heavy elements contents compared to DMSt1 tesserae; DMSt2 tesserae also display higher lime (8.30-10.86 wt%) and lower soda (14.10-17.45 wt%) compared to all other samples (Fig.6.27). Tesserae belonging to group DMSt2 have been manufactured by using a sand low in the heavy accessory minerals. In addition, the relatively high alumina suggests the use of a mature sand, and the positive correlation between high lime and high strontium indicates a coastal sand containing shells rather than an inland one (Fig.6.30) (Freestone et al. 2003; Phelps et al. 2016). This is further confirmed by the low CaO/Sr ratios, having a mean value of 201.

If a closer look is given at scatter plots in Fig.6.27-6.29, it can be noticed that, though consistent with Levantine I compositional category, some of DMSt2 tesserae fall at a more intermediate position between Apollonia-type and Jalame-type[62]. A similar behaviour has been observed by Barford and

[62] Jalame-type compositional category refers to glass made at the 4ht century primary furnaces identified at Jalame, along the Syro-palestinian coast and about 70-80 Km far from Apollonia (Brill 1988; Phelps et al. 2016; Barford et al. 2018).

colleagues in a study dealing with the geochemistry of Byzantine and Early Islamic glass from Jerash, in Jordan (Barford et al. 2018): results have led to the hypothesis that some of the Levantine I analysed glasses could result from "recycling" Jalame-type into Apollonia-type. According to compositional data, it cannot, thus, be excluded that something analogous also occurred for some of the tesserae belonging to DMSt2 group.

The third group, from now on labelled **DMSt3**, is formed by samples 4D, 7G, 13Ngr, 15P and 18S. These tesserae are made of a natron-based glass with

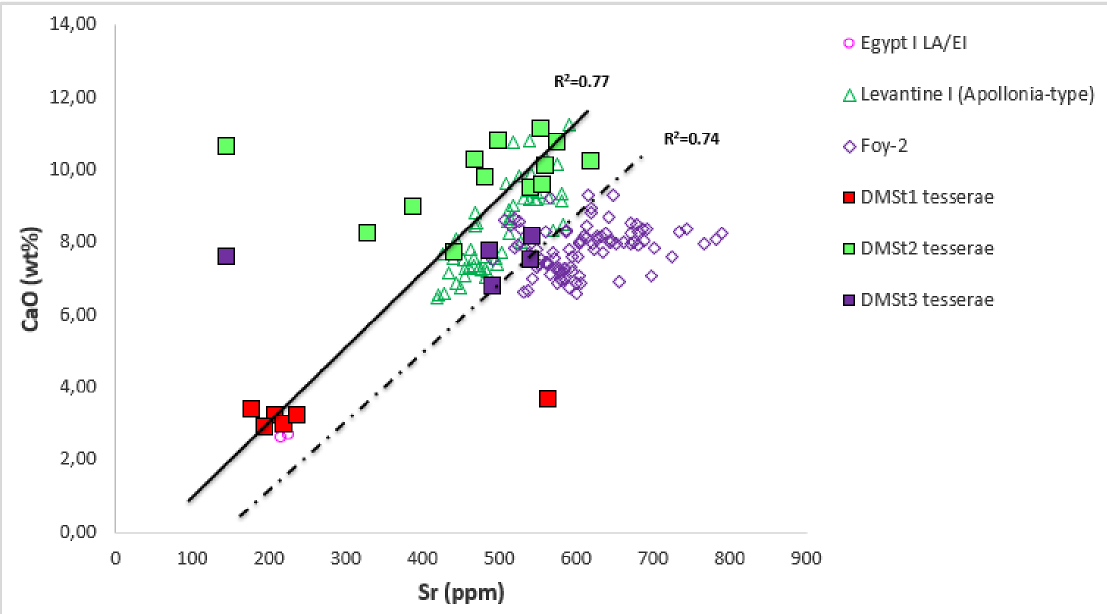


Fig.6.30 CaO (wt%) versus Sr (ppm) bi-plot (for the opaque tesserae, reduced wt% contents are used). The black and the dotted lines show, respectively, positive correlation between CaO and Sr contents for DMSt1 and DMSt2 samples and from the literature (Phelps et al. 2016).

slightly higher contents of magnesium (0.80-1.52 wt%), manganese (1.14-2.12 wt%)[63], titanium (0.11 to 0.18 wt%) and iron oxides (0.56 and 1.06 wt%), with zirconium ranging from 62 to 103 ppm and strontium between 486 and 853 ppm. These features are consistent with the so-called Foy-2 compositional category (Fig.6.27-6.29), found among late antique assemblages from France (Foy et al. 2003), Carthage (Schibille, Sterrett-Krause & Freestone 2017), Byzantine glass weights (Schibille et al. 2016), and the HLIMT group identified in Cyprus (Ceglia et al. 2015). First identified by Daniéle Foy and colleagues

[63] For MnO, take here into account non-recalculated EPMA data, Tab.6.6a.

and believed to be of an Egyptian provenance (Foy et al. 2003), this category further splits into two sub-groups: the primary production group série 2.1 and the so-called série 2.2, showing signs of recycling. While the glasses of série 2.1 have been dated to the 6th and 7th CE and seem to have been quite widespread (Ceglia et al. 2015; Nenna 2014; Neri et al. 2017; Neri, Gratuze & Schibille 2017), the recycled série 2.2 dates from 7th to late 8th CE (Foy et al. 2003).

As already noticed for recently studied glass tesserae from the Durres amphitheatre matching Foy-2 compositional category, it is complicated to unambiguously relate samples to either of the two sub-groups (Neri, Gratuze & Schibille 2017). Tesserae from Damascus are, like those from Durres, intermediate between primary production group série 2.1 and série 2.2 (Fig.6.31a-c). More precisely, DMSt3 samples are characterised by lower iron, magnesium, titanium and zirconium contents when compared to primary production group série 2.1, and trace elements contents cannot be fully indicative as they are influenced by the addition of colourants and opacifiers to the base glass.

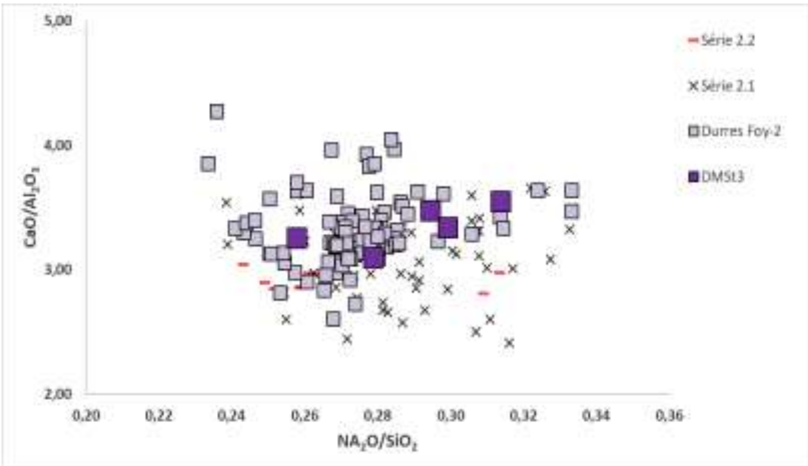


Fig.6.31a CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot, comparing Foy-2 tesserae from Damascus (DMSt3 group) with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

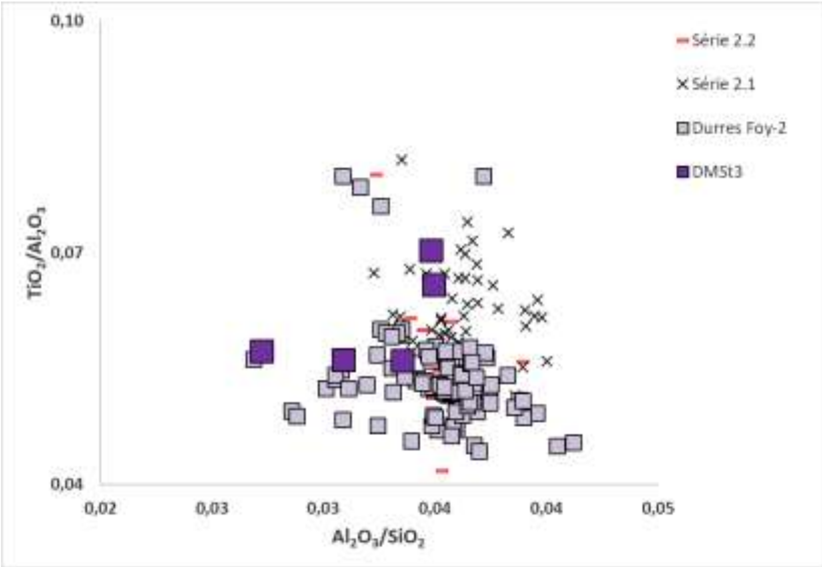


Fig.6.31b TiO/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot, comparing Foy-2 tesserae from Damascus (DMSt3 group) with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

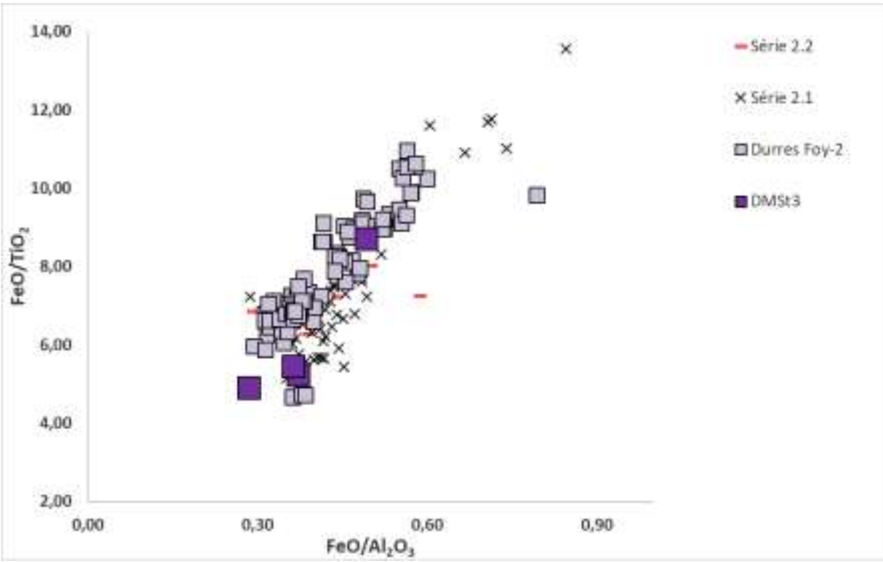


Fig.6.31c FeO/TiO_2 versus FeO/Al_2O_3 bi-plot, comparing Foy-2 tesserae from Damascus (DMSt3 group) with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

In conclusion, EPMA and LA-ICP-MS analyses performed on the assemblage of coloured tesserae from the Great Mosque of Damascus demonstrated the occurrence of three distinct types of base glass, respectively matching Egypt I (although slightly different from that manufactured at the primary furnaces located at Wadi Natrun), Apollonia-type and Foy-2 compositional categories.

6.2.2 Colourants and opacifiers

6.2.2a Copper-based phases

Tessera 13Ngr, whose seeming colour is black, is made of opaque dark red streaks alternated with translucent green ones (Fig.6.32a). According to compositional features detected by means of EPMA and LA-ICP-MS data, this sample matches Foy-2 glass group (DMSt3).

The microstructure of this tessera is characterized by the presence of light zoned bands in BSE, corresponding to the visible red streaks, while the green ones are darker; BSE images also show a dispersion of nanometric rounded particles in the glassy matrix, mainly concentrated in the red streaks and tending to form aggregates nearby the margins between the green and the red zones (Fig.6.32).

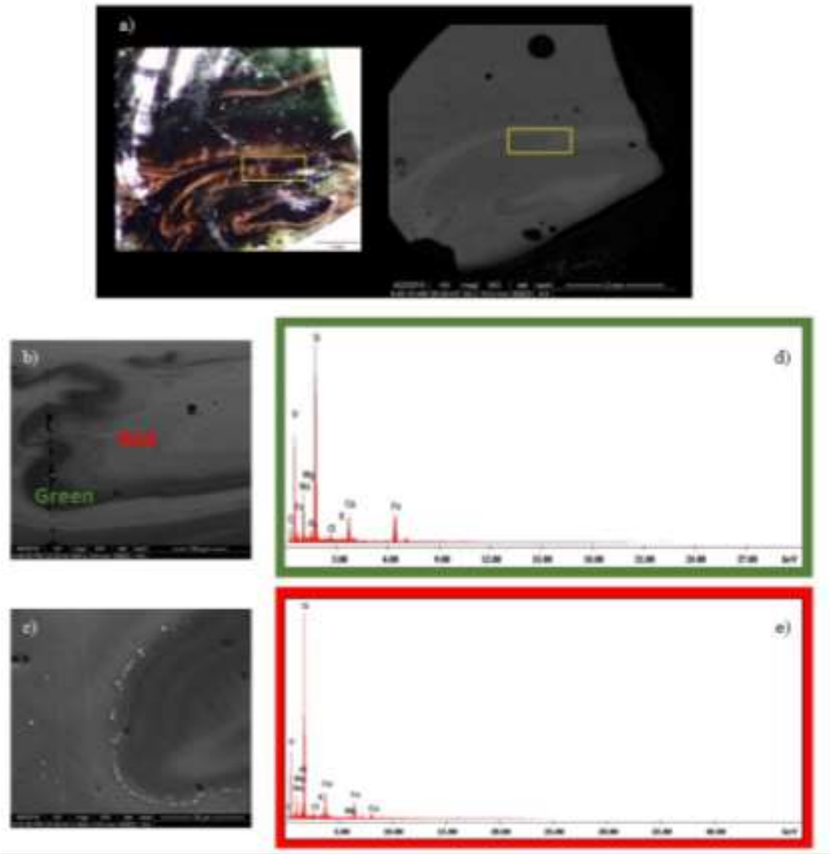


Fig.6.32 a) Comparison between OM and BSE image of tessera 13Ngr; b) and c) details of diffusion streaks; d) and e) EDS spectra acquired on green and red streaks.

In spite of the interference of the glassy matrix in the measurements, EDS spot analyses indicated that these nanometric inclusions are mainly made of copper, and XRPD analysis allowed exactly identifying the crystalline phase as metallic copper (Fig.6.33).

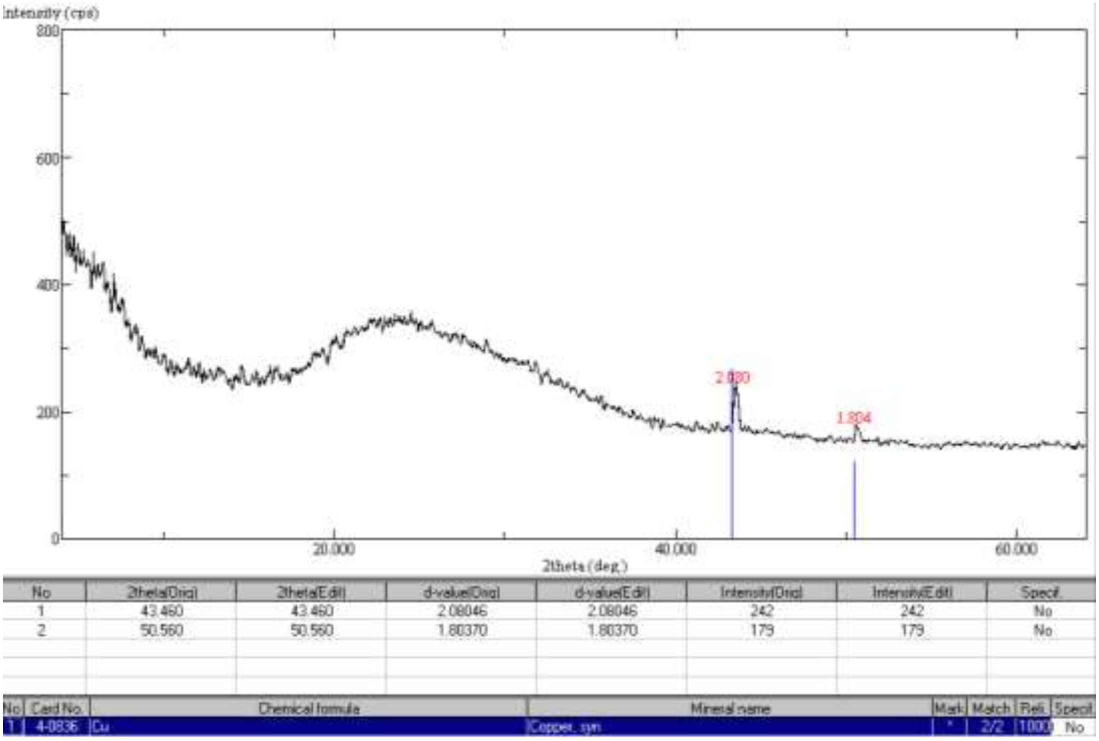


Fig.6.33 XRPD pattern of tessera 13Ngr.

Though the chemical composition of the red and green streaks is similar, slightly higher copper contents (red: 0.69 wt%; green: 0.07 wt%) can be observed in the red streaks, while the green ones have higher FeO (red: 1.35 wt%; green: 12.21 wt%). The presence of iron in relatively high concentration suggests its intentional addition, maybe to help reduce the cuprous ions to metallic copper (Barber et al. 2010; Arletti et al. 2006; Arletti, Vezzalini et al. 2011). It can, thus, be hypothesised that the chemical composition of the red and the green streaks is similar because in the latter the “pigment” has simply dissolved and the copper ion determined the green colour (Neri et al. 2017; Wypyski & Becker 2004). The comparison between compositional and micro-structural data seem to imply that this tessera was the result of a “failed” red colouration.

The apparently black colour of 13Ngr tessera is also confirmed by its RS curve (Fig.6.34), showing an entirely flat behaviour in the wavelength range 400-700 nm, with the absence of any increase of reflectance intensity.

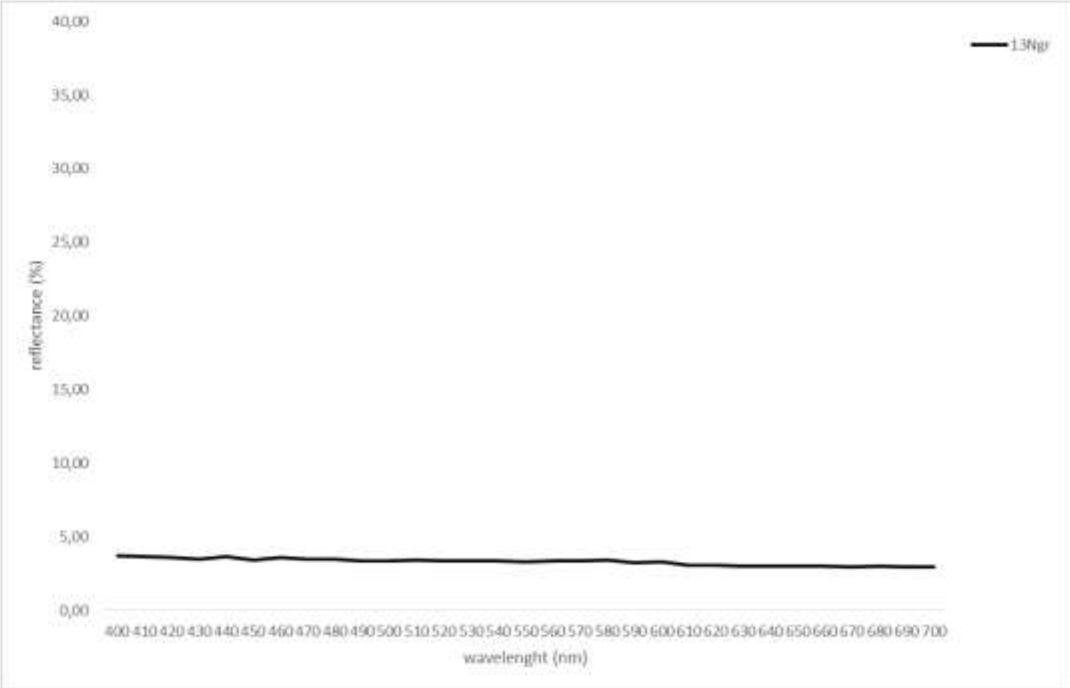


Fig.6.34 Reflectance curve acquired on tessera 13Ngr.

6.2.2b Tin-based phases

2Ba, 2Bb, 7G, 9I yellow, 1Aa, 1Ab, 3C, 5Eb, 17R, 20U green and 10L blue tesserae were opacified by means of tin-based phases, regardless the different compositional categories they belong to (Egypt I – DMSt1, Apollonia-type – DMSt2, Foy-2 – DMSt3).

All the yellow and some of the green-shaded tesserae (more exactly the yellowish green 1Aa, 1Ab and 3C) show an inhomogeneous micro-texture, the matrix being characterised by lighter bands in BSE containing higher lead than the darker areas (Fig.6.35a). Aggregates formed by the opacifying (and colouring) agent occur in different shapes and sizes. The majority show an anhedral crystalline habit with a mean size of maximum 5 μm, mainly containing lead and tin (Fig. 6.35b,c).

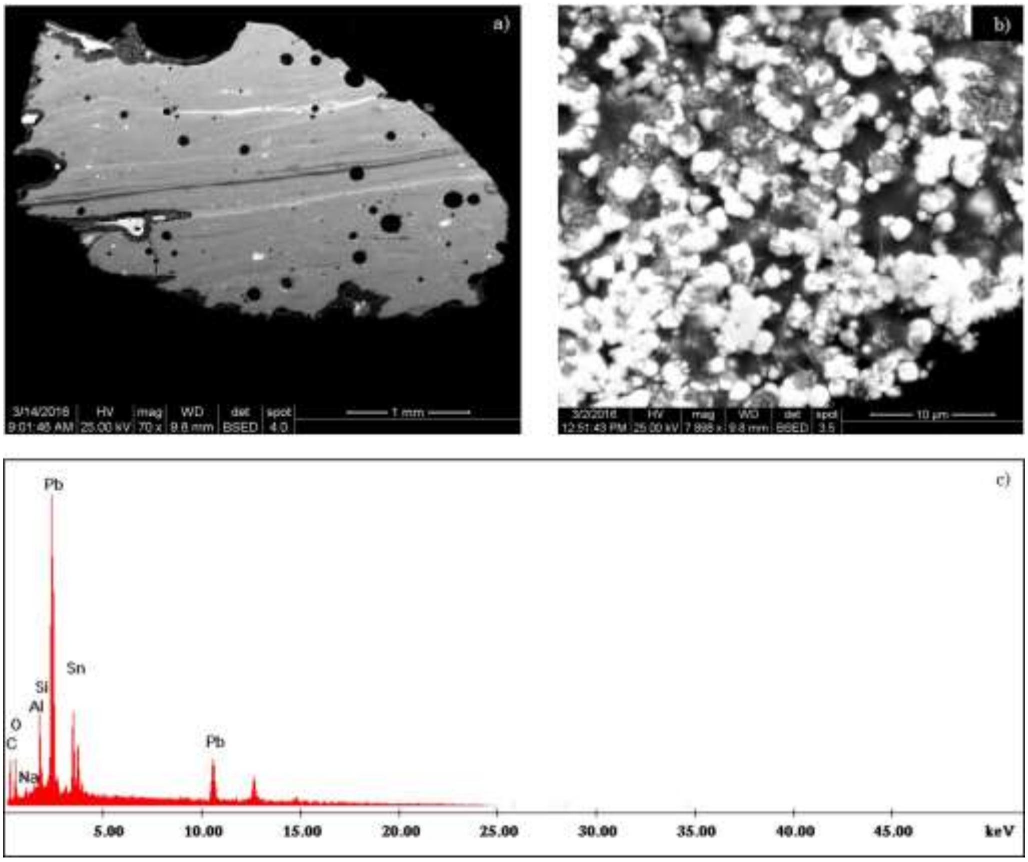


Fig.6.35 a) BSE image of G7 tessera; b) detail of anhedral lead-tin based inclusions; c) EDS spectrum collected on an anhedral inclusion.

Acicular crystals (mean thickness between 1 and 2 μm) were also detected, either forming aggregates or surrounding the anhedral phases; these acicular crystals are mainly composed of tin (Fig.6.36), though their exact chemical composition could not be measured by EDS spot analyses due to their exiguous dimensions.

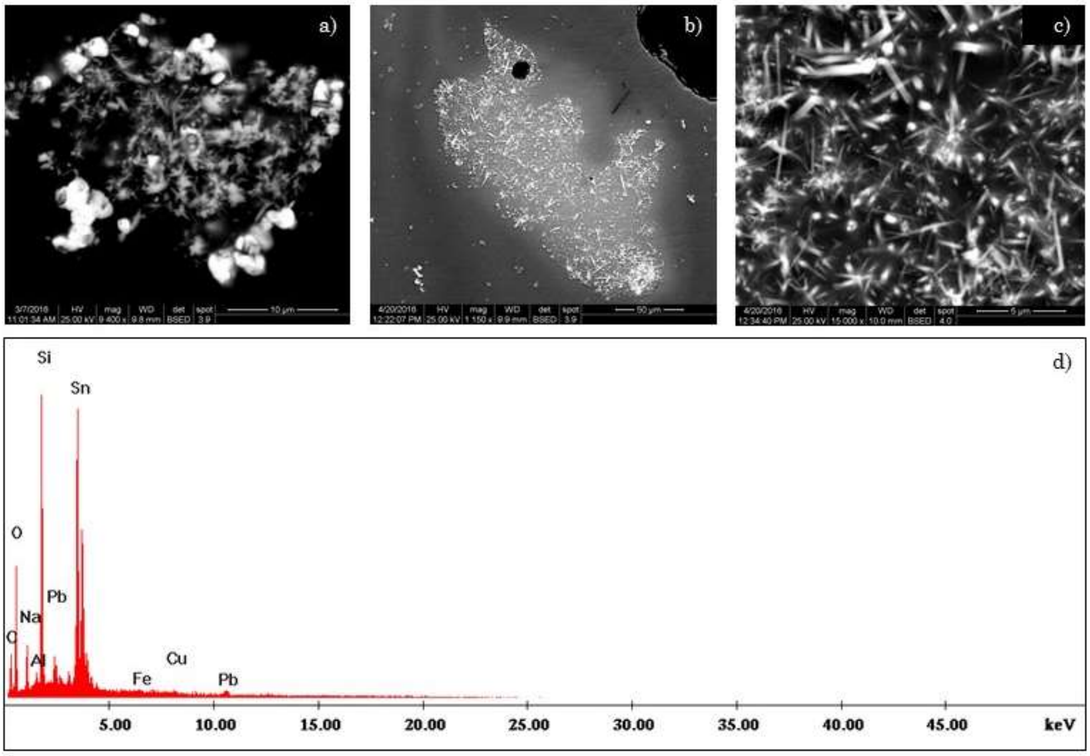


Fig.6.36 a) details of a mixed inclusion detected in 9I tessera; b) and c) details of acicular inclusions; d) EDS spectrum collected on an acicular inclusion.

SEM-EDS analyses suggest, therefore, that tin-based phases were used to opacify these tesserae.

Micro-Raman measurements performed on the anhedral crystals show bands at about 68, 138, 327 and 455 cm^{-1} (Fig.6.37), matching those reported in the literature for the so-called "Lead Tin Yellow type II" (Sefců et al. 2015; Welter et al. 2007; Zhao et al. 2013). As previously discussed, Lead Tin Yellow type II ($PbSn_{1-x}Si_xO_3$) is a lead tin silicon oxide that can show a variable stoichiometry, either $PbSnO_3$, $Pb(Sn,Si)O_3$ or $PbSn_2SiO_3$. As already occurred for the yellow and green tesserae from Khirbat al-Mafjar, it was not possible to make a direct comparison between Raman signatures of pure $PbSnO_3$ and $PbSn_{1-x}Si_xO_3$, since a spectrum of $PbSnO_3$ cannot be found in the literature.

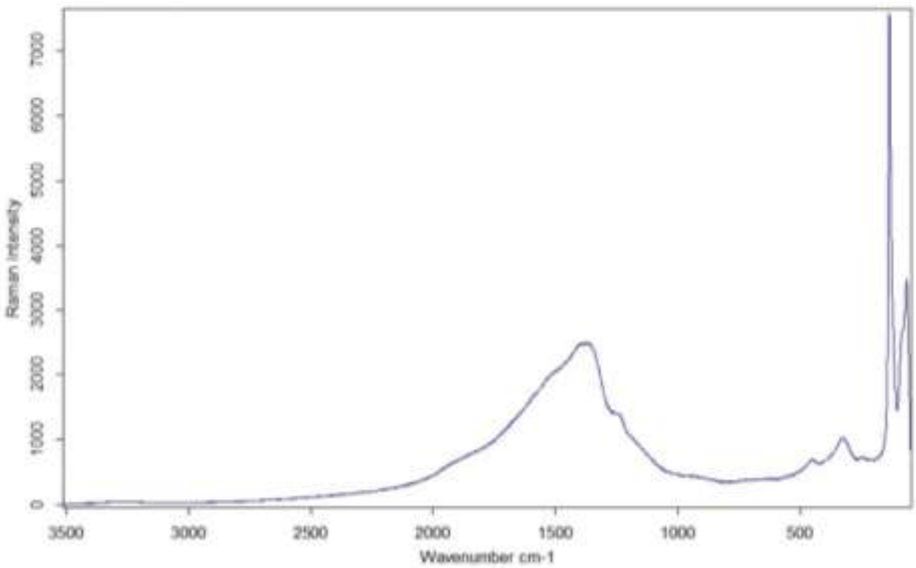


Fig.6.37 Raman spectrum collected on an anhedral inclusion (tessera 7G).

XRPD was, therefore, carried out, and the diffraction patterns seem, once again, to compare best to $PbSnO_3$ (Fig.6.38).

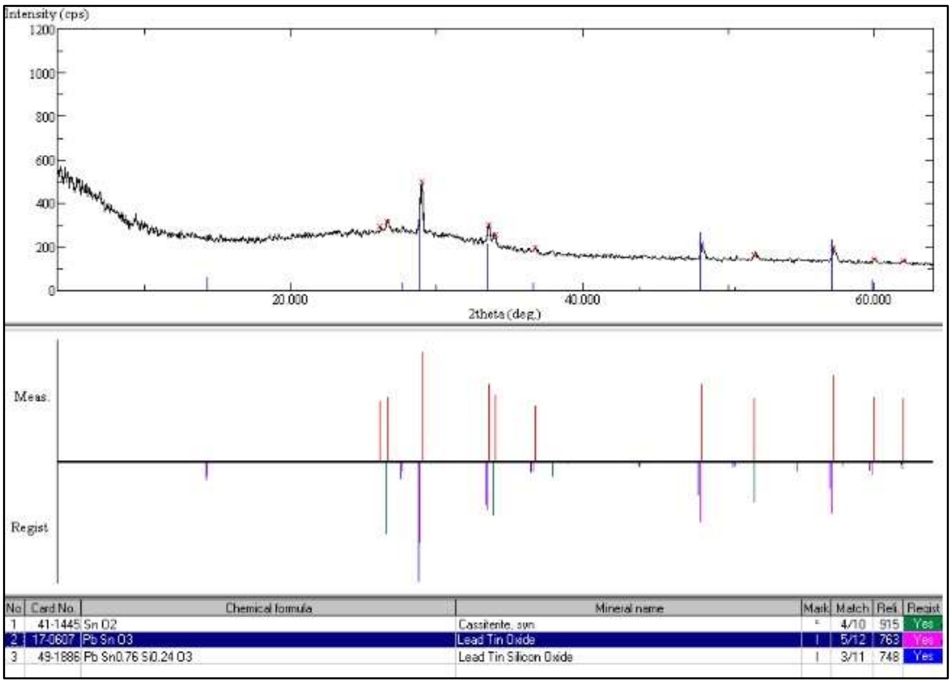


Fig.6.38 XRPD pattern of tessera 7G.

Concerning acicular-shaped crystals, Raman spectra acquired are highly affected by fluorescence, probably also due to their very exiguous dimensions (Fig.6.39). A band at about 634 cm^{-1} is always observed, being the one related to cassiterite (SnO_2). Though, a univocal characterisation cannot be stated due to the lack of the two other main bands of SnO_2: 471 and 773 cm^{-1} (Bouchard and Smith 2003; Welter et al. 2007; Zhao et al. 2013). According to the literature (Tite et al. 2008), the precipitation of crystals made of cassiterite (SnO_2) may have occurred when mixing the tin-based opacifier to the molten glass, as a result of the initial dissolution of $PbSnO_3$.

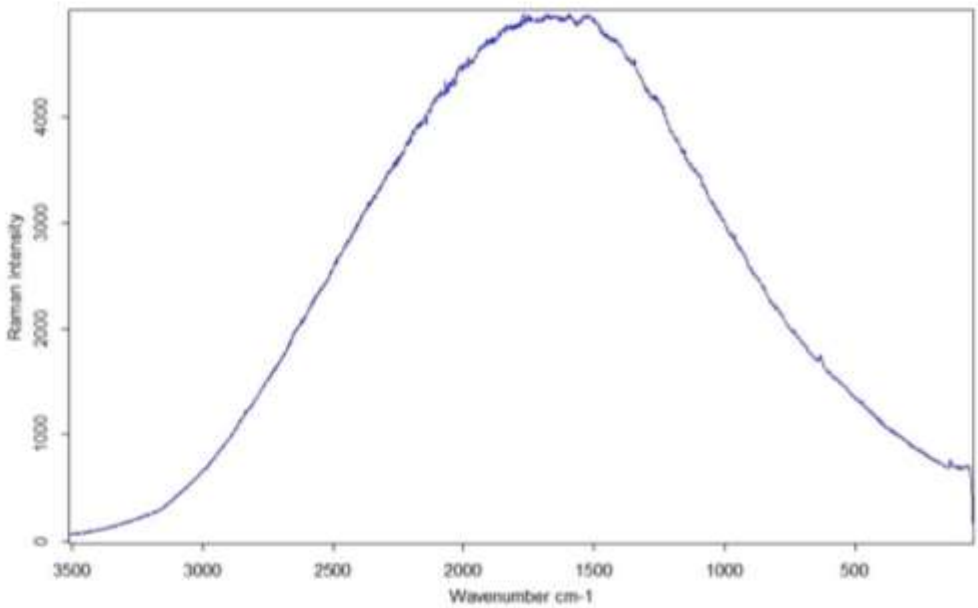


Fig.6.39 Raman spectrum collected on an acicular inclusion (tessera 7G).

5Eb, 17R and 20U green and 10L blue tesserae were opacified by using a different kind of Sn-based phase. Their micro-texture is quite homogeneous and BSE images demonstrated the presence of thick acicular-shaped crystals in the base glass, mainly made of tin (Fig.6.40).

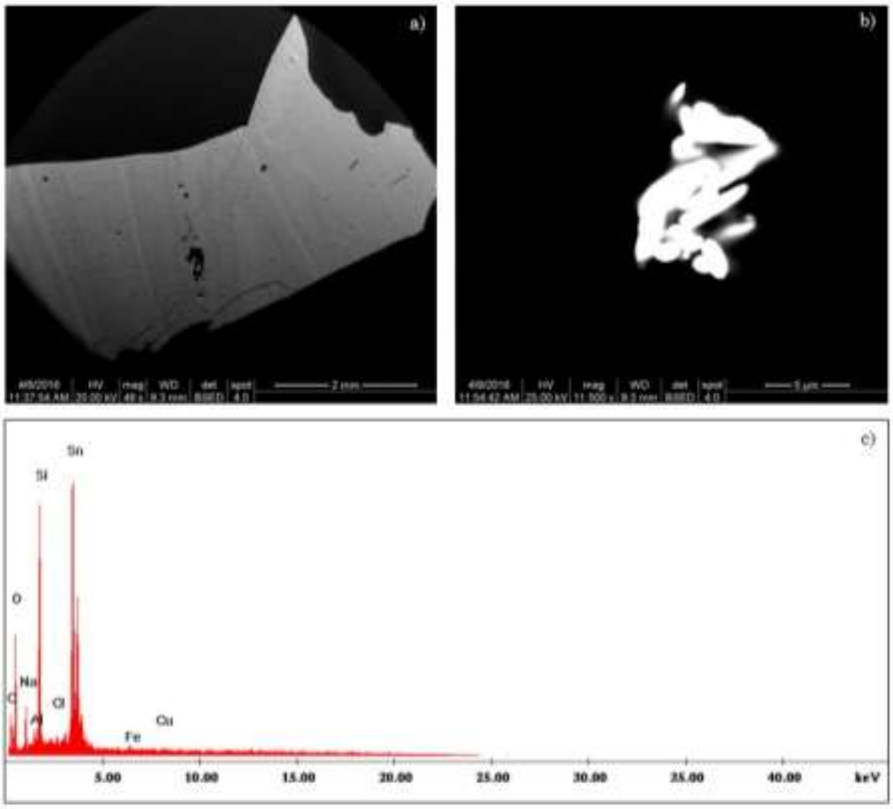


Fig.6.40 a) BSE image of tessera 10L; b) thick acicular-shaped inclusions; c) EDS spectrum collected on thick acicular-shaped inclusions.

Though they are highly affected by fluorescence, micro-Raman spectra acquired on these inclusions show a main band at about 637 cm^{-1}, consistent with SnO_2 (Fig.6.41). It is, therefore, probable that cassiterite was added to the transparent glass to act as an opacifier.

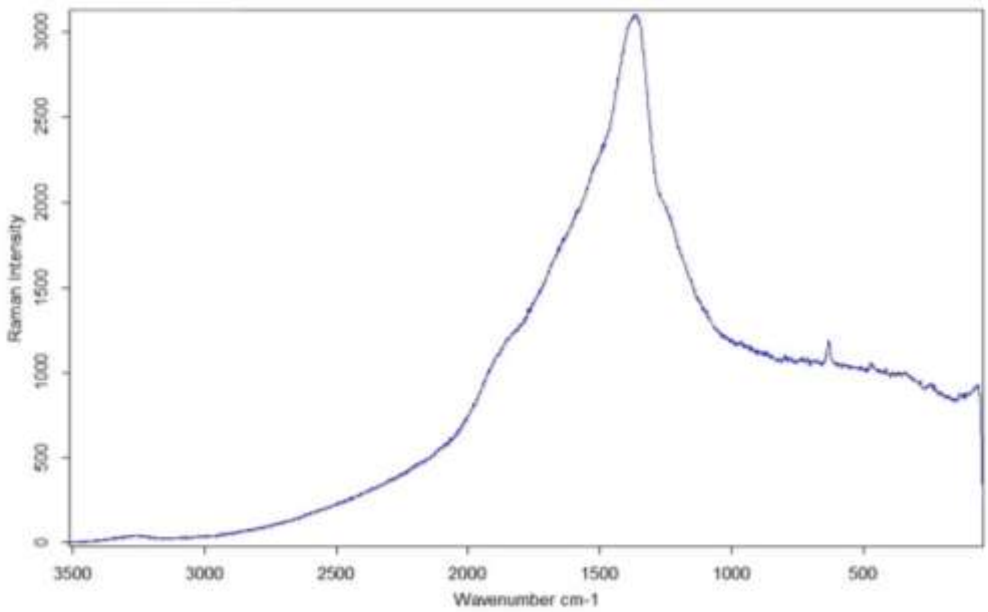


Fig.6.41 Raman spectrum collected on a thick acicular-shaped inclusion (tessera 10L).

Concerning the colours, yellow tesserae owe their hues to cubic $PbSnO_3$, also acting as opacifier; 1Aa, 1Ab and 3C tesserae are in shades of green because of the combination between the blue hue conferred by copper-based cations dispersed in the glassy matrix and the yellow colour due to Lead Tin Yellow Type II; copper is also responsible for the green shades of 5Eb, 17R and 20U tesserae.

Fig.6.42a,b shows reflectance curves acquired on green and yellow opaque tesserae by VIS-RS. It can be noticed that 1Aa, 1Ab and 3C green tesserae have a characteristic bell-shaped curve with a reflectance peak between 440 and 540 nm, consistent with the presence of copper acting as colouring agent (Galli et al. 2006; Galli et al. 2007). It can also be observed that, though copper is always responsible for the colour shades, RS curves have a slightly different morphology for tesserae 5Eb and 17R: this is possibly due to the presence of cassiterite rather than lead stannate as opacifier, responsible for a green colour more similar to turquoise. Unlike what observed for the NCS-Green tesserae from Khirbat al-Mafjar, in this case no direct correlation can be observed between copper content and reflectance.

Regarding the yellow tesserae, their curve shapes are comparable to those reported by Cloutis and co-workers for powdered Lead Tin Yellow type II pigment (Cloutis et al. 2016).

The reasons responsible for the different RS curve of green/yellow 11M tessera will be discussed in the next paragraph.

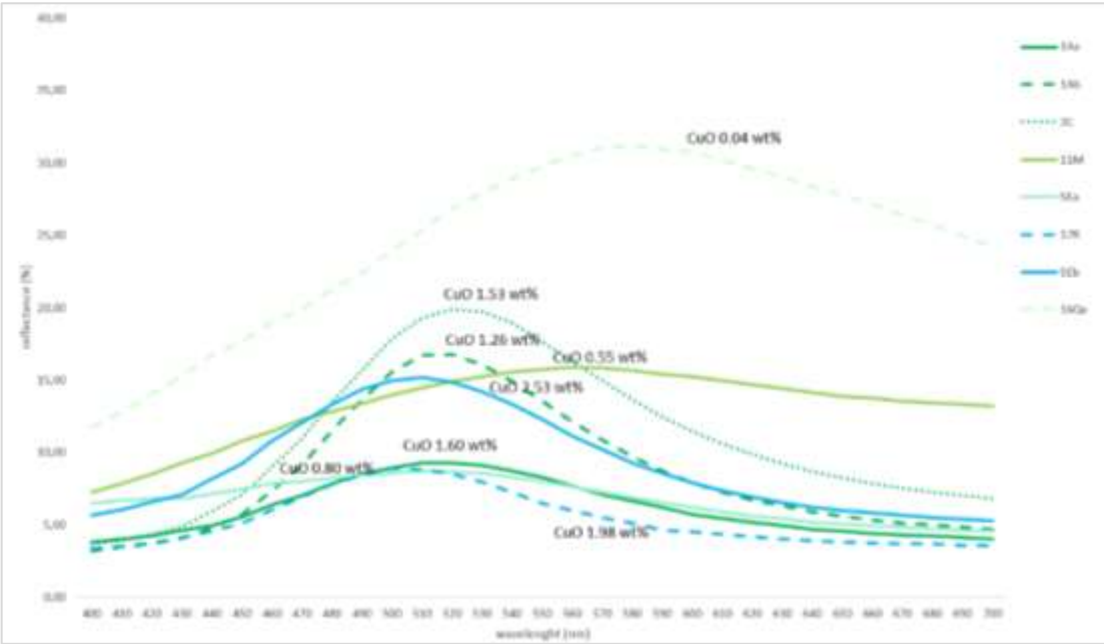


Fig.6.42a Reflectance curves acquired on opaque green and opaque blue tesserae opacified and coloured by Sn-based phases (except 11M) and copper.

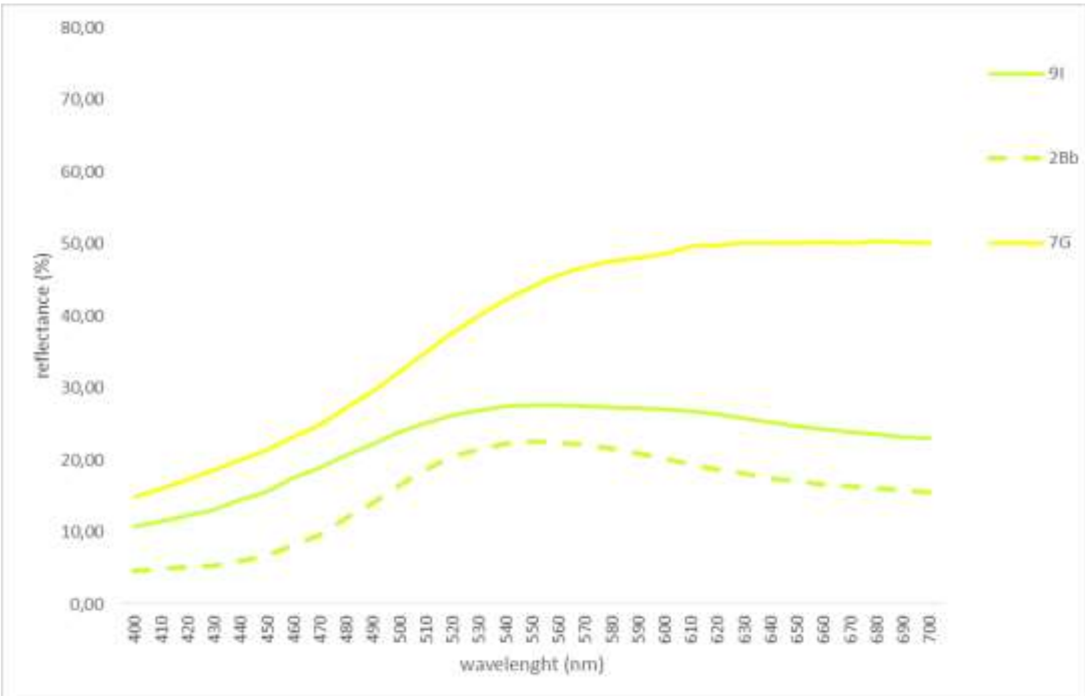


Fig.6.42b Reflectance curves acquired on opaque yellow tesserae opacified and coloured by Lead Tin Yellow type II.

6.2.2c Antimony-based phases

Antimony-based phases were detected only in 11M green tessera, matching Apollonia-type compositional category (DMSt2).

These phases (calcium antimonate, white, and lead antimonate, yellow) were used from the beginning of glass production in the Near East and Egypt around 1500 BC until the Roman period (Boschetti et al. 2016). The 4th CE has long been considered the chronological limit of this technology, replaced by tin-based materials (Tite et al. 2008). However, recent research has demonstrated a more intricate scenario, with a coexistence of both the technologies since the 1st century CE (Maltoni & Silvestri 2016; Verità et al. 2013).

BSE images show the presence of aggregates of small euhedral crystals, having dimensions ranging from 5 to 10 µm. EDS spot analyses demonstrated that these inclusions are mainly made of Sb and Pb (Fig.6.43).

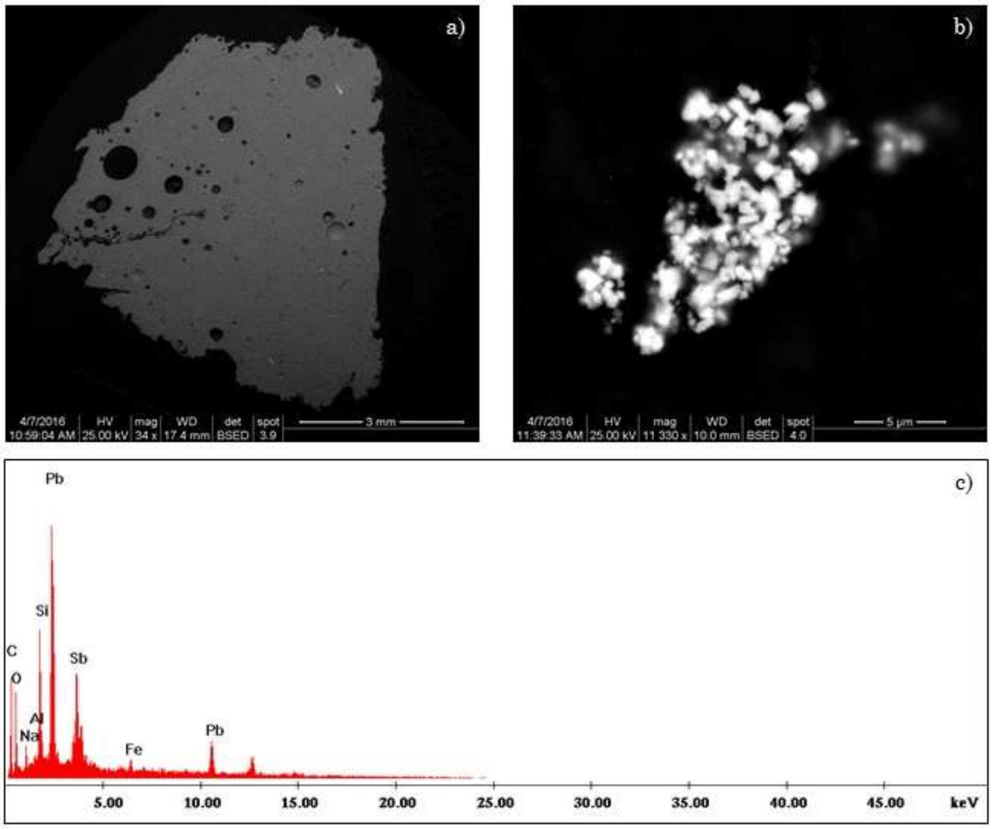


Fig.6.43 BSE images of a) 11M tessera; b) Sb-based aggregates; c) EDS spectrum acquired on euhedral inclusions.

Micro-Raman measurements determined the inclusions as lead-tin antimonate ($Pb_2Sb_{2-x}Sn_xO_{7-x/2}$) rather than lead antimonate ($Pb_2Sb_2O_7$). In addition to the peaks at 140, 335, 508 cm^{-1}, diagnostic for lead antimonate, recorded spectra also show a band between 300 and 350 cm^{-1} and a shoulder at about 450 cm^{-1} (Fig.6.44), indicative of the partial replacement of Sb^{+5} species by a larger Sn^{4+} cation (Rosi et al. 2009; Rosi et al. 2011).

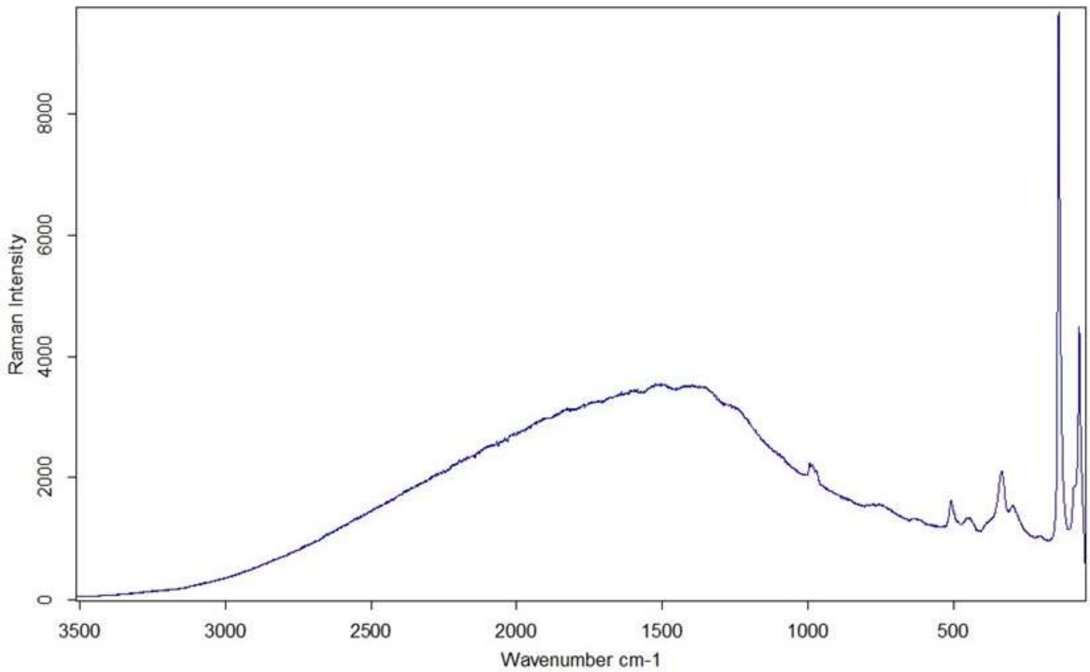


Fig.6.44 Raman spectrum acquired on euhedral Sb-based inclusions in tessera 11M.

Basso and colleagues also identified this kind of antimonate in some yellow and green Roman mosaic glass tesserae from the thermal bath of Villa dei Quintili, Rome (Basso et al. 2014). Authors hypothesised that the presence of this compound could be ascribable to the addition of a *corpo* (an opacifier-rich glass), containing yellow opacifier, to the molten glass; tin could have been unintentionally introduced in the batch from the minerals used for the preparation of the *corpo*. The hypothesis of an *ex situ* opacification is here further supported by the evidence of partial dissolution of the crystals in the glassy matrix, as well as by their euhedral morphology, explained by the precipitation of Sb-based phases upon cooling after their partial dissolution (Shortland 2002). Moreover, like the tesserae from Villa dei Quintili, tessera

11M from Damascus also show two additional bands at about 970-980cm-1, linkable to the vibration of the $(SO4)^{2-}$ unit of noselite, a mineral of the sodalite group probably being related to the raw materials used as source to obtain the lead antimonate (Basso et al. 2014).

Concerning the colour, it can be noticed that 11M tessera has a different RS curve compared to those recorded for green and yellow tesserae coloured and opacified by means of tin-based phases, with a flatter behaviour and the absence of a bell-shaped morphology (Fig.6.42a).

6.2.2d Phosphorus-based phases

Calcium phosphate was detected as opacifier in 5Ea and 16Qa green tesserae, belonging to Apollonia-type compositional category (DMSt2).
BSE images show that phosphorus-based inclusions have dimensions ranging from about 60 to 500 μm, exhibit irregular shapes and are dotted with small vacuoles. EDS data demonstrated that these inclusions are mainly composed of calcium and phosphorus (Fig.6.45).

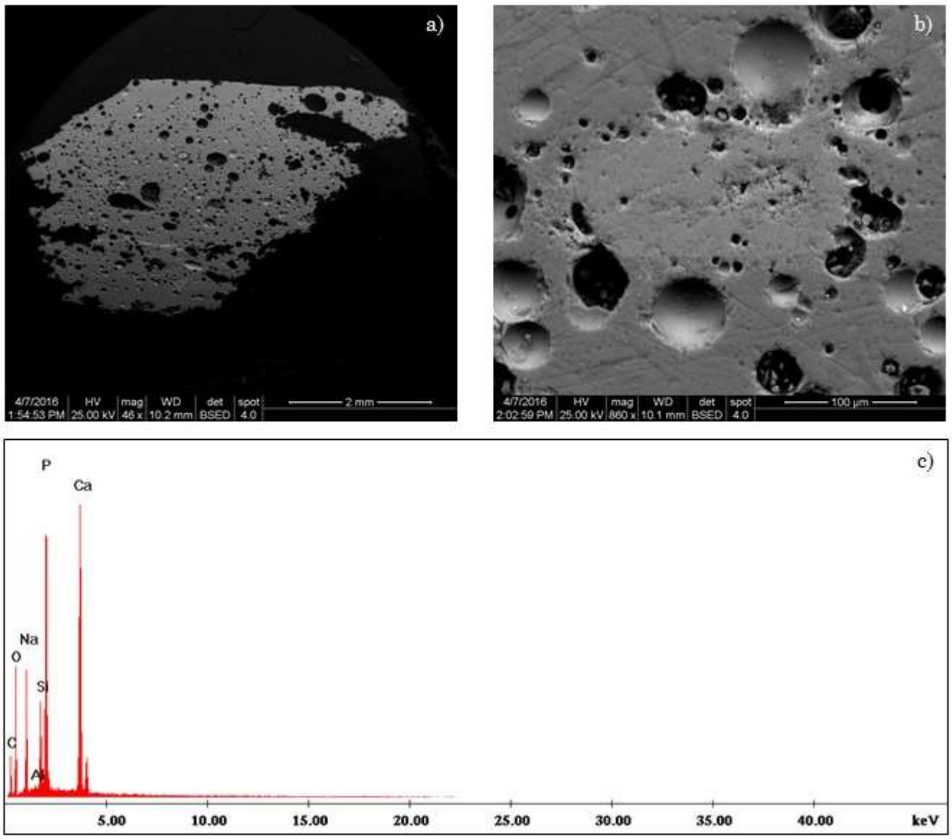


Fig.6.45 BSE images of a) 16Qa tessera; b) P-based inclusion;
c) EDS spectrum acquired on the P-based inclusion.

Micro-Raman measurements were performed to achieve a more precise characterization of the phosphorus-based opacifiers. Acquired spectra are consistent with hydroxyapatite (Penel et al. 2003), the band positions being at 1073, 1045, 1027, 962, 610. 591, 579, 448 and 430 cm^{-1}, where vibrational modes within the phosphate tetrahedra of the apatite occur (Silvestri et al. 2016) (Fig.6.46).

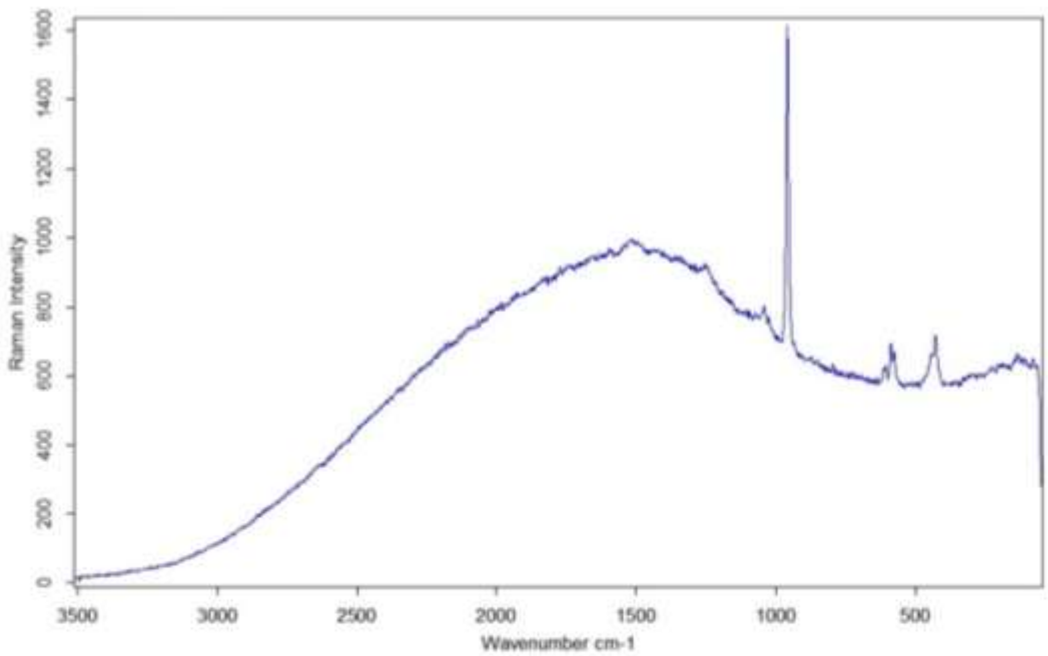


Fig.6.46 Raman spectrum acquired on a P-based inclusion in tessera 16Qa.

Glassy matrices of the tesserae opacified by calcium phosphate also show a number of gas bubbles into them, probably due to the decomposition of hydroxyapatite during the melting step and also responsible for the opacity. 5Ea tessera also contains small sporadic acicular-shaped crystals mainly made of tin, consistent with cassiterite (Fig.6.47).

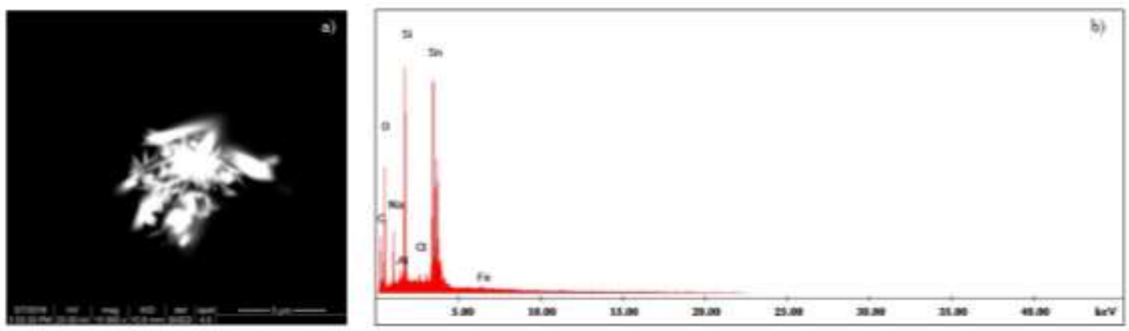


Fig.6.47 a) BSE image of acicular-shaped inclusions in tessera 5Ea;
b) EDS spectrum acquired on the inclusion.

Green tessera 5Ea shows a CuO content of 0.80 wt% and, therefore, it can be assumed that copper dispersed into the base glass is responsible for the light green hue.

RS curve of tessera 5Ea is comparable to those recorded for 17R and 5Eb tesserae, with a weak bell-shaped morphology and a reflectance peak between 440 and 540 nm (Fig.6.48). A different reflectance curve can, instead, be observed for 16Qa, with a reflectance peak at about 570-580 nm and a higher reflectance percentage compared to other tesserae. This differences can presumably be linked to compositional features, as 16Qa tessera is characterised by a PbO content of 2.33 wt%. The higher reflectance percentage can, thus, be due to the addition of lead oxide to the base glass responsible for an increase in the brilliance and, therefore, of the reflectance of the surface.

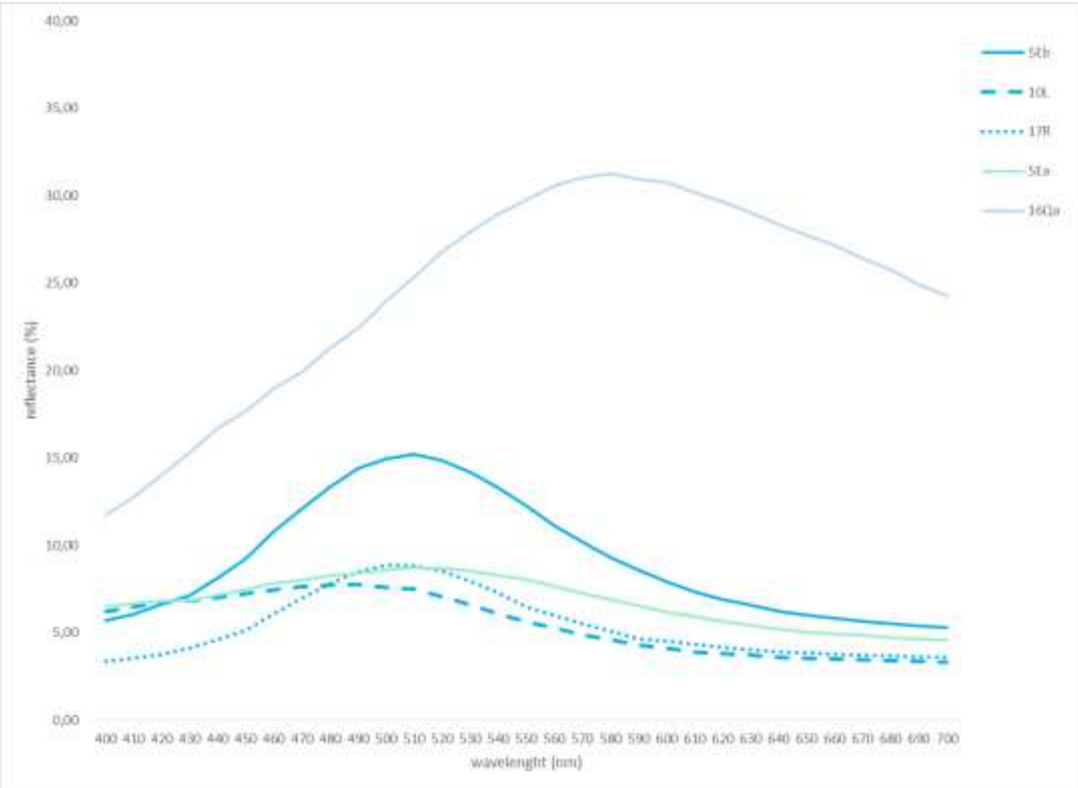


Fig.6.48 A comparison between RS curves acquired on green- and blue-shaded tesserae, all coloured by copper but opacified by means of P-based phases (16Qa), Sn-based phases (5Eb, 10L, 17R) or both (5Ea).

6.2.2e Silicon-based phases

SEM inspection of green 13Nv and yellow 14O tesserae showed the presence of thick acicular-shaped inclusions into the glassy matrix (Fig.6.49).
EDS measurements demonstrated that these inclusions are mainly made of Ca and Si; further analyses carried out by m-Raman and XRPD did not provide useful data for a more in-depth characterisation of these inclusions.

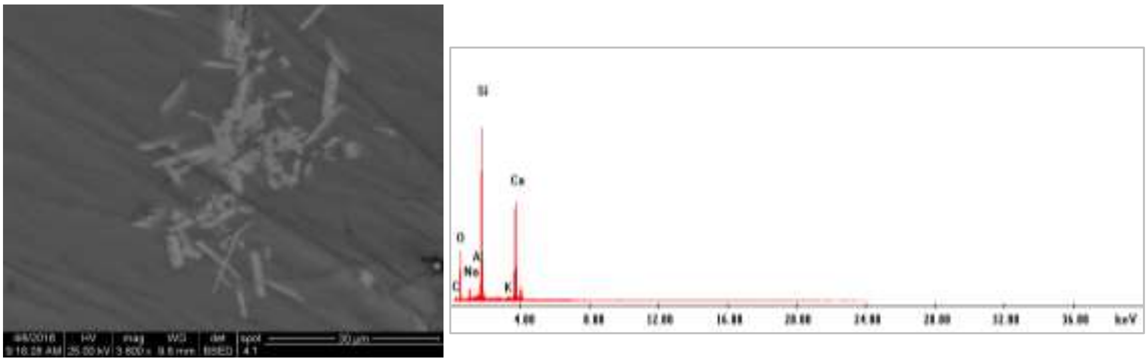
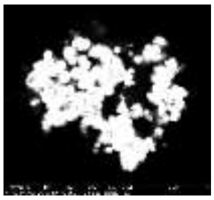
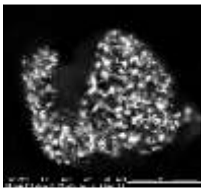
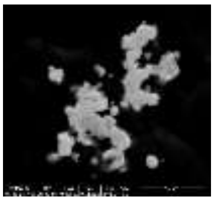
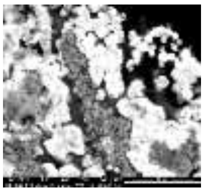
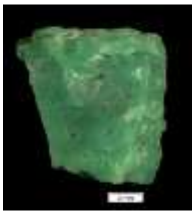
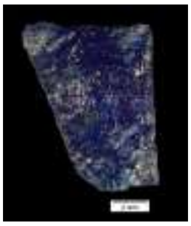


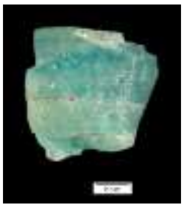
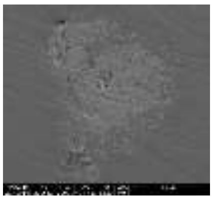
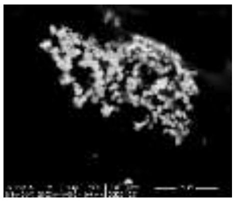
Fig.6.49 a) acicular-shaped inclusions found in tessera 14O; b) EDS spectrum acquired on the inclusion.

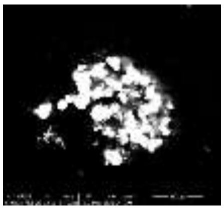
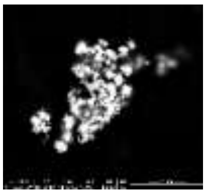
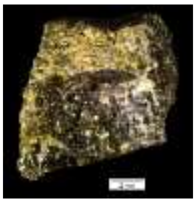
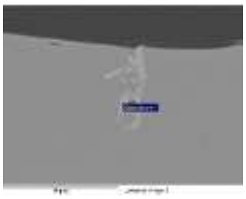
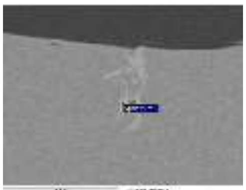
As they are mainly made of Ca and Si, it can be hypothesised that they are consistent with wollastonite ($CaSiO_3$), a by-product of the devitrification of soda-lime-silica glass, occurring at temperatures between 750 and 1200°C.
The incidence of these crystals on the opacification is still debated: Mirti and colleagues (Mirti et al. 2002) suggest that they contribute to the opacity of the glass, whilst other authors (Silvestri et al. 2012; Bonnerot et al. 2016) find this hypothesis unlikely, as the particles are quite small and have a refractory index too close to that of the glassy matrix to significantly contribute to its opacification.
As suggested by EPMA data, iron dissolved into the matrix is responsible for the green shade of tessera 13Nv. RS curve did not provide useful information, since it shows an entirely flat behaviour in the wavelength range 400-700 nm.

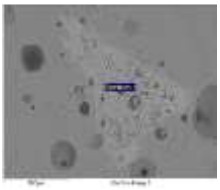
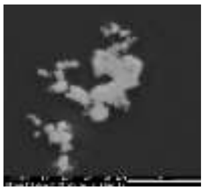
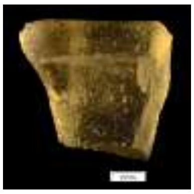
6.2.2f Translucent and transparent tesserae

Translucent blue tessera 4D was coloured by the addition of CoO (0.08 wt%). 6Fs, 18S and 19T translucent yellow tesserae respectively have MnO contents of 4.04, 0.89 and 2.55 wt%, thus indicating an intentional addition of manganese to the base glass as colouring agent. 6Fc and 15P colourless tesserae also show relatively high MnO contents, respectively being 5.21 and 1.71 wt% and, thus, acting as a decolourant.

Sample	Base glass	Colour	Opacity
 DMS_1_Aa	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 4040-G] L* | a* | b* 41.16 | -24.35 | 16.32 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DMS_1_Ab	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 4040-G] L* | a* | b* 32.98 | -12.91 | 6.49 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DMS_2_Ba	Soda-silica-lime Natron-based Compositional category Apollonia-type	Yellow [NCS S 2030-G70Y] L* | a* | b* - | - | - Lead Tin Yellow II	 Lead Tin Yellow II
 DMS_2_Bb	Soda-silica-lime Natron-based Compositional category Egypt I	Yellow [NCS S 2030-G70Y] L* | a* | b* 51.51 | -9.22 | 30.56 Lead Tin Yellow II	 Lead Tin Yellow II
 DMS_3_C	Soda-silica-lime Natron-based Compositional category Apollonia-type	Green [NCS S 3040-G20Y] L* | a* | b* 46.10 | -21.84 | 19.66 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DMS_4_D	Soda-silica-lime Natron-based Compositional category Foy-2	Blue [NCS S 7020-R80B] L* | a* | b* - | - | - Cobalt	Translucent

Sample	Base glass		Colour					Opacity
				L*	a*	b*		
 DMS_5_Ea	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Green [NCS S 5020-B90G]	33.01	-7.56	0.05	Copper	 Calcium phosphate
 DMS_5_Eb	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Green [NCS S 5020-B90G]	40.23	-17.90	4.68	Copper	 Cassiterite
 DMS_6_Fs	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Yellow [NCS S 8502-Y]	-	-	-	Manganese	Translucent
 DMS_6_Fc	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Colourless [...]	-	-	-	Manganese-decoloured	Transparent
 DMS_7_G	Soda-silica-lime Natron-based	Compositional category Foy-2	Yellow [NCS S 1020-Y]	70.78	1.72	28.34	Lead Tin Yellow II	 Lead Tin Yellow II
 DMS_8_H	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Green [NCS S 3020-B90G]	-	-	-		Translucent

Sample	Base glass	Colour	Opacity
 DMS_9_I	Soda-silica-lime Natron-based Compositional category Apollonia-type	Yellow [NCS S S3020-G70Y] L* 40.23 / a* -17.90 / b* 4.68 Lead Tin Yellow II	 Lead Tin Yellow II
 DMS_10_L	Soda-silica-lime Natron-based Compositional category Egypt I	Blue [NCS S 4050-B20G] L* - / a* - / b* - Copper	 Cassiterite
 DMS_11_M	Soda-silica-lime Natron-based Compositional category Apollonia-type	Green/Yellow [NCS S 4020-G50Y] L* 45.52 / a* -3.70 / b* 10.58 Lead Antimonate + copper	 Lead Antimonate
 DMS_13_Nv	Soda-silica-lime Natron-based Compositional category Apollonia-type	Green [NCS S 8502-G] L* 25.06 / a* -0.03 / b* 1.95 Iron	 Ca-Si based
 DMS_13_Ngr	Soda-silica-lime Natron-based Compositional category Foy-2	Black [NCS S 8502] L* 21.28 / a* -0.59 / b* -1.22 Cu nano-particles	 Cu nano-particles
 DMS_14_O	Soda-silica-lime Natron-based Compositional category Apollonia-type	Yellow [NCS S 6020-Y10R] L* 36.78 / a* 2.35 / b* 11.63 Iron (?)	 Ca-Si-based

Samples	Base glass	Compositional category	Colour	L*	a*	b*	Colour (agent)	Opacity
 DMS_15_P	Soda-silica-lime Natron-based	Compositional category Foy-2	Colourless [...]	-	-	-	Manganese-decoloured	Transparent
 DMS_16_Qa	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Green [NCS S 0907-B80G]	67.68	-1.04	12.63	Copper	 Calcium phosphate
 DMS_17_R	Soda-silica-lime Natron-based	Compositional category Egypt I	Green [NCS S 4550-B90G]	30.60	-14.56	3.44	Copper	 Cassiterite
 DMS_18_S	Soda-silica-lime Natron-based	Compositional category Foy-2	Yellow [NCS S 2030-Y]	-	-	-	Manganese	Translucent
 DMS_19_T	Soda-silica-lime Natron-based	Compositional category Apollonia-type	Yellow [NCS S 3040-Y10R]				Manganese	Translucent
 DMS_20_U	Soda-silica-lime Natron-based	Compositional category Egypt I	Green/Blue [NCS S 2050-B50G]	-	-	-	Copper	 Cassiterite

Tab.6.8 Summary of results obtained by analyses carried out on tesserae from the Great Mosque of Damascus. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

6.3 The assemblage from the Dome of the Rock

The assemblage from the Dome of the Rock (Gerusalem) comprises coloured mosaic glass tesserae, opaque, translucent and some transparent.
Samples were collected from the interior mosaic decoration of the building, still largely 7th century and, thus, Umayyad in date (see chapter 5)[64].
Detailed description and documentation of all tesserae is provided in Table 5.4.

6.3.1 Base glass

For the analysed tesserae from the Dome of the Rock, EPMA data for major and minor oxides are reported in Tab.6.9a, while LA-ICP-MS data for trace elements are shown in Tab.6.10.
EPMA compositional data were recalculated according to the method discussed in chapter 4. The subtracted oxides were CuO, SnO_2, PbO, CoO and MnO. Sb_2O_3 was not subtracted due to its negligible values (up to 0.03 wt%). Reduced compositional data are shown in Tab.6.9b.
The analysed samples can be classified as natron type glasses, being MgO and K_2O contents below 1.5 wt%, (Fig.6.50). Tesserae Am3_Au, Am5_Ag and Y1_Au are characterised by slightly higher MgO and K_2O contents (respectively ranging between 1.70 wt% and 1.72 wt% and between 0.94 wt% and 1.93 wt%), but well below the value of 2.5 wt%, unequivocally referable to the use of plant ash as flux (Lyliquist and Brill 1993).
Trace element patterns display a split of the analysed tesserae into three main groups (Fig.6.51).
The first group, from now on labelled **DRt1**, comprises samples BK3, BK4, BK5, G2, G3, G4, G5, g6, G7, GR1, GY2 and LB1. DRt1 tesserae have lower strontium and higher heavy elements contents (Ti, V, Cr, Zr, Nb, Hf) compared to others.

[64] Analysed tesserae were kindly provided by Prof. Ian Freestone during candidate's viwsiting research period at The Wolfson Ar5chaeological Science Laboratories (UCL – Institute of Archaeology).

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	CoO	CuO	SnO_2	Sb_2O_3	PbO	Total
DR-BK3	Tessera	Egypt I	DRt1	Opaque	Black	**Mean**	20.90	0.62	2.74	65.59	0.07	0.26	2.11	0.47	2.32	0.28	0.01	0.03	2.34	0.01	0.17	0.11	0.01	0.96	99.00
						StDev	0.56	0.02	0.21	0.42	0.03	0.04	0.05	0.05	0.03	0.03	0.01	0.02	0.29	0.02	0.04	0.04	0.02	0.19	
DR-BK4	Tessera	Egypt I	DRt1	Opaque	Black	**Mean**	14.70	0.44	2.16	63.56	0.10	0.19	1.54	0.40	4.39	0.10	0.00	0.02	0.41	0.01	1.96	0.77	0.01	8.80	99.56
						StDev	0.57	0.02	0.10	0.64	0.03	0.04	0.03	0.03	0.07	0.01	0.00	0.02	0.03	0.01	0.08	0.43	0.01	0.74	
DR-BK5	Tessera	Egypt I	DRt1	Opaque	Black	**Mean**	19.22	0.72	3.34	68.58	0.16	0.19	1.95	0.48	2.99	0.25	0.01	0.02	2.05	0.01	0.11	0.12	0.00	1.19	101.39
						StDev	0.29	0.02	0.15	0.71	0.04	0.04	0.05	0.09	0.10	0.02	0.01	0.02	0.18	0.01	0.05	0.03	0.01	0.15	
DR-G2	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	15.89	0.59	2.93	67.80	0.08	0.12	1.64	0.40	2.22	0.22	0.00	0.02	0.97	0.01	0.92	0.36	0.00	4.02	98.19
						StDev	0.65	0.03	0.18	2.28	0.02	0.05	0.02	0.08	0.06	0.02	0.00	0.03	0.02	0.01	0.08	0.20	0.01	1.68	
DR-G3	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	19.47	0.72	3.14	67.07	0.19	0.24	2.03	0.47	2.69	0.28	0.00	0.03	2.06	0.01	0.41	0.19	0.00	1.56	100.57
						StDev	0.21	0.03	0.06	0.53	0.03	0.08	0.08	0.04	0.08	0.02	0.00	0.02	0.26	0.01	0.05	0.05	0.00	0.12	
DR-G4	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	15.86	0.70	3.31	68.93	0.12	0.08	1.49	0.39	2.95	0.23	0.00	0.03	1.01	0.01	1.03	0.28	0.00	3.58	100.02
						StDev	0.33	0.02	0.14	0.72	0.05	0.02	0.04	0.05	0.09	0.02	0.00	0.03	0.04	0.01	0.08	0.11	0.00	0.35	
DR-G5	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	15.79	0.53	2.88	67.23	0.10	0.07	1.64	0.45	1.91	0.19	0.00	0.02	0.86	0.01	1.89	0.58	0.00	6.03	100.17
						StDev	0.34	0.01	0.10	1.64	0.03	0.03	0.03	0.04	0.04	0.02	0.00	0.02	0.03	0.01	0.08	0.22	0.00	1.78	
DR-G6	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	18.80	0.70	2.38	63.65	0.07	0.33	2.16	0.32	4.50	0.24	0.00	0.02	0.89	0.01	1.26	0.47	0.00	4.45	100.24
						StDev	0.46	0.04	0.17	0.67	0.02	0.05	0.05	0.07	0.09	0.02	0.00	0.02	0.06	0.02	0.04	0.10	0.00	0.27	
DR-G7	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	16.07	0.40	2.40	69.59	0.06	0.29	1.46	0.34	2.30	0.15	0.01	0.01	0.70	0.01	1.00	0.45	0.00	4.63	99.85
						StDev	0.45	0.03	0.11	1.60	0.04	0.04	0.04	0.05	0.11	0.02	0.01	0.01	0.04	0.01	0.03	0.21	0.00	1.29	
DR-GR1	Tessera	Egypt I	DRt1	Opaque	Green	**Mean**	17.73	0.67	3.34	68.86	0.11	0.24	1.62	0.47	2.87	0.24	0.01	0.01	1.11	0.00	0.57	0.42	0.01	2.39	100.68
						StDev	0.64	0.04	0.23	1.05	0.03	0.03	0.04	0.02	0.05	0.02	0.01	0.02	0.09	0.01	0.09	0.23	0.02	0.36	
DR-GY2	Tessera	Egypt I	DRt1	Opaque	Yellow	**Mean**	16.32	0.50	2.29	63.62	0.15	0.24	1.79	0.34	2.30	0.18	0.00	0.07	0.81	0.01	0.68	0.94	0.00	9.65	99.88
						StDev	0.39	0.02	0.13	0.37	0.04	0.04	0.05	0.05	0.04	0.02	0.00	0.03	0.05	0.02	0.05	0.10	0.00	0.23	
DR-LB1	Tessera	Egypt I	DRt1	Opaque	Blue/Green	**Mean**	18.68	0.63	3.33	70.52	0.29	0.26	1.75	0.45	2.59	0.25	0.00	0.03	1.03	0.01	0.07	0.05	0.00	0.74	100.68
						StDev	0.33	0.03	0.10	0.88	0.12	0.03	0.05	0.05	0.06	0.03	0.00	0.02	0.06	0.01	0.02	0.04	0.00	0.14	
DR-A1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Green	**Mean**	12.46	0.65	2.79	61.08	0.11	0.10	0.97	0.72	9.08	0.07	0.00	0.02	0.47	0.01	1.27	0.55	0.00	9.39	99.76
						StDev	0.42	0.02	0.12	0.64	0.04	0.05	0.02	0.10	0.09	0.02	0.00	0.01	0.03	0.01	0.02	0.10	0.00	0.43	
DR-BK2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Black	**Mean**	15.33	0.58	1.55	64.33	0.05	0.24	1.45	0.40	6.17	0.12	0.02	0.06	8.45	0.00	0.16	0.10	0.00	0.48	99.49
						StDev	3.72	0.03	0.09	2.46	0.03	0.07	0.09	0.08	0.28	0.01	0.01	0.02	1.76	0.00	0.24	0.05	0.01	0.11	
DR-R1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Red	**Mean**	14.75	0.85	3.02	67.92	0.17	0.13	1.13	0.84	9.97	0.10	0.00	0.25	1.46	0.01	0.44	0.07	0.00	0.07	101.18
						StDev	0.36	0.03	0.12	1.33	0.04	0.03	0.04	0.08	0.24	0.01	0.00	0.06	0.95	0.01	0.47	0.09	0.01	0.08	
DR-T2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	**Mean**	14.16	0.71	2.83	68.45	0.15	0.10	1.21	0.76	9.57	0.09	0.00	0.05	0.46	0.01	1.80	0.25	0.00	0.34	100.95
						StDev	0.27	0.01	0.14	0.71	0.02	0.03	0.02	0.06	0.07	0.02	0.00	0.03	0.02	0.01	0.06	0.05	0.01	0.16	
DR-T3	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	**Mean**	16.04	0.82	2.96	66.94	0.39	0.21	1.22	0.87	9.73	0.11	0.00	0.31	0.74	0.01	1.02	0.06	0.01	0.13	101.56
						StDev	0.34	0.02	0.11	0.64	0.11	0.02	0.06	0.09	0.06	0.02	0.00	0.06	0.06	0.01	0.04	0.03	0.03	0.09	
DR-T4	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	**Mean**	14.62	0.73	3.06	70.52	0.10	0.12	1.38	0.82	8.22	0.09	0.00	0.02	0.41	0.00	0.62	0.03	0.01	0.11	100.85
						StDev	0.26	0.03	0.12	0.90	0.03	0.04	0.06	0.09	0.10	0.02	0.00	0.02	0.07	0.01	0.30	0.04	0.01	0.09	
DR-B1	Tessera	Foy-2	DRt3	Opaque	Blue	**Mean**	18.91	0.90	2.11	65.99	0.12	0.44	1.22	0.59	7.41	0.15	0.00	1.37	1.26	0.08	0.06	0.03	0.00	0.16	100.79
						StDev	0.42	0.03	0.15	0.58	0.05	0.05	0.03	0.06	0.05	0.02	0.00	0.06	0.04	0.03	0.02	0.02	0.01	0.07	
DR-GY1	Tessera	Foy-2	DRt3	Opaque	Yellow	**Mean**	16.51	0.65	1.89	65.49	0.21	0.26	1.57	0.43	4.98	0.15	0.00	0.10	0.60	0.00	0.70	0.62	0.00	5.57	99.72
						StDev	0.28	0.03	0.12	0.52	0.03	0.03	0.03	0.07	0.08	0.01	0.00	0.03	0.04	0.01	0.04	0.12	0.00	0.36	
DR-R2	Tessera	Foy-2	DRt3	Opaque	Red	**Mean**	17.13	1.12	2.18	61.39	0.34	0.37	1.03	0.76	8.91	0.11	0.02	1.35	4.17	0.00	1.99	0.19	0.00	0.62	101.69
						StDev	0.27	0.02	0.06	0.66	0.05	0.05	0.05	0.10	0.07	0.01	0.01	0.04	0.10	0.01	1.03	0.04	0.01	0.14	
DR-T1	Tessera	Foy-2	DRt3	Opaque	Blue	**Mean**	20.74	0.83	1.74	65.38	0.31	0.24	2.45	0.25	7.11	0.15	0.01	0.06	0.59	0.01	1.18	0.06	0.01	0.17	101.27
						StDev	0.62	0.03	0.11	0.73	0.04	0.04	0.05	0.03	0.03	0.01	0.01	0.02	0.03	0.01	0.06	0.02	0.01	0.09	
DR-Am1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	18.89	1.31	2.34	65.24	0.07	0.33	1.34	0.63	9.10	0.13	0.00	1.62	0.88	0.01	0.01	0.01	0.04	0.02	101.95
						StDev	0.51	0.02	0.10	0.58	0.06	0.04	0.03	0.05	0.05	0.02	0.00	0.02	0.04	0.02	0.01	0.02	0.02	0.04	
DR-Am2-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	18.89	1.29	2.45	64.63	0.11	0.27	1.50	0.66	8.89	0.16	0.00	1.94	0.88	0.01	0.01	0.02	0.01	0.01	101.73
						StDev	0.43	0.05	0.11	0.77	0.03	0.03	0.03	0.07	0.10	0.01	0.00	0.08	0.04	0.01	0.02	0.02	0.02	0.02	
DR-Am3-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	17.80	1.56	2.27	65.49	0.21	0.37	1.12	1.05	8.82	0.15	0.00	2.43	0.82	0.01	0.02	0.01	0.00	0.01	102.13
						StDev	0.26	0.03	0.09	0.46	0.01	0.05	0.04	0.12	0.14	0.02	0.00	0.08	0.04	0.01	0.01	0.02	0.01	0.02	
DR-Am4-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	19.40	1.06	2.18	66.18	0.04	0.32	1.41	0.46	7.61	0.12	0.01	1.80	0.70	0.00	0.02	0.02	0.01	0.00	101.34
						StDev	0.31	0.02	0.15	0.35	0.03	0.04	0.03	0.09	0.10	0.02	0.01	0.09	0.05	0.00	0.02	0.03	0.01	0.01	
DR-Am5-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	17.52	1.70	2.73	64.47	0.20	0.37	1.09	0.94	9.90	0.18	0.00	2.15	1.12	0.02	0.01	0.01	0.01	0.05	102.48
						StDev	0.41	0.04	0.07	0.61	0.04	0.02	0.03	0.03	0.06	0.02	0.00	0.04	0.06	0.02	0.01	0.01	0.03	0.04	
DR-Am6-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	17.47	1.22	2.39	65.69	0.10	0.42	1.06	0.67	9.90	0.17	0.00	1.73	0.86	0.01	0.02	0.01	0.02	0.02	101.76
						StDev	0.25	0.04	0.12	0.71	0.03	0.05	0.04	0.06	0.07	0.02	0.00	0.06	0.05	0.01	0.02	0.01	0.01	0.03	
DR-Y1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	**Mean**	15.04	1.72	3.71	67.90	0.39	0.06	1.63	1.93	6.67	0.29	0.00	1.60	1.51	0.01	0.01	0.01	0.01	0.03	102.53
						StDev	0.50	0.05	0.15	0.72	0.05	0.02	0.05	0.07	0.09	0.02	0.00	0.05	0.06	0.01	0.03	0.01	0.01	0.05	
DR-G1-Au	Tessera	outlier		Translucent	Green	**Mean**	11.18	0.06	0.91	58.34	0.00	0.10	0.06	0.90	4.96	0.03	2.19	0.07	1.87	0.02	1.16	0.02	0.21	14.82	96.91
						StDev	0.34	0.02	0.10	0.48	0.00	0.03	0.02	0.11	0.09	0.02	0.08	0.03	0.05	0.02	0.04	0.03	0.02	0.53	
DR-BK1	Tessera	outlier		Opaque	Black	**Mean**	16.74	0.89	1.57	69.54	0.18	0.20	1.49	0.60	6.39	0.14	0.00	1.06	0.88	0.00	0.56	0.10	0.02	0.52	100.87
						StDev	0.27	0.03	0.18	0.75	0.02	0.06	0.04	0.07	0.08	0.01	0.00	0.07	0.05	0.00	0.04	0.03	0.02	0.09	

Tab.6.9a Chemical compositions of the glassy matrices of tesserae, obtained by EMPA.
All data are expressed as percentage concentrations of element oxides.

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	FeO	Sb_2O_3
DR-BK3	Tessera	Egypt I	DRt1	Opaque	Black	Mean	21.39	0.64	2.81	67.11	0.07	0.27	2.16	0.48	2.37	0.28	0.01	2.39	0.01
DR-BK4	Tessera	Egypt I	DRt1	Opaque	Black	Mean	16.71	0.50	2.45	72.23	0.12	0.21	1.75	0.46	4.98	0.12	0.00	0.46	0.01
DR-BK5	Tessera	Egypt I	DRt1	Opaque	Black	Mean	19.23	0.72	3.34	68.61	0.16	0.19	1.96	0.48	3.00	0.25	0.01	2.05	0.00
DR-G2	Tessera	Egypt I	DRt1	Opaque	Green	Mean	17.11	0.64	3.15	73.01	0.09	0.13	1.77	0.43	2.39	0.23	0.00	1.05	0.00
DR-G3	Tessera	Egypt I	DRt1	Opaque	Green	Mean	19.80	0.73	3.19	68.19	0.19	0.24	2.07	0.48	2.74	0.28	0.00	2.10	0.00
DR-G4	Tessera	Egypt I	DRt1	Opaque	Green	Mean	16.69	0.73	3.48	72.50	0.12	0.08	1.57	0.41	3.11	0.24	0.00	1.07	0.00
DR-G5	Tessera	Egypt I	DRt1	Opaque	Green	Mean	17.23	0.58	3.14	73.35	0.11	0.07	1.79	0.49	2.09	0.21	0.00	0.93	0.00
DR-G6	Tessera	Egypt I	DRt1	Opaque	Green	Mean	19.99	0.74	2.53	67.69	0.07	0.35	2.29	0.34	4.78	0.26	0.00	0.95	0.00
DR-G7	Tessera	Egypt I	DRt1	Opaque	Green	Mean	17.14	0.43	2.56	74.22	0.06	0.31	1.55	0.36	2.46	0.15	0.01	0.75	0.00
DR-GR1	Tessera	Egypt I	DRt1	Opaque	Green	Mean	18.22	0.69	3.43	70.78	0.11	0.25	1.67	0.49	2.95	0.24	0.01	1.14	0.01
DR-GY2	Tessera	Egypt I	DRt1	Opaque	Yellow	Mean	18.44	0.56	2.58	71.87	0.17	0.27	2.02	0.38	2.60	0.20	0.00	0.91	0.00
DR-LB1	Tessera	Egypt I	DRt1	Opaque	Blue/Green	Mean	18.72	0.63	3.34	70.68	0.29	0.26	1.75	0.45	2.60	0.25	0.00	1.03	0.00
DR-A1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Green	Mean	14.08	0.74	3.15	69.01	0.12	0.12	1.10	0.82	10.26	0.08	0.00	0.53	0.00
DR-BK2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Black	Mean	15.53	0.58	1.57	65.19	0.05	0.25	1.47	0.41	6.25	0.12	0.02	8.57	0.00
DR-R1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Red	Mean	14.70	0.85	3.01	67.68	0.17	0.13	1.13	0.83	9.94	0.10	0.00	1.45	0.00
DR-T2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	14.37	0.72	2.88	69.49	0.16	0.10	1.23	0.78	9.72	0.09	0.00	0.47	0.00
DR-T3	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	16.04	0.82	2.96	66.92	0.39	0.21	1.22	0.87	9.73	0.11	0.00	0.74	0.01
DR-T4	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	14.61	0.73	3.06	70.47	0.10	0.12	1.38	0.81	8.22	0.09	0.00	0.41	0.01
DR-B1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	19.08	0.91	2.13	66.59	0.12	0.44	1.23	0.59	7.47	0.15	0.00	1.27	0.00
DR-GY1	Tessera	Foy-2	DRt3	Opaque	Yellow	Mean	17.80	0.70	2.03	70.62	0.23	0.28	1.69	0.46	5.37	0.16	0.00	0.65	0.00
DR-R2	Tessera	Foy-2	DRt3	Opaque	Red	Mean	17.57	1.15	2.23	62.95	0.35	0.38	1.05	0.78	9.14	0.11	0.02	4.27	0.00
DR-T1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	20.79	0.83	1.75	65.52	0.31	0.24	2.46	0.25	7.12	0.15	0.01	0.59	0.01
DR-BK1	Tessera	outlier		Opaque	Black	Mean	16.97	0.90	1.59	70.50	0.19	0.20	1.51	0.61	6.48	0.14	0.00	0.89	0.02

Tab.6.9b Reduced percentage concentrations of element oxides detected by EMPA, calculated for the opaque tesserae

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Sn	Sb	Ba	La
DR-BK3	Tessera	Egypt I	DRt1	Opaque	Black	Mean	3.42	1522.33	16.28	28.24	3.95	8.80	1209.67	104.03	5.11	4.61	111.40	5.31	81.93	2.61	641.23	7.16	152.58	6.46
DR-BK4	Tessera	Egypt I	DRt1	Opaque	Black	Mean	3.84	1402.67	16.40	28.65	4.01	11.62	2970.17	367.75	5.72	4.88	141.32	4.89	72.73	2.37	1064.50	13.03	161.38	6.09
DR-BK5	Tessera	Egypt I	DRt1	Opaque	Black	Mean	3.81	1444.00	18.36	31.49	4.07	9.21	1499.35	134.14	6.55	5.59	172.22	5.36	80.51	2.53	811.93	9.90	180.38	6.59
DR-G2	Tessera	Egypt I	DRt1	Opaque	Green	Mean	4.45	1200.33	17.21	27.61	4.04	11.95	5909.00	298.17	5.89	5.28	116.47	4.96	73.73	2.17	3080.83	23.47	149.23	6.09
DR-G3	Tessera	Egypt I	DRt1	Opaque	Green	Mean	2.97	572.90	6.61	12.61	2.47	14.56	13575	776.10	4.45	4.85	313.45	3.69	44.05	1.24	9353.67	40.15	136.58	4.44
DR-G4	Tessera	Egypt I	DRt1	Opaque	Green	Mean	4.04	1271.17	15.64	30.09	4.11	14.67	7768.50	231.80	6.09	5.20	162.80	4.97	65.17	2.25	2882.00	10.29	174.17	6.03
DR-G5	Tessera	Egypt I	DRt1	Opaque	Green	Mean	3.24	1055.83	13.03	23.55	4.39	10.97	13418.3	101.87	5.17	5.13	112.82	4.64	57.93	1.97	2814.50	16.91	156.80	6.04
DR-G6	Tessera	Egypt I	DRt1	Opaque	Green	Mean	3.31	1332.67	15.31	28.83	2.90	9.15	10034.2	85.09	4.43	3.91	279.47	4.93	69.20	2.25	3223.50	23.95	126.90	5.72
DR-G7	Tessera	Egypt I	DRt1	Opaque	Green	Mean	2.69	768.80	10.25	16.12	3.10	14.19	7292.17	596.77	4.50	3.81	89.12	3.87	47.78	1.59	3957.17	50.67	121.40	5.25
DR-GR1	Tessera	Egypt I	DRt1	Opaque	Green	Mean	4.34	1349.83	17.22	31.01	3.85	9.58	2297.50	137.62	6.39	5.47	159.83	5.45	98.12	2.45	587.05	18.75	169.17	6.65
DR-GY2	Tessera	Egypt I	DRt1	Opaque	Yellow	Mean	3.55	1004.27	12.31	21.67	3.62	10.56	4733.17	226.15	4.88	4.18	122.83	4.39	76.46	1.93	11668.7	65.62	137.40	5.34
DR-LB1	Tessera	Egypt I	DRt1	Opaque	Blue/Green	Mean	3.72	1390.00	14.78	30.08	3.48	7.39	430.75	33.57	6.01	5.50	139.77	5.32	90.02	2.41	496.67	7.89	181.82	6.80
DR-A1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Green	Mean	3.53	470.55	9.68	13.91	3.91	38.88	9270.83	10.69	7.04	9.92	414.45	5.79	42.16	1.71	7120.17	18.57	207.18	6.27
DR-BK2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Black	Mean	2.23	703.93	7.58	14.89	2.64	5.14	827.53	48.33	3.11	3.42	446.95	3.68	57.29	1.38	1229.67	6.95	80.60	4.05
DR-R1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Red	Mean	2.48	585.45	13.64	19.03	10.43	25.61	4736.00	339.53	7.09	9.86	497.95	5.96	45.18	1.61	1170.18	19.80	243.48	6.58
DR-T2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	2.26	437.82	8.21	21.12	3.96	48.27	13775	337.13	6.48	8.82	429.20	5.64	34.99	1.20	1742.33	10.33	223.88	5.94
DR-T3	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	2.51	464.92	8.41	12.22	2.68	14.08	9841.50	18.41	6.91	10.06	693.37	5.90	33.86	1.30	667.05	9.88	257.28	6.56
DR-T4	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	2.18	438.25	6.61	11.77	1.83	12.00	7060.00	24.03	6.35	10.34	452.67	5.81	34.18	1.27	581.80	4.26	240.23	6.20
DR-B1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	3.75	787.73	26.16	17.35	558.93	27.92	376.72	34.40	9.09	7.25	522.28	6.02	73.28	1.96	125.88	37.19	307.93	6.73
DR-GY1	Tessera	Foy-2	DRt3	Opaque	Yellow	Mean	2.98	743.33	9.01	15.65	3.18	8.86	4252.33	214.00	3.97	3.72	354.43	3.82	50.13	1.48	5970.83	35.80	123.93	4.64
DR-R2	Tessera	Foy-2	DRt3	Opaque	Red	Mean	3.45	730.03	30.62	31.39	18.64	43.21	15950	1540.83	8.67	7.28	580.82	6.03	66.30	1.87	1287.00	87.36	328.50	6.82
DR-T1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	2.54	861.15	9.72	15.91	7.36	11.81	8525.17	281.77	3.85	2.99	472.50	5.02	51.21	1.67	505.48	18.44	131.38	5.65
DR-Am1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	3.20	816.75	26.49	16.82	6.75	9.95	53.93	20.04	7.58	6.37	681.93	6.41	71.85	2.21	6.74	113.00	275.68	7.24
DR-Am2-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	1.88	238.58	5.35	618.38	11.84	250.73	9572.83	3789.33	3.04	2.45	24.59	2.29	26.39	0.86	70.70	1798.17	113.18	2.10
DR-Am3-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	2.72	865.85	24.80	17.23	5.84	8.93	43.78	18.36	7.12	7.04	715.35	6.37	74.59	2.36	6.01	240.33	265.97	7.42
DR-Am4-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	2.69	831.90	29.22	16.98	6.21	19.54	52.10	28.59	7.29	6.41	811.67	5.93	68.88	2.18	5.05	20.31	283.93	7.00
DR-Am5-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	2.48	652.25	23.42	14.49	4.36	7.03	37.84	13.61	7.59	4.98	586.67	5.38	53.77	1.70	1.41	2.74	318.00	6.20
DR-Am6-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	3.13	1064.00	31.57	20.36	8.07	17.50	69.92	32.66	8.53	6.64	943.30	6.84	83.86	2.83	8.44	43.94	322.70	8.29
DR-Y1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	4.55	1630.33	25.07	28.08	26.09	14.98	80.50	43.65	8.70	8.71	470.22	6.09	95.19	3.87	3.20	5.98	265.70	8.30
DR-G1-Au	Tessera	outlier		Translucent	Green	Mean	1.85	215.60	5.05	529.25	10.72	226.75	8519.17	3296.83	2.87	2.28	21.93	2.18	24.45	0.86	64.97	1632.17	100.65	1.93
DR-BK1	Tessera	outlier		Opaque	Black	Mean	2.73	784.75	13.07	15.64	4.21	10.64	4293.83	180.25	3.77	3.91	459.37	4.87	55.95	1.54	602.32	11.06	129.58	7.12

Tab.6.10 Trace element composition of the analysed samples obtained by LA-ICP-MS. All data are expressed in ppm.

Sample	Typology	Compositional category	Group	Opacity	Colour	Value	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
DR-BK3	Tessera	Egypt I	DRt1	Opaque	Black	Mean	11.18	1.31	6.74	1.43	0.34	1.20	0.17	1.01	0.20	0.58	0.08	0.64	0.09	2.09	0.18	6438.17	0.92	0.68
DR-BK4	Tessera	Egypt I	DRt1	Opaque	Black	Mean	10.81	1.27	6.40	1.35	0.34	1.14	0.16	0.96	0.19	0.55	0.08	0.57	0.08	1.89	0.17	11580	0.85	0.72
DR-BK5	Tessera	Egypt I	DRt1	Opaque	Black	Mean	11.67	1.36	6.88	1.47	0.37	1.23	0.17	1.08	0.21	0.60	0.08	0.66	0.09	2.11	0.18	8650.33	0.90	0.80
DR-G2	Tessera	Egypt I	DRt1	Opaque	Green	Mean	10.60	1.25	6.31	1.36	0.34	1.13	0.16	1.02	0.19	0.55	0.08	0.59	0.08	1.85	0.16	22732	0.82	0.70
DR-G3	Tessera	Egypt I	DRt1	Opaque	Green	Mean	7.49	0.89	4.45	0.94	0.23	0.80	0.11	0.68	0.14	0.40	0.06	0.42	0.06	1.20	0.09	72556.7	0.60	0.72
DR-G4	Tessera	Egypt I	DRt1	Opaque	Green	Mean	10.53	1.25	6.32	1.38	0.35	1.14	0.16	0.96	0.19	0.55	0.08	0.59	0.08	1.69	0.16	32685	0.82	0.97
DR-G5	Tessera	Egypt I	DRt1	Opaque	Green	Mean	10.50	1.23	6.22	1.32	0.33	1.11	0.15	0.90	0.18	0.52	0.07	0.53	0.07	1.54	0.14	21868.3	0.76	0.66
DR-G6	Tessera	Egypt I	DRt1	Opaque	Green	Mean	9.71	1.17	5.94	1.28	0.30	1.08	0.15	0.92	0.19	0.54	0.08	0.60	0.08	1.78	0.16	27916.7	0.86	1.05
DR-G7	Tessera	Egypt I	DRt1	Opaque	Green	Mean	9.43	1.07	5.29	1.08	0.27	0.88	0.13	0.78	0.15	0.43	0.06	0.47	0.06	1.26	0.11	40306.7	0.71	1.11
DR-GR1	Tessera	Egypt I	DRt1	Opaque	Green	Mean	11.67	1.38	6.92	1.47	0.37	1.22	0.17	1.09	0.21	0.60	0.09	0.66	0.09	2.35	0.17	6342.20	1.01	1.46
DR-GY2	Tessera	Egypt I	DRt1	Opaque	Yellow	Mean	9.26	1.08	5.43	1.16	0.28	0.99	0.14	0.87	0.17	0.48	0.07	0.53	0.07	1.84	0.14	79293.3	0.75	0.72
DR-LB1	Tessera	Egypt I	DRt1	Opaque	Blue/Green	Mean	11.99	1.41	7.06	1.51	0.36	1.24	0.17	1.05	0.21	0.59	0.09	0.64	0.09	2.31	0.17	6911.33	1.03	1.53
DR-A1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Green	Mean	10.13	1.46	6.39	1.57	0.64	1.39	0.39	1.26	0.43	0.79	0.30	0.84	0.29	1.25	0.33	68438.33	0.81	1.06
DR-BK2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Black	Mean	6.70	0.81	4.04	0.85	0.19	0.73	0.10	0.66	0.14	0.40	0.06	0.46	0.06	1.47	0.10	8223.17	0.61	0.71
DR-R1	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Red	Mean	10.77	1.32	6.69	1.40	0.36	1.23	0.17	1.09	0.21	0.60	0.08	0.61	0.08	1.18	0.12	1718.67	0.69	0.85
DR-T2	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	9.86	1.21	6.06	1.28	0.35	1.13	0.16	1.01	0.20	0.56	0.08	0.56	0.10	0.96	0.09	2812.83	0.58	0.60
DR-T3	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	10.96	1.32	6.74	1.40	0.38	1.25	0.17	1.06	0.21	0.60	0.08	0.58	0.08	0.92	0.09	1517.50	0.62	0.54
DR-T4	Tessera	Apollonia-type Levantine I	DRt2	Opaque	Blue	Mean	10.37	1.25	6.47	1.35	0.36	1.20	0.17	1.02	0.21	0.58	0.08	0.57	0.07	0.91	0.09	1398.33	0.60	0.44
DR-B1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	10.08	1.33	6.65	1.40	0.34	1.24	0.18	1.14	0.24	0.65	0.10	0.69	0.10	1.79	0.15	1593.60	0.86	1.15
DR-GY1	Tessera	Foy-2	DRt3	Opaque	Yellow	Mean	7.96	0.95	4.67	0.98	0.24	0.83	0.12	0.71	0.15	0.43	0.06	0.45	0.06	1.33	0.11	43105	0.67	0.95
DR-R2	Tessera	Foy-2	DRt3	Opaque	Red	Mean	10.29	1.32	6.63	1.43	0.34	1.22	0.17	1.14	0.22	0.63	0.09	0.66	0.09	1.63	0.13	5084.50	1.08	1.04
DR-T1	Tessera	Foy-2	DRt3	Opaque	Blue	Mean	9.01	1.13	5.74	1.23	0.28	1.07	0.15	0.90	0.18	0.51	0.07	0.52	0.07	1.34	0.12	1826.33	0.71	0.67
DR-Am1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	11.34	1.46	7.12	1.49	0.36	1.32	0.20	1.22	0.24	0.68	0.10	0.71	0.11	1.81	0.17	88.09	0.92	1.03
DR-Am2-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	3.05	0.36	1.65	0.37	0.07	0.34	0.05	0.34	0.07	0.19	0.03	0.19	0.03	0.71	0.09	136200	0.44	0.37
DR-Am3-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	11.72	1.46	7.32	1.50	0.35	1.28	0.18	1.19	0.23	0.65	0.09	0.70	0.09	1.95	0.16	59.22	0.97	1.07
DR-Am4-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	10.86	1.38	6.94	1.44	0.33	1.25	0.17	1.10	0.22	0.61	0.09	0.67	0.09	1.83	0.14	62.13	0.89	0.94
DR-Am5-Ag	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	9.61	1.22	6.14	1.28	0.30	1.14	0.15	1.02	0.20	0.55	0.08	0.59	0.08	1.45	0.11	8.50	0.71	0.98
DR-Am6-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	13.12	1.63	8.12	1.68	0.38	1.43	0.20	1.29	0.26	0.73	0.10	0.79	0.10	2.22	0.19	91.01	1.10	1.11
DR-Y1-Au	Tessera	Foy-2	DRt3	Translucent	Yellow	Mean	15.78	1.67	8.13	1.73	0.40	1.40	0.19	1.23	0.24	0.66	0.10	0.76	0.10	2.37	0.25	37.57	1.28	0.57
DR-G1-Au	Tessera	outlier		Translucent	Green	Mean	2.78	0.40	1.56	0.41	0.16	0.37	0.12	0.38	0.13	0.23	0.09	0.26	0.09	0.73	0.16	119267	0.47	0.44
DR-BK1	Tessera	outlier		Opaque	Black	Mean	7.93	1.26	6.19	1.28	0.29	1.09	0.15	0.93	0.19	0.55	0.08	0.58	0.08	1.44	0.11	4423.33	0.67	0.94

Tab.6.10 (continuing) Trace element composition of the analysed samples obtained by LA-ICP-MS. All data are expressed in ppm.

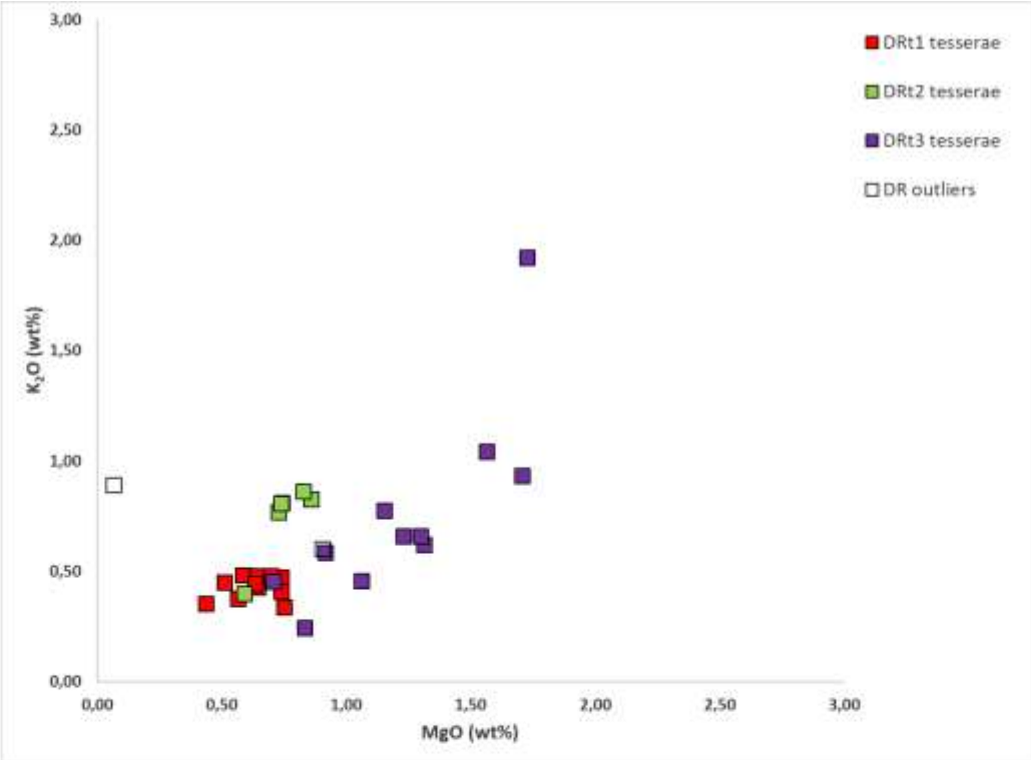


Fig.6.50 K_2O versus MgO bi-plot
(for the opaque tesserae, reduced wt% contentsare used).

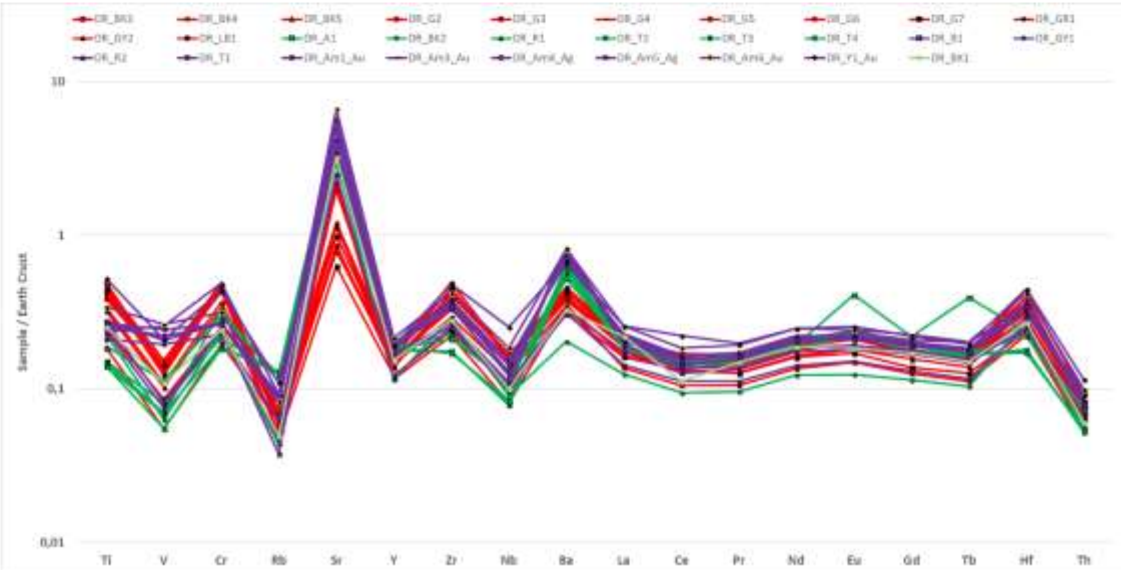


Fig.6.51 Trace elements patterns of the tesserae (LA-ICP-MS data). Averages are normalised to the mean values in the continental crust (Kamber et al. 2005). Red lines are used for samples of group DRt1, green lines for samples belonging to group DRt2, purple lines for samples of group DRt3.

Furthermore, DRt1 tesserae have lower lime (2.37-4.78 wt%) and slightly higher soda (16.69-21.39 wt%), alumina (2.45-3.48 wt%) and iron oxide (0.46-2.39 wt%). The above features are all markedly presented in CaO/Al_2O_3:Na_2O/SiO_2, TiO_2/Al_2O_3:Al_2O_3/SiO_2 and FeO/TiO_2:FeO/Al_2O_3 bi-plots (Fig.6.52-6.54).

DRt1 tesserae were manufactured by using a sand rich in the heavy accessory minerals. These features, together with the high soda contents, are typical of Egyptian glasses (Foy et al. 2003; Nenna 2014; Phelps et al. 2016; Picon, Thirion-Merle & Vichy 2008). More precisely, compositional data show that DRt1 tesserae are consistent with Egypt I compositional category. If a closer look is given to CaO/Al_2O_3:Na_2O/SiO_2, TiO_2/Al_2O_3:Al_2O_3/SiO_2 and FeO/TiO_2:FeO/Al_2O_3 bi-plots (Fig.6.52-6.54), it can also be noticed that DRt1 tesserae show closer affinities with late antique/early Islamic Egypt I than with earlier Egypt I, referable to Wadi Natrun furnaces.

The second sub-group of tesserae, from now on named **DRt2**, includes samples A1, BK2, R1, T2, T3 and T4. They show higher strontium and lower contents of heavy elements (Ti, V, Cr, Zr, Nb, Hf) compared to DRt1 tesserae (Fig.6.52); DRt2 tesserae also have higher lime (6.25-10.26 wt%), lower soda (14.08-16.04 wt%) and lower iron oxide (0.41-0.74 wt%) compared to all other samples (Fig6.54). Tesserae belonging to group DRt2 were made by using a less rich sand in the heavy accessory minerals. Moreover, the relatively high alumina suggests the use of a mature sand, and the correlation between lime and strontium suggests a coastal sand containing shells rather than an inland (Fig.6.55) (Freestone et al.2003; Phelps et al. 2016); this is also confirmed by the low CaO/Sr ratios, being on average 193. The same diagram also suggests the use of a coastal (rather than an inland) sand for DRt1 tesserae: though strontium and calcium oxide contents are lower compared to DRt2 group, they are positively correlated, and their ratio is on average 210. In accordance with these features, DRt2 tesserae are ascribable to Apollonia-type compositional category, also known as Levantine I.

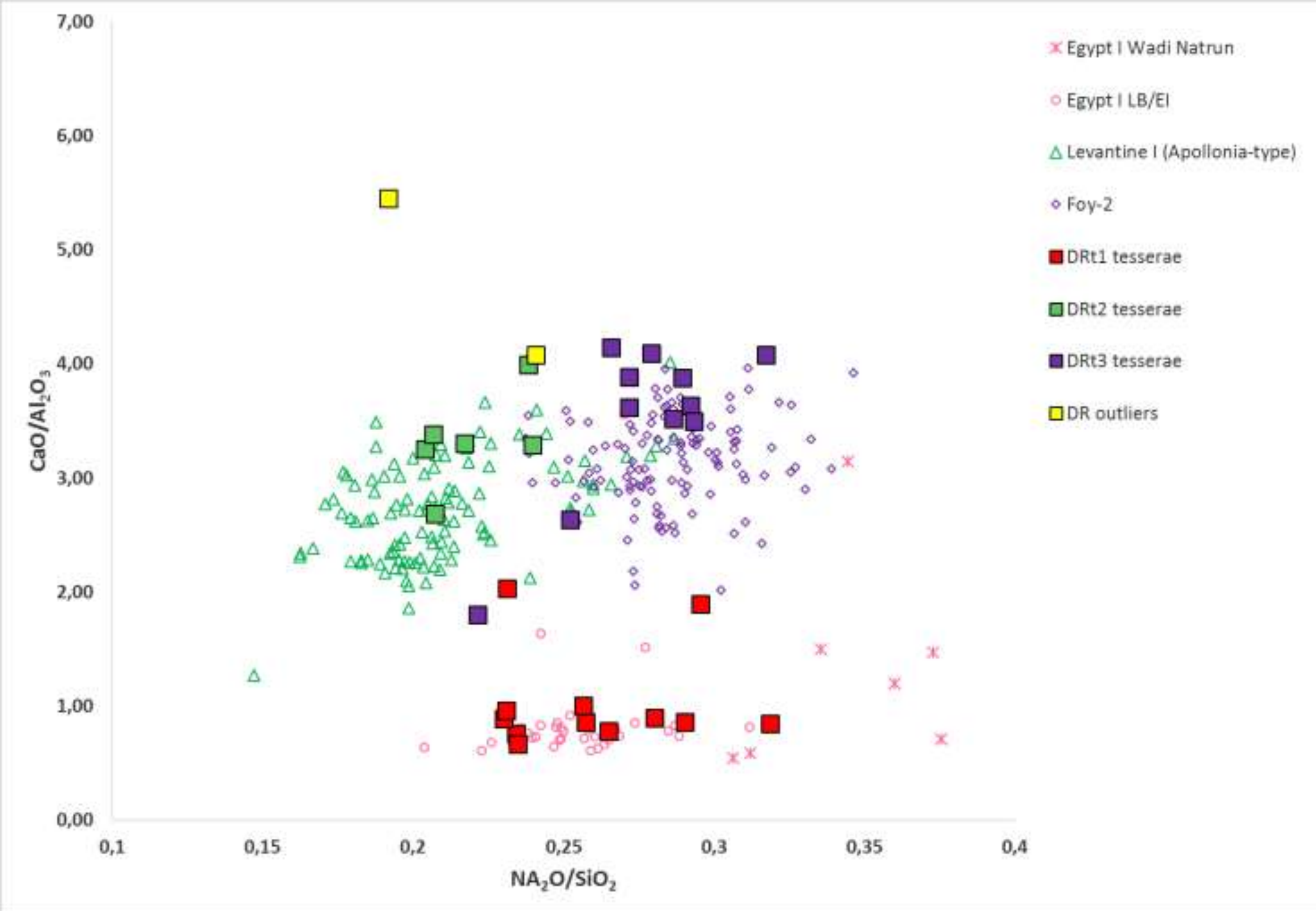


Fig.6.52 CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017..

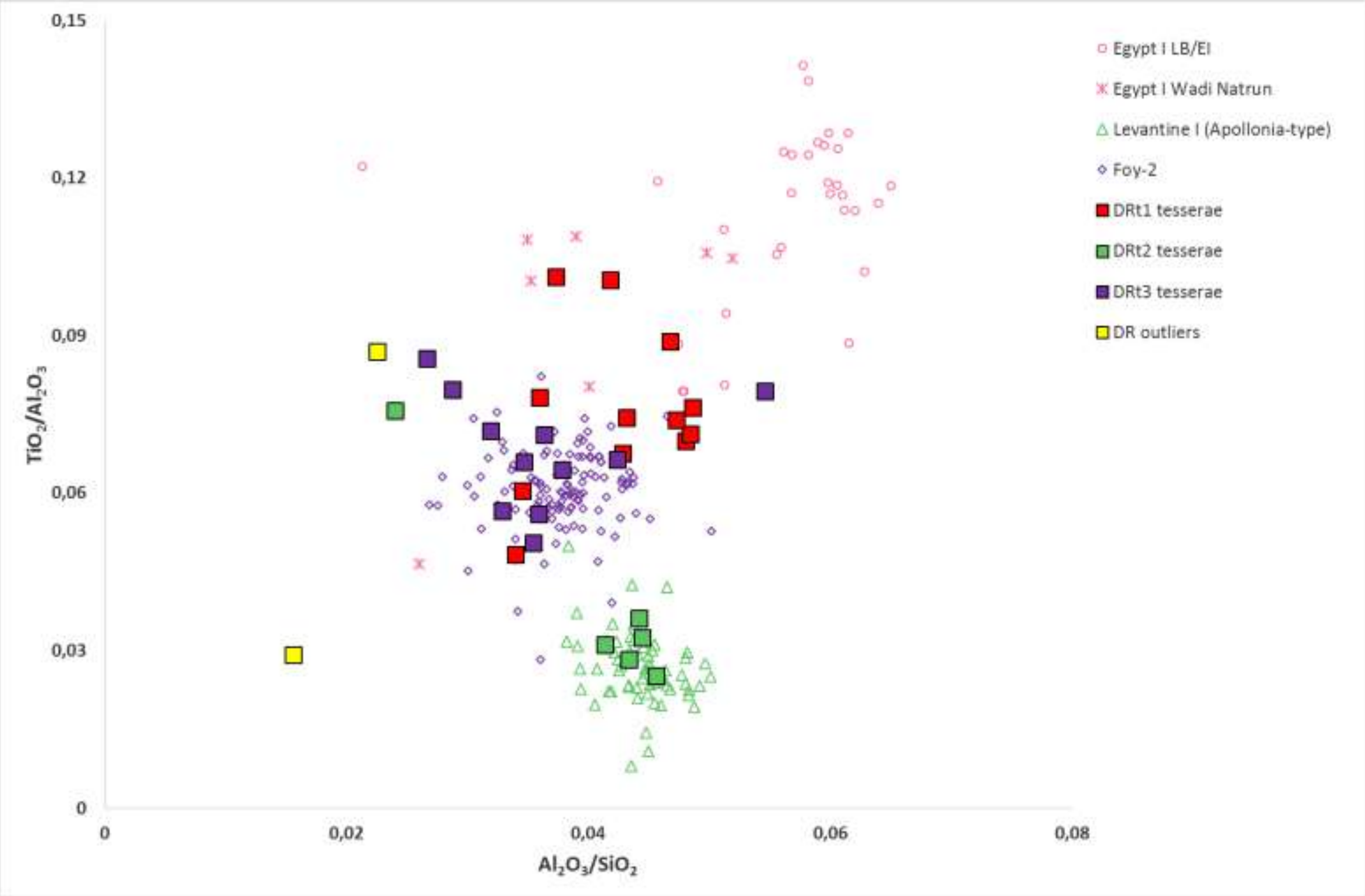


Fig.6.53 TiO_2/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017..

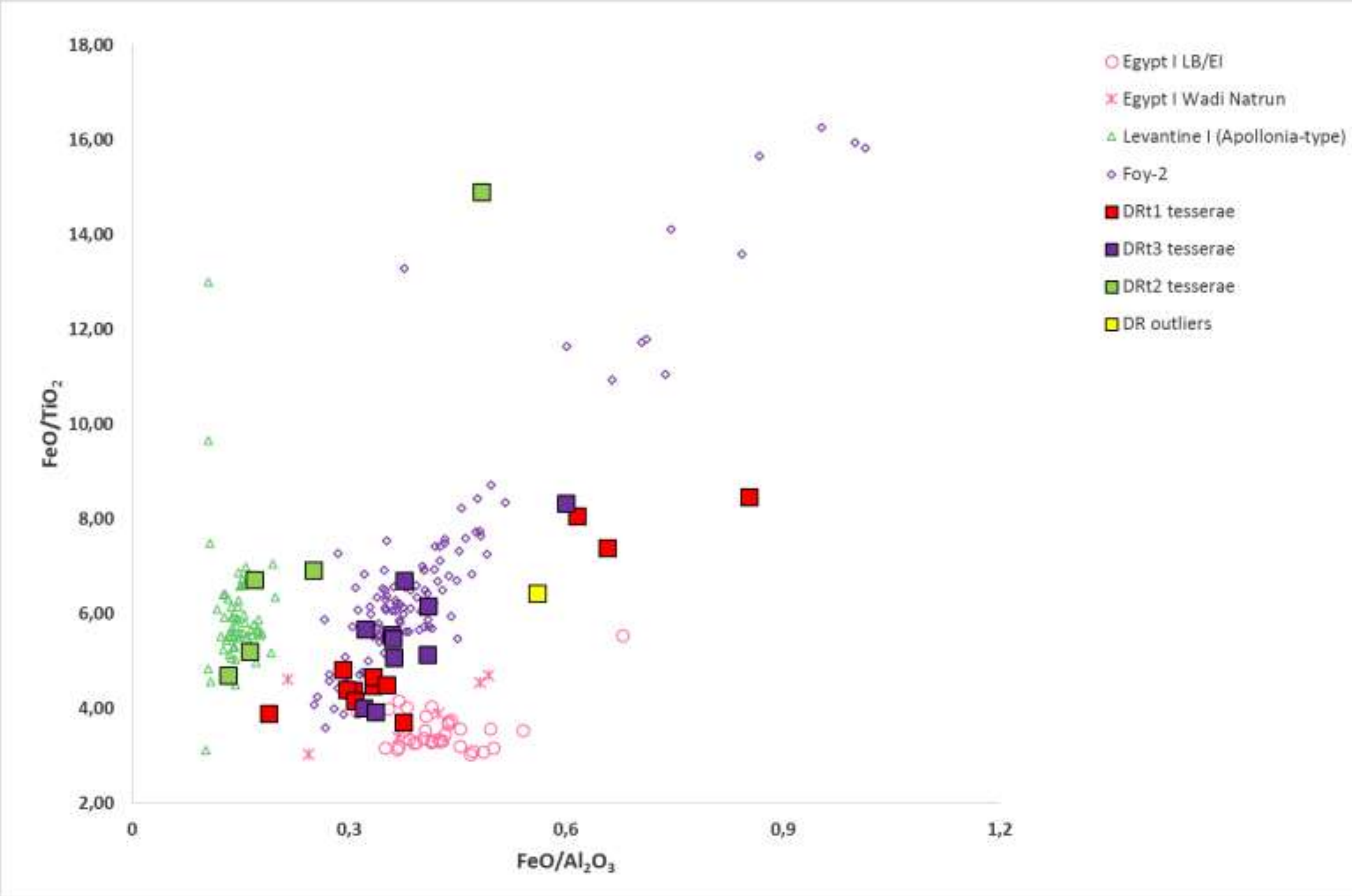


Fig.6.54 FeO/TiO_2 versus FeO/Al_2O_3 bi-plot (for the opaque tesserae, reduced wt% contents are used). References: Apollonia-type: Freestone et al. 2000; Freestone et al. 2008; Phelps et al. 2016; Tal et al. 2004;); Egypt I late antique/early Islamic: Ceglia et al. 2015; Foy, Picon & Vichy 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Egypt I Wadi Natrun: Picon, Thirion-Merle & Vichy 2008; Foy-2: Conte et al. 2014; Ceglia et al. 2015; Foy et al. 2003; Neri et al. 2017; Neri, Gratuze & Schibille 2017.

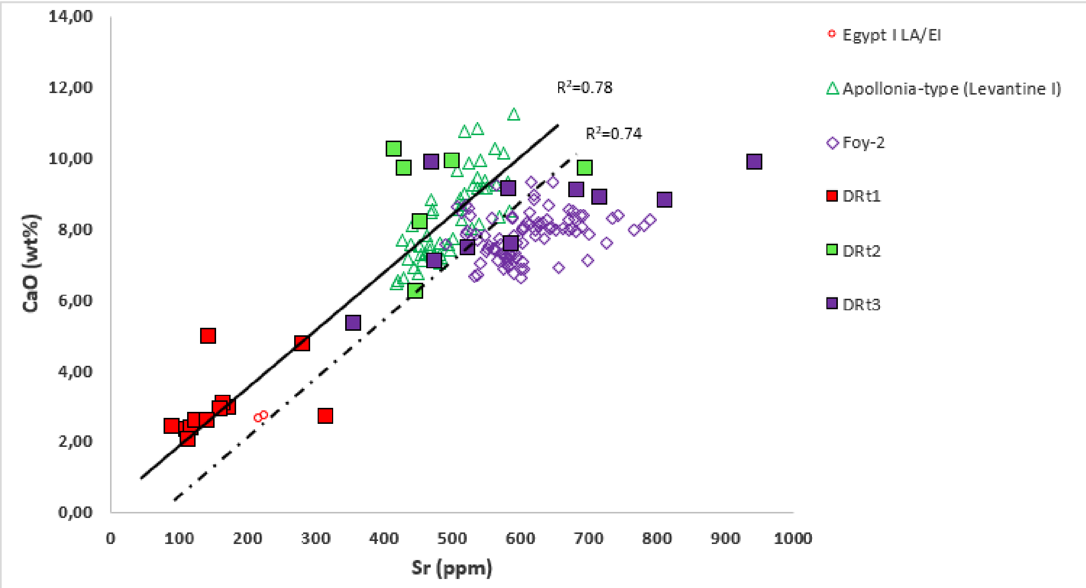


Fig.6.55 CaO (wt%) versus Sr (ppm) bi-plot (for the opaque tesserae the reduced wt% contents are used). The black and the dotted lines show, respectively, positive correlation between CaO and Sr contents for DRt1 and DRt2 samples and from the literature (Phelps et al. 2016).

The third group, from now referred to as DRt3, encompasses samples B1, GY1, R2, T1, Am1_Au, Am3_Au, Am4_Ag, Am5_Ag, Am6_Au and Y1_Au. These tesserae are made of a natron-based glass with slightly higher contents of magnesium (0.70-1.70 wt%), manganese (1.35-2.43 wt%)[65], titanium (0.12 to 0.29 wt%) and iron oxides (between 0.70 and 1.51 wt%), with zirconium ranging from 50 to 83 ppm and strontium between 354 and 943 ppm (Fig.6.51, 6.52-54). These features are consistent with the so-called Foy-2 compositional category, first identified by Daniéle Foy and colleagues (Foy et al. 2003) and further splitting into two sub-groups: the primary production group série 2.1 and the so-called série 2.2, showing signs of recycling. As already emerged from the analyses of DMSt3 tesserae, as well as from a recent study on mosaic glass tesserae from the Durres amphitheatre, matching Foy-2 compositional category, it is quite challenging to relate samples to either série 2.1 or série 2.2 (Neri, Gratuze & Schibille 2017). Tesserae under study are, like those from Durres, intermediate between the two sub-groups (Fig.6.66a-c), and trace

[65] For MnO, take here into account non-recalculated EPMA data, Tab.6.9a.

elements cannot be fully indicative as they are affected by the addition of colourants and opacifiers to the base glass.

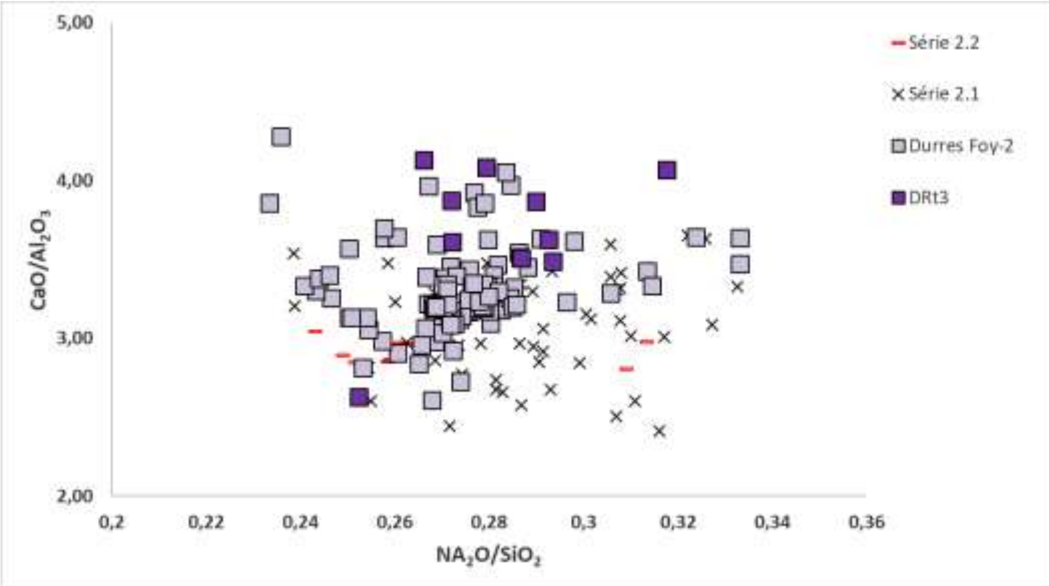


Fig.6.66a CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot, comparing DRt3 tesserae with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

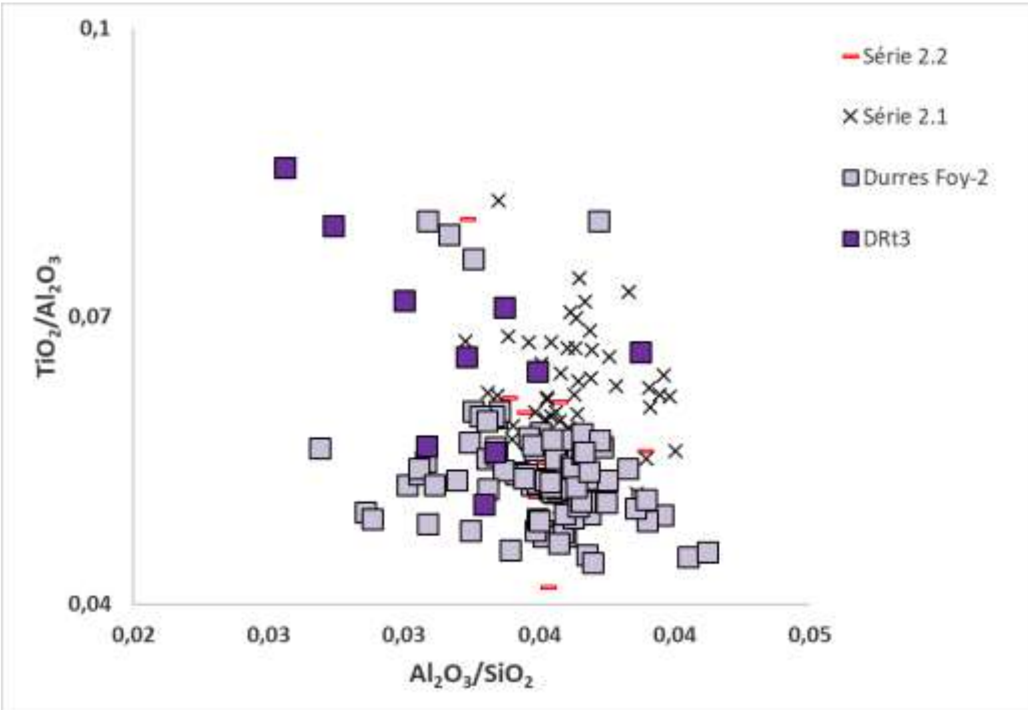


Fig.6.66b TiO/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot, comparing DRt3 tesserae with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

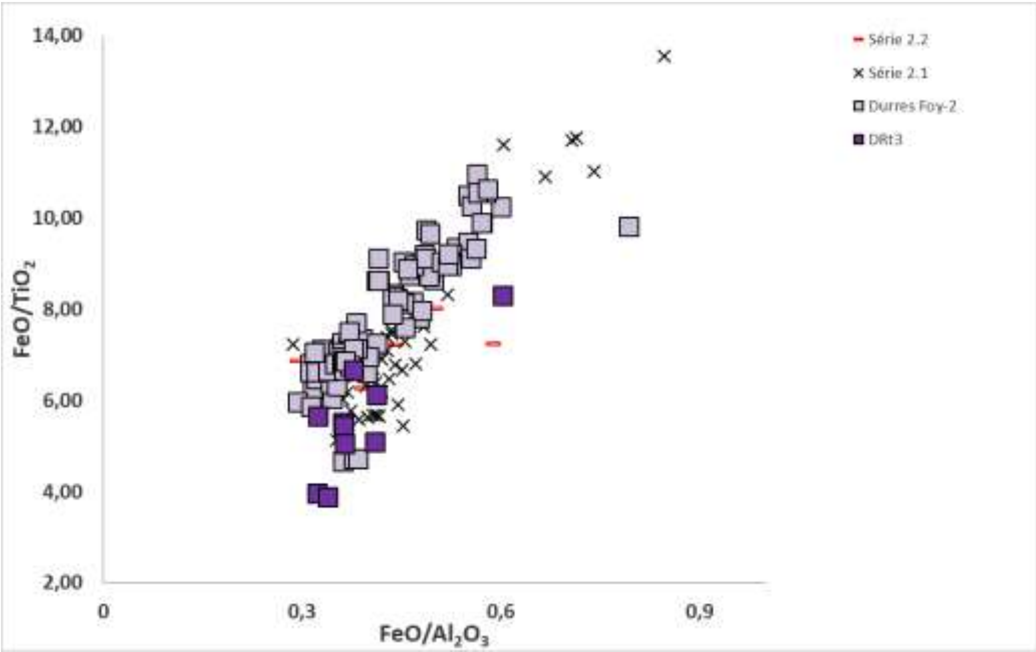


Fig.6.66c FeO/TiO_2 versus FeO/Al_2O_3 bi-plot, comparing DRt3 tesserae with Foy-2 tesserae from the Durres Amphitheatre (Neri, Gratuze & Schibille 2017).

At this point, some additional considerations on Foy-2 compositional category can be made when CaO/Sr ratio is plotted against Nd/Zr ratio (Fig.6.67): the diagram clearly shows that samples matching Foy-2 compositional category collocate themselves at an intermediate position between Egypt I and Apollonia-type groups. This seems to suggest the use of a sand with an intermediate mineralogical and geological signature between those employed, respectively, in the manufacture of Egypt I and Apollonia-type glass. If a closer look is given at the distribution of trace elements patterns (Fig.6.61), it will also be noticed that Foy-2 tesserae are characterised by heavy elements with intermediate contents between those recorded for Egypt I and Apollonia-type tesserae.

These data could suggest a collocation of primary production sites of Foy-2 glass at an intermediate geographical position between Egypt and the Syro-Palestinian coast. Last, CaO/Sr ratios are on average 135, this suggesting the use of a sand from a coastal rather than inland location.

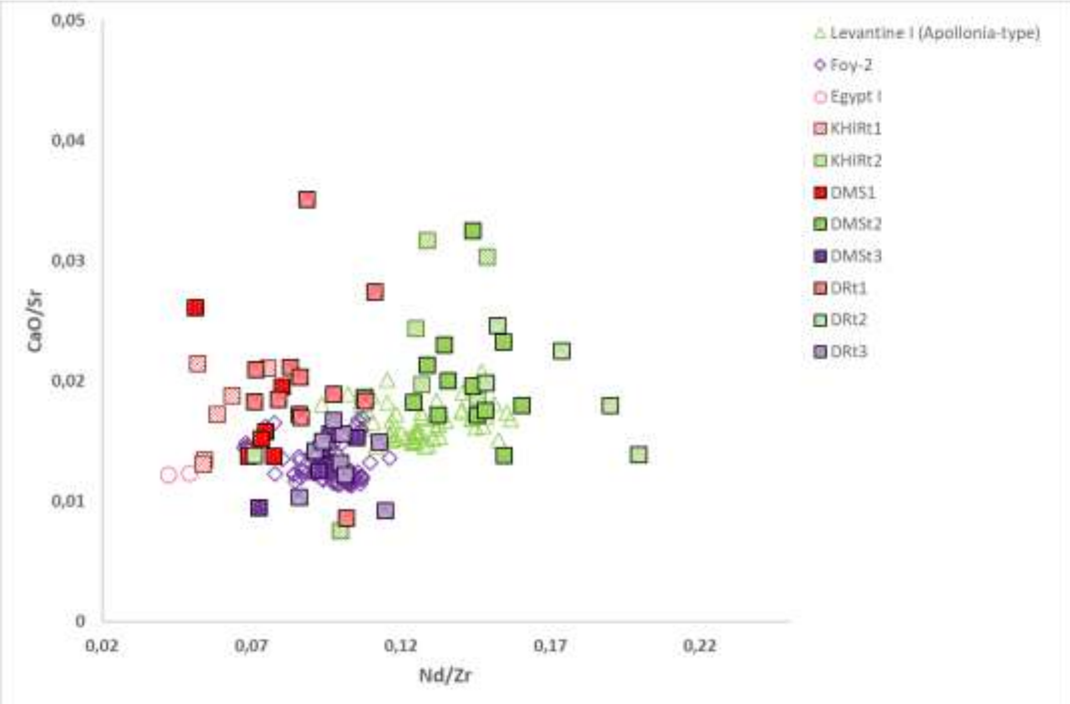


Fig.6.67 CaO/Sr versus Nd/Zr bi-plot. Reference data: Apollonia-type: Neri et al. 2017; Neri, Gratuze & Schibille 2017; Egypt I: Phelps et al. 2016.

In conclusion, EPMA and LA-ICP-MS analyses performed on the assemblage of coloured tesserae from the Dome of the Rock highlighted the occurrence of three distinct types of base glass, respectively matching Egypt I (although slightly different from that manufactured at the primary furnaces located at Wadi Natrun), Apollonia-type and Foy-2 compositional categories.

6.3.2 Colourants and opacifiers

6.3.2a Copper-based phases

R1 and R2 opaque red, as well as opaque black BK1, BK2, BK3, BK4 and BK5 tesserae, were coloured and opacified by means of copper-based phases.
According to previously discussed EPMA and LA-ICP-MS data, these samples match different compositional categories of natron-based glasses: R1 and BK2 are consistent with Apollonia-type (DRt2); R2 matches Foy-2 (DRt3); Bk3, Bk4 and BK5 correspond to late antique/early Islamic Egypt I (DRt1); BK1 is an outlier.
BSE images show a dispersion of nanometric rounded particles in the glassy matrix, and EDS spot analyses demonstrated that they are made of copper (Fig.6.68).

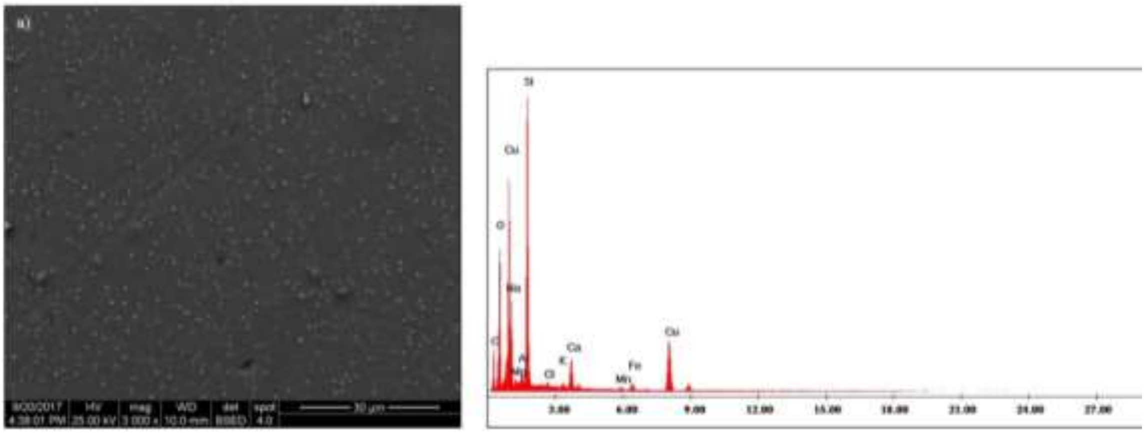


Fig.6.68 a) BSE image of nanometric rounded inclusions in tessera R2;
b) EDS spectrum collected on the inclusions.

Diffraction patterns achieved by XRPD analysis allowed identifying the crystalline phase as metallic copper (Fig.6.69).

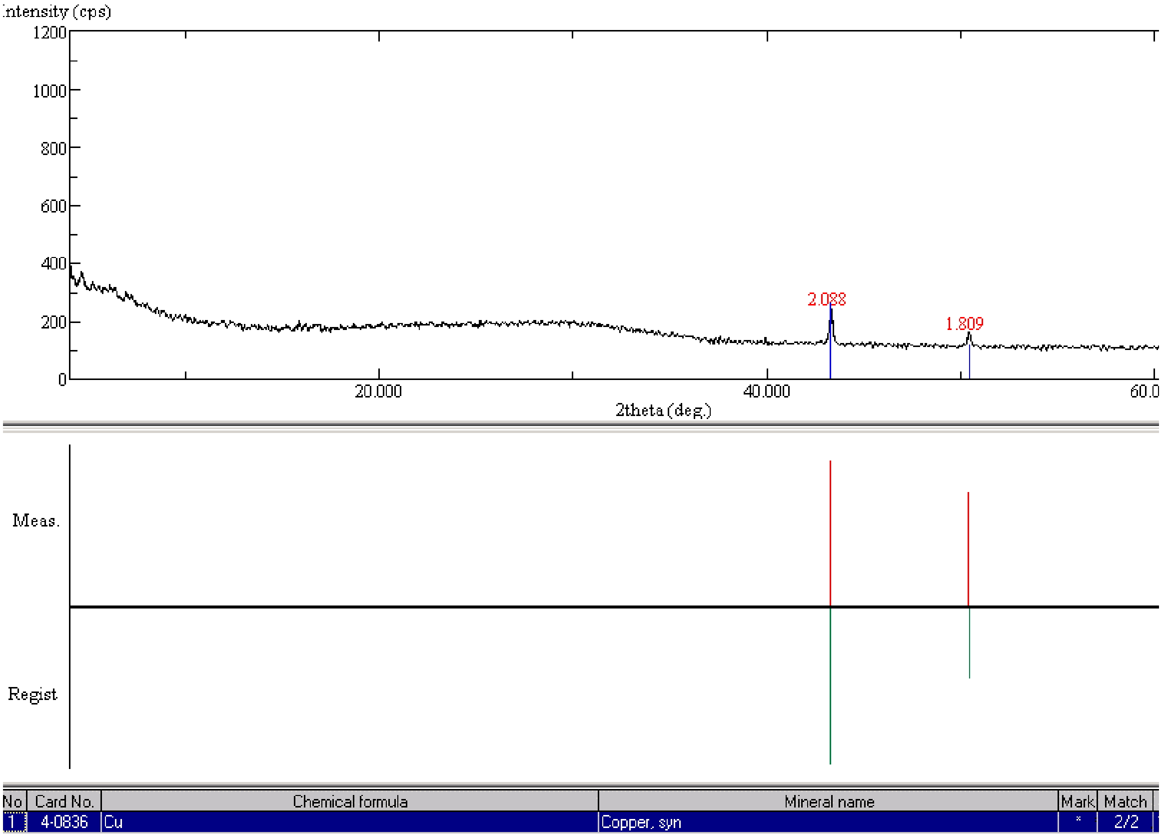


Fig.6.69 XRPD pattern of tessera R2.

All red- and black-coloured tesserae have low CuO (0.11-1.99 wt%), dispersed into the glassy matrix as sub-micron droplets (diameter less than 1 μm), and low PbO (0.17-8.80 wt%). These features are consistent with the so-called "dullish red glass", a low-lead low-copper glass coloured and opacified by nanometric droplets of metallic copper (Freestone, Stapleton & Rigby 2003).

BSE images also highlighted that samples BK1, BK4 and R2 have a homogenous matrix, while tesserae R1, BK2, BK3 and BK5 show the presence of slightly lighter zoned bands (Fig.6.70). However, no significant enrichment in lead, copper or iron can be observed when the bands are compared to the surrounding glass (PbO streaks: 1.77-5.43 wt%; PbO matrix: 1.08-4.72 wt%; CuO streaks: 0.29-3.37 wt%; CuO matrix: 0.24-3.50 wt%; FeO streaks: 0.93-4.21 wt%; FeO matrix: 0.75-3.54 wt%).

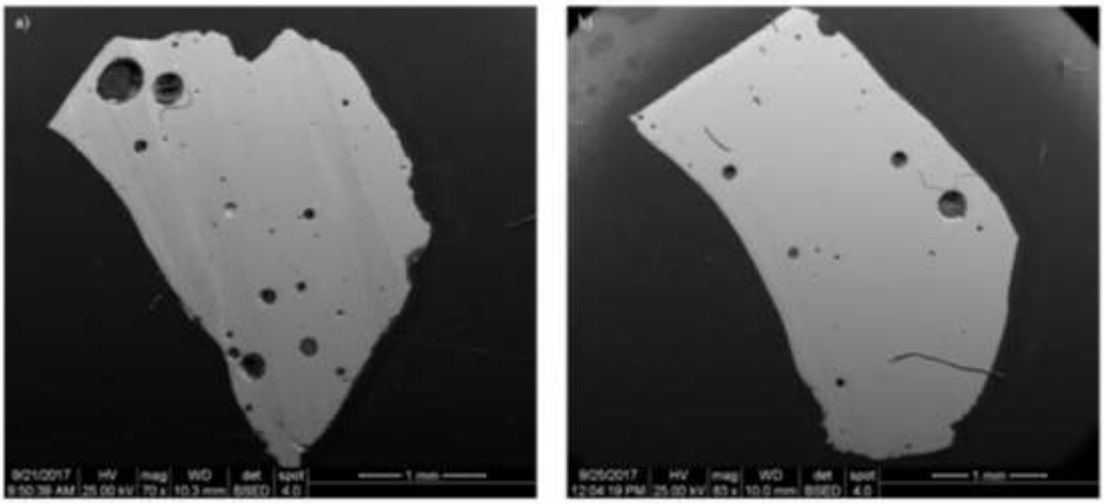


Fig.6.70 BSE images of a) R2 (opaque red) and b) BK2 (opaque black) tesserae, respectively showing the presence and the absence of lighter zoned bands in the glassy matrix.

Fig.6.71 shows RS curves of opaque red and black tesserae coloured and opacified by means of copper-based phases. It can be noticed that R1 and R2 red tesserae have an increase of reflectance intensity for the wavelength above 580 nm, due to their dull red hue (Mirti et al. 2002). Conversely, the curves of BK1, BK2, BK3, BK4 and BK5 black tesserae display an entirely flat behaviour in the wavelength range 400-700 nm.

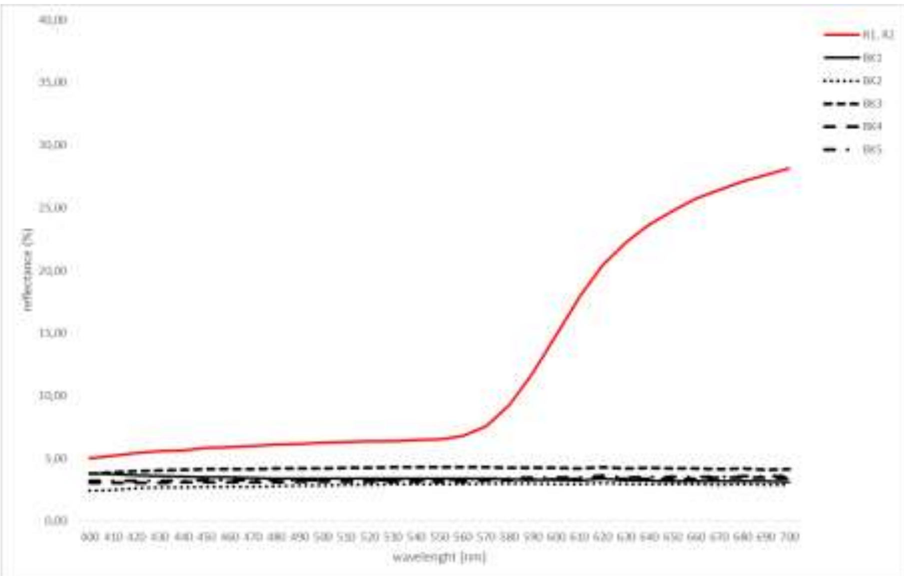


Fig.6.71 RS curves of opaque red and opaque black tesserae.

6.3.2b Tin-based phases

Opaque yellow (GY1, GY2) and opaque green (A1, G2, G3, G4, G5, G6, G7) tesserae were opacified by the addition tin-based phases, regardless the different compositional categories they belong to.

EMPA and LA-ICP-MS data demonstrated that the above tesserae split into different compositional categories: GY1 matches Foy-2 group (DRt3); A1 is consistent with Apollonia-type (DRt2); GY2, G2, G3, G4, G5, G6 and G7 correspond to late antique/early Islamic Egypt I (DRt1).

Opaque yellow- and green-coloured tesserae have a highly inhomogeneous micro-texture, the matrix being characterised by lighter bands in BSE containing higher lead than the darker areas (Fig.6.72a). Aggregates of different shapes and sizes were detected into the glassy matrix. The majority show an anhedral crystalline habit with a mean size of about 2-3 μm, mainly containing lead and tin (Fig.6.72b,c). Tiny acicular crystals (mean thickness less than 1 μm) were also found, either forming aggregates or surrounding the anhedral phases (Fig.6.73a,b); these acicular crystals are mainly composed of tin (Fig.6.73c), though their precise chemical composition could not be measured by EDS due to their small sizes.

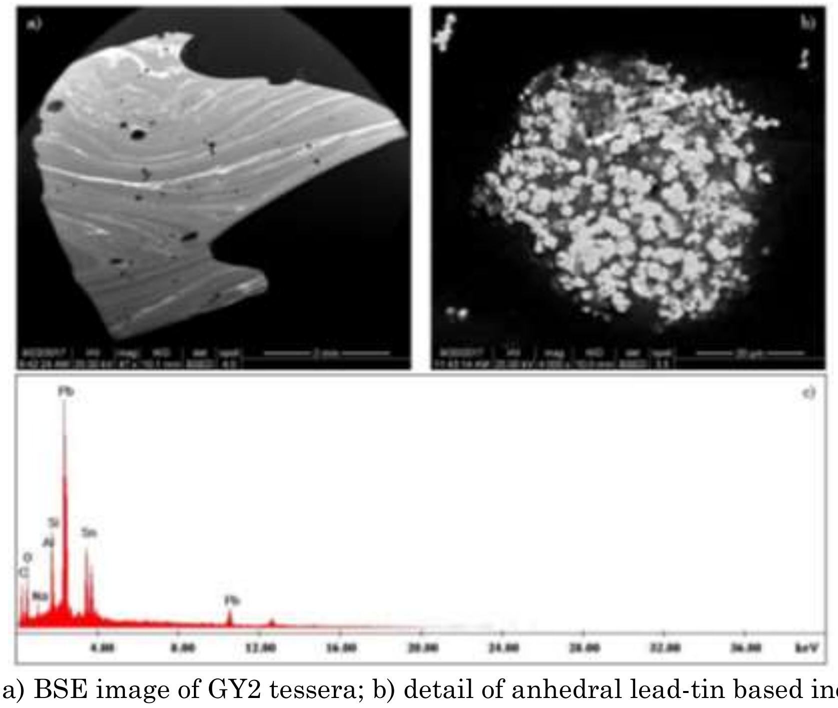


Fig.6.72 a) BSE image of GY2 tessera; b) detail of anhedral lead-tin based inclusions; c) EDS spectrum collected on an anhedral inclusion.

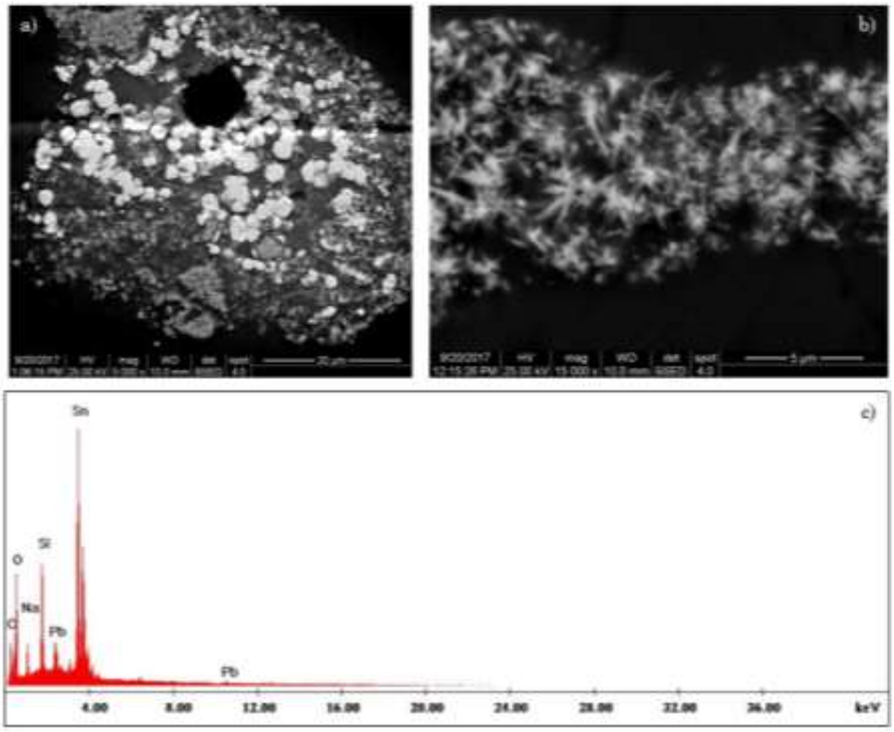


Fig.6.73 a) details of a mixed inclusion detected in GY2 tessera; b) details of acicular inclusions; c) EDS spectrum collected on an acicular inclusion.

SEM-EDS analyses indicate, therefore, that tin-based phases were used to opacify yellow and green tesserae.

Micro-Raman spectra acquired on the anhedral inclusions mainly made of Pb and Sn show bands at about 68, 138, 327 and 455 cm^{-1} (Fig.6.74), matching those reported in the literature for the so-called "Lead Tin Yellow type II" (Sefců et al. 2015; Welter et al. 2007; Zhao et al. 2013)[66].

[66] As previously discussed in the paragraph on tin-based phases detected in the assemblage from Khirbat al-Mafjar.

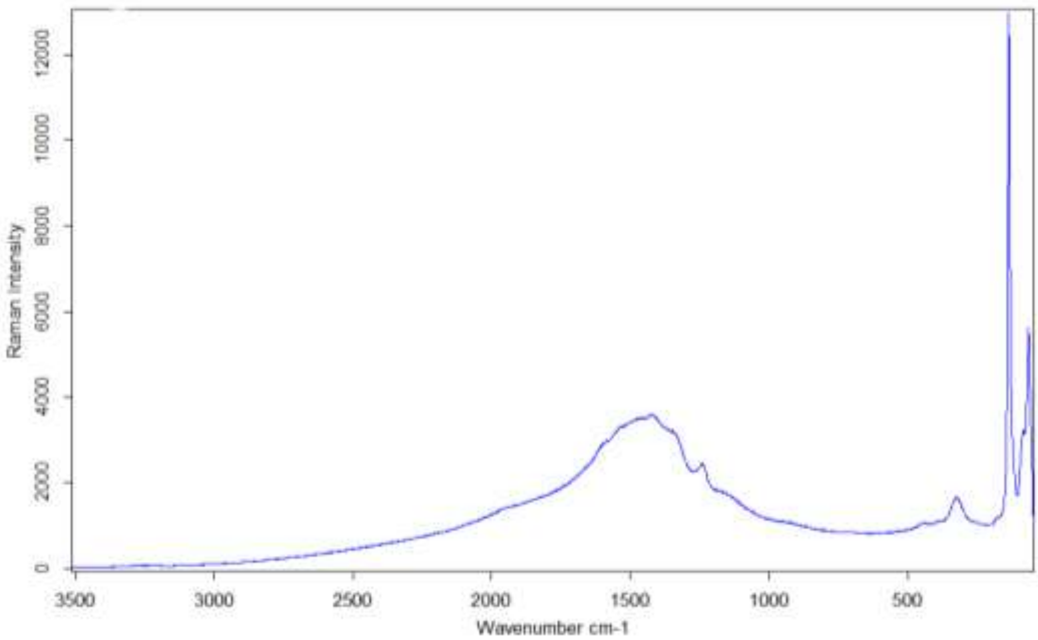


Fig.6.74 Raman spectrum collected on an anhedral inclusion (sample GY2).

XRPD was, therefore, performed in the attempt of better defining the mineralogical phase; it can be noticed that the diffraction patterns show, again, closer affinities with $PbSnO_3$ (Fig.6.75). The presence of cassiterite (SnO_2) was also detected.

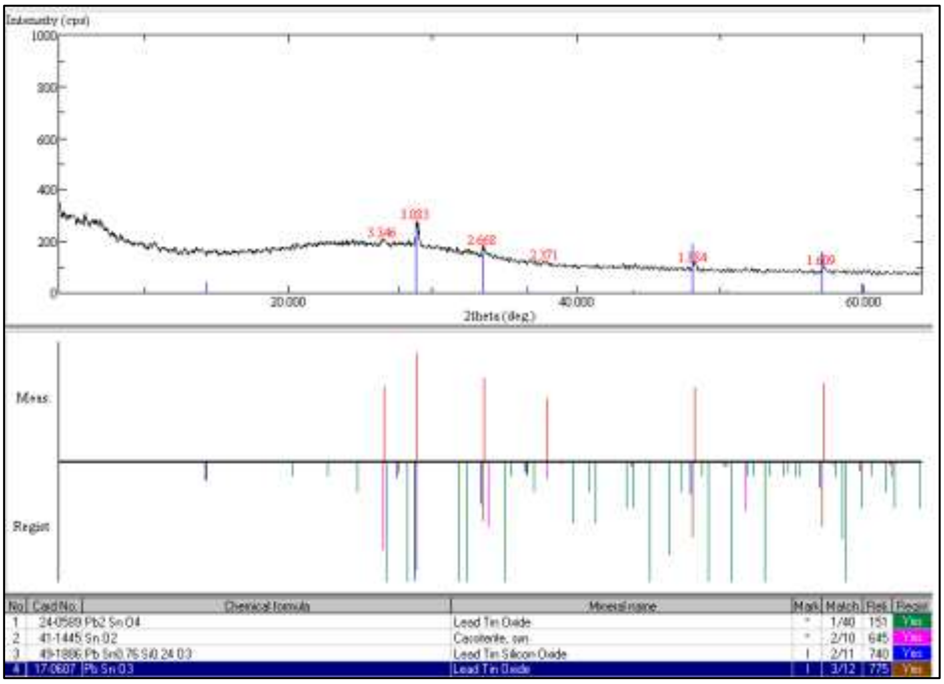


Fig.6.75 XRPD pattern of tessera GY2.

Raman spectra acquired on acicular-shaped crystals were highly affected by fluorescence, probably also due to the very exiguous dimensions of the inclusions (Fig.6.76). A band at about 637 cm^{-1} was always detected, being related to cassiterite (SnO_2). However, a univocal identification cannot be proved due to the lack of the two other main bands of SnO_2: 471 and 773 cm^{-1} (Bouchard and Smith 2003; Welter et al. 2007; Zhao et al. 2013).

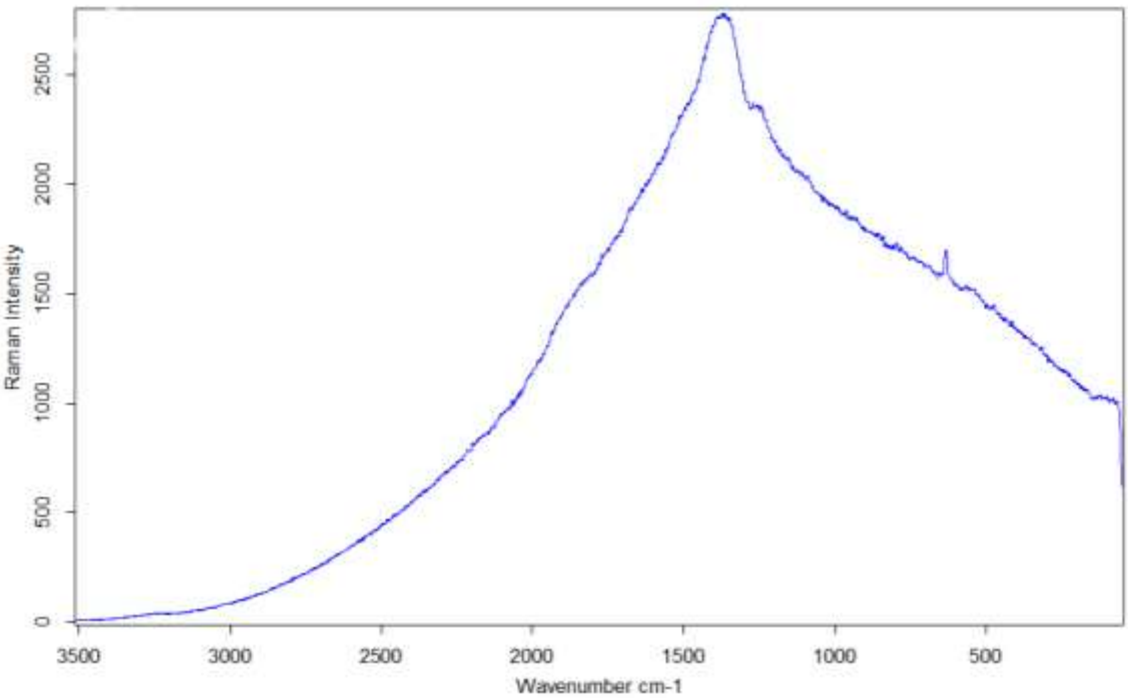


Fig.6.75 Raman spectrum collected on an acicular inclusion (tessera GY2).

In A1 (green) and B1 (blue) tesserae, the presence of acicular-shaped inclusions was only detected by SEM-BSE inspection. EDS spot measurements demonstrated that these inclusions are mainly made od Sn, and acquired micro-Raman spectra are consistent with cassiterite (SnO_2).

About the chromatic shades, in the case of the yellow tesserae the detected Lead Tin Yellow type II is also responsible for the colour. For the green-coloured tesserae, the blue hue conferred by copper-based cations dispersed in the glassy matrix, combined with the yellow colour due to lead-tin oxide, is responsible for the observed shades. Fig.6.76 shows RS spectra acquired by VIS-RS on opaque yellow and green tesserae.

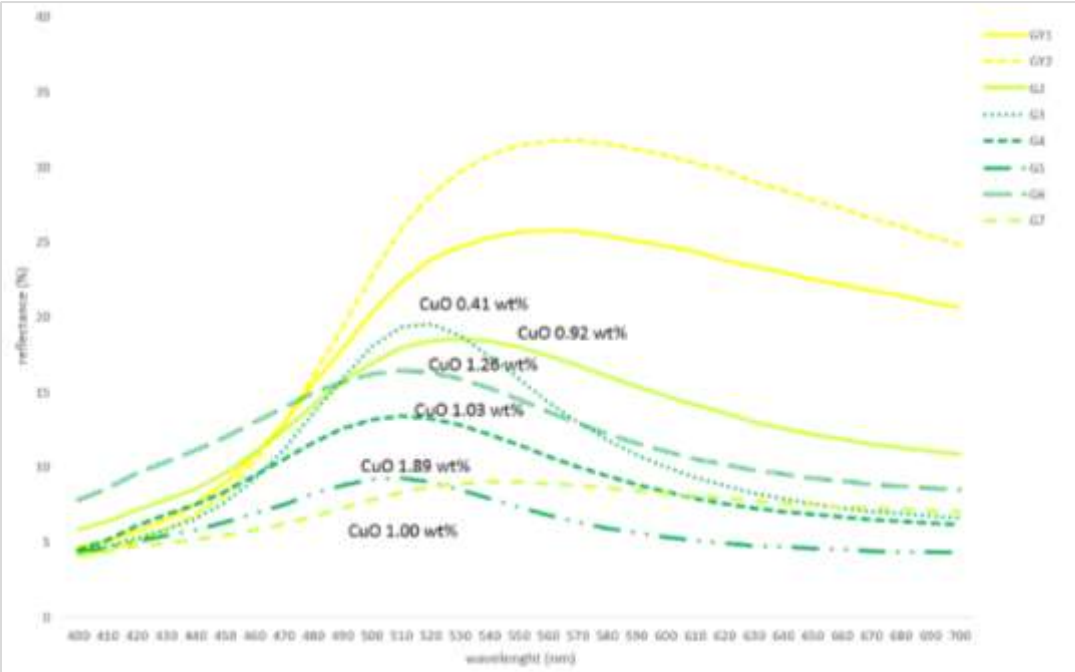


Fig.6.76 Reflectance curves acquired by VIS-RS on opaque yellow and green tesserae.

For NCS-Green tesserae, no univocal correlation can be observed between the decrease of reflectance and the increase of copper content.

The profile of the curves acquired on yellow tesserae are comparable to the ones reported by Cloutis and colleagues (Cloutis et al. 2016) for powdered lead-tin oxide yellow pigments, more closely resembling that of standard PIG818, Lead-Tin Yellow type II. Green tesserae show differently bell-shaped RS curves, with reflectance peaks between 4400 and 540 nm, ascribable to the presence of copper as colouring agent (Galli et al. 2007).

6.3.2c Phosphorus-based phases

Opaque green GR1 and opaque blue tesserae LB1, T1, T2, T3, T4 were opacified by means of addition of phosphorus-based phases.
According to EPMA and LA-ICP-MS data, these tesserae are all made of natron-based glass, but they match different compositional categories: GR1 and LB1 are consistent with late antique/early Islamic Egypt I (DRt1); T1 corresponds to Foy-2 (DRt3); T2, T3 and T4 are of an Apollonia-type glass (DRt2).
BSE images show that phosphorus-based inclusions have dimensions ranging from about 50 to 400 μm, display irregular shapes and are generally dotted with small vacuoles. EDS data demonstrated that these inclusions are mainly composed of calcium and phosphorus (Fig.6.77).

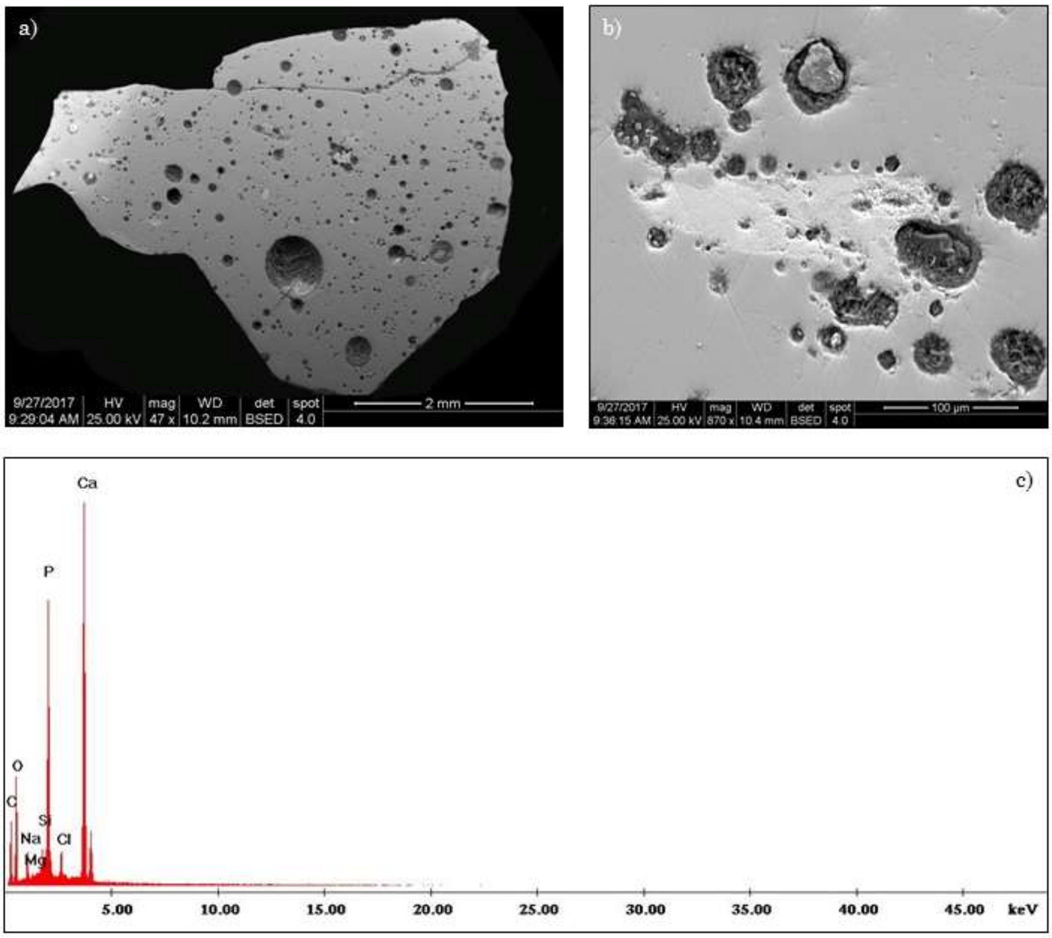


Fig.6.77 BSE images of a) T3 tessera; b) P-based inclusion;
c) EDS spectrum acquired on the P-based inclusion.

Micro-Raman measurements were carried out to provide specific characterization of the phosphorus-based opacifiers. Acquired spectra are consistent with hydroxyapatite (Penel et al. 2003), the band positions being at 1073, 1045, 1027, 962, 610. 591, 579, 448 and 430 cm^{-1}, where vibrational modes within the phosphate tetrahedra of the apatite occur (Silvestri et al. 2016) (Fig.6.78).

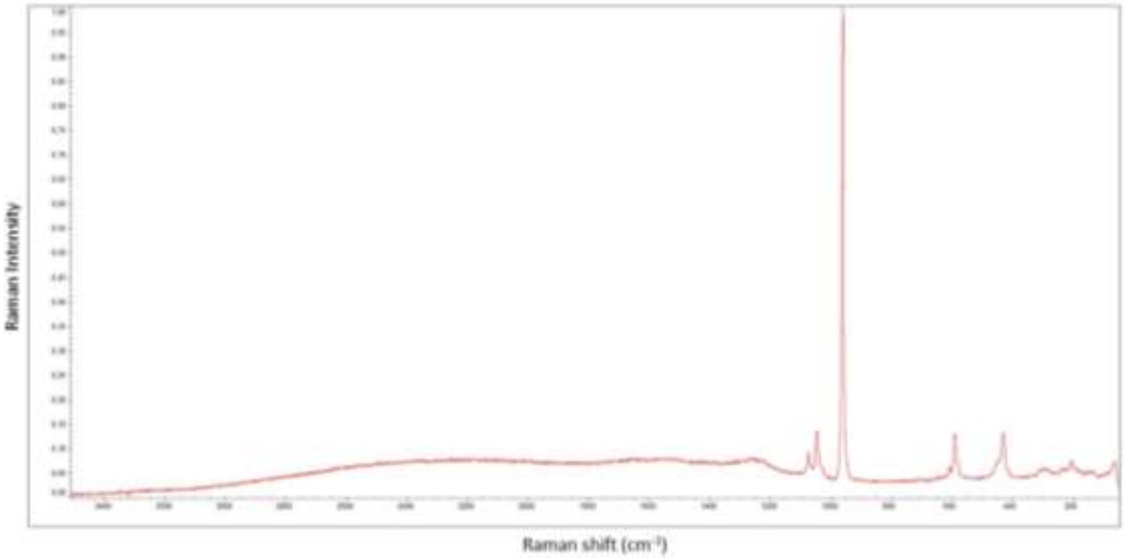


Fig.6.78 Raman spectrum acquired on a P-based inclusion in tessera LB1.

Blue tesserae T1, T2 and T3 show slightly higher CuO contents, ranging between 1.02 and 1.80 wt% and, therefore, it can be assumed that copper dispersed into the glassy matrix is responsible for the light blue shades. This is confirmed by RS curves, showing a weak bell-shaped morphology and a reflectance peak between 440 and 540 nm (Fig.6.79). Slightly different reflectance curve can be observed for tesserae GR1 and LB1, with weaker reflectance peaks at about 500-550 nm and higher reflectance percentages. According to compositional data, GR1 and LB1 tesserae have lower CuO contents compared to samples T1, T2 and T3, while PbO is slightly higher; this is responsible for an increase of the lightness (L*) of GR1 and LB1 tesserae, resulting in a higher reflectance percentage.

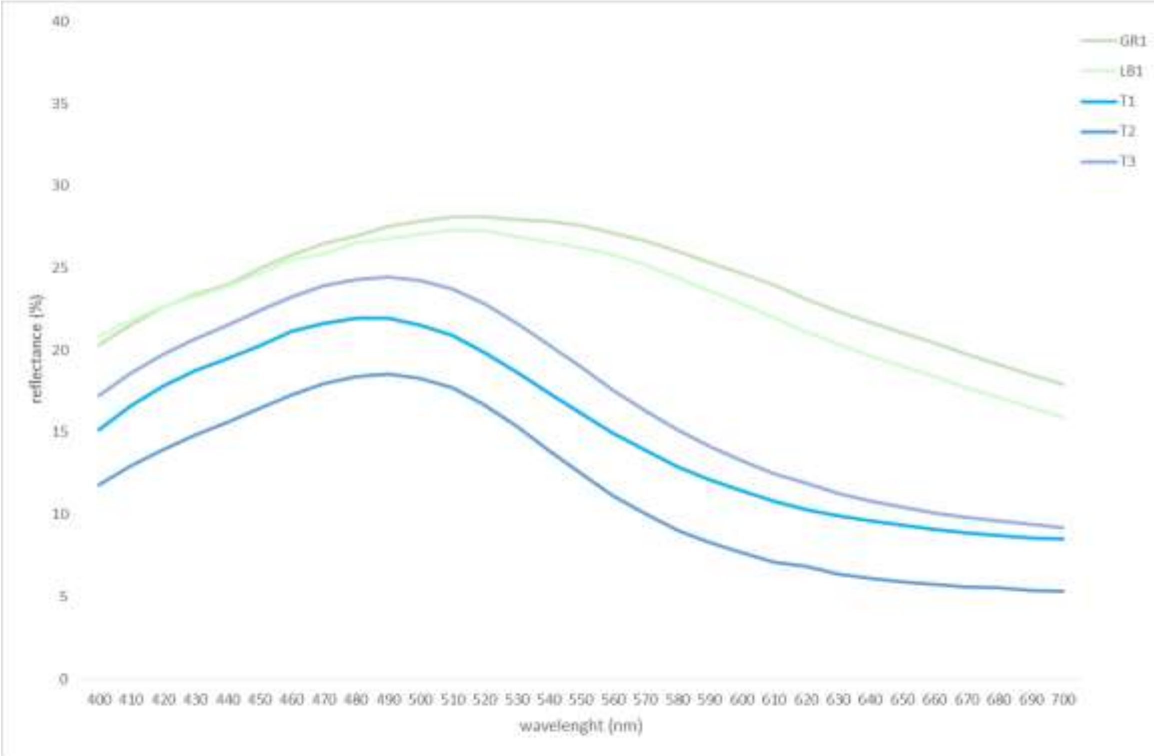


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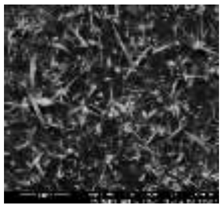
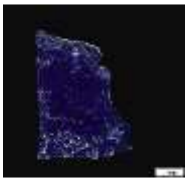
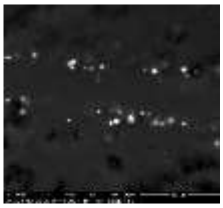
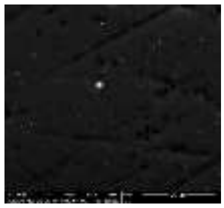
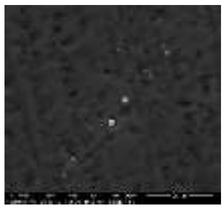
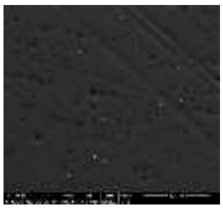
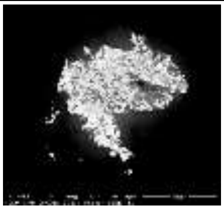
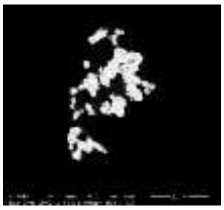
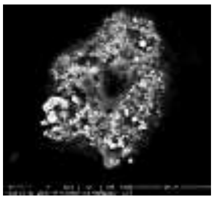
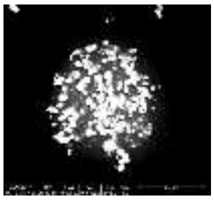
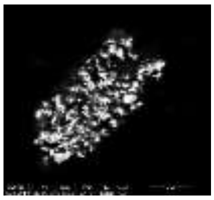
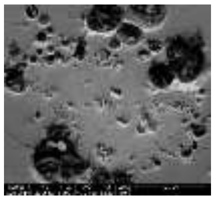
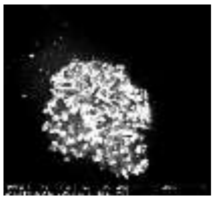
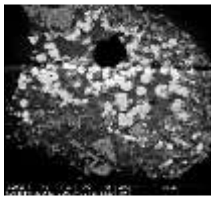
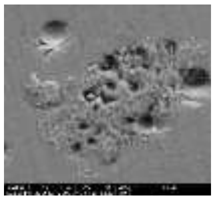
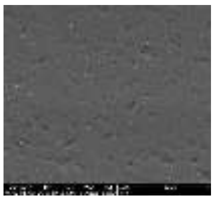
Fig.6.79 Comparison between RS curves acquired on green- and blue-shaded tesserae, all opacified by phosphorus-based phases. The different shapes exhibited by green (GR1 and LB1) and blue (T1, T2, T3) tesserae are ascribable to the different colouring agents.

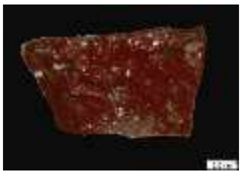
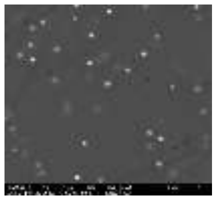
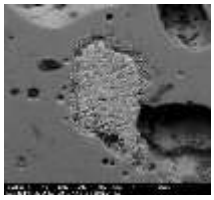
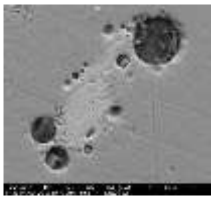
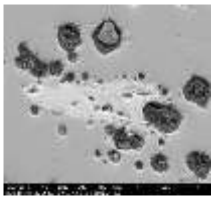
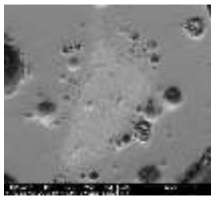
6.3.2d Translucent and transparent tesserae

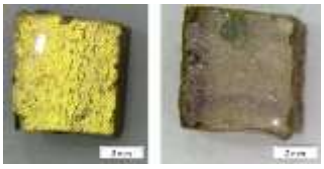
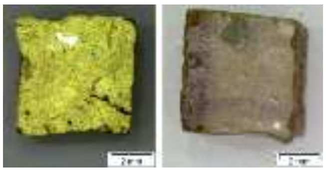
All translucent yellow tesserae (Am1-Au, Am2_Au, Am3_Au, Am4_Ag, Am5_Ag, Am6_Au and Y1_Au) are characterised by MnO contents ranging between 1.62 and 2.43 wt%, responsible for the colour. Translucent green tessera G1_Au shows CuO of 1.16 wt, acting as colouring agent.

<table>
<tr><th>Sample</th><th>Base glass</th><th colspan="3">Colour</th><th>Opacity</th></tr>
<tr><td rowspan="4">
DR_A1</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Green
[NCS S 3040-B80G]</td><td rowspan="4">
Cassiterite</td></tr>
<tr><td rowspan="3">Compositional
category
Apollonia-type</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>43.88</td><td>-12.6</td><td>-2.25</td></tr>
<tr><td colspan="3">Copper</td></tr>
<tr><td rowspan="4">
DR_B1</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Blue
[NCS S 7020-R80B]</td><td rowspan="4">
Cassiterite</td></tr>
<tr><td rowspan="3">Compositional
category
Foy-2</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>28.8</td><td>0.34</td><td>-7.83</td></tr>
<tr><td colspan="3">Cobalt</td></tr>
<tr><td rowspan="4">
DR_BK1</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Black
[NCS S 9000-N]</td><td rowspan="4">
Cu nano-particles</td></tr>
<tr><td rowspan="3">Compositional
category
outlier</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>24.15</td><td>0.01</td><td>-1.1</td></tr>
<tr><td colspan="3">Cu nano-particles</td></tr>
<tr><td rowspan="4">
DR_BK2</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Black
[NCS S 9000-N]</td><td rowspan="4">
Cu nano-particles</td></tr>
<tr><td rowspan="3">Compositional
category
Apollonia-type</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>24.7</td><td>0.01</td><td>0.6</td></tr>
<tr><td colspan="3">Cu nano-particles</td></tr>
<tr><td rowspan="4">
DR_BK3</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Black
[NCS S 8550-N]</td><td rowspan="4">
Cu nano-particles</td></tr>
<tr><td rowspan="3">Compositional
category
Egypt I</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>27.6</td><td>-0.33</td><td>0.3</td></tr>
<tr><td colspan="3">Cu nano-particles</td></tr>
<tr><td rowspan="4">
DR_BK4</td><td>Soda-silica-lime
Natron-based</td><td colspan="3">Black
[NCS S 8500-N]</td><td rowspan="4">
Cu nano-particles</td></tr>
<tr><td rowspan="3">Compositional
category
Egypt I</td><td>L*</td><td>a*</td><td>b*</td></tr>
<tr><td>24.4</td><td>0.97</td><td>0.42</td></tr>
<tr><td colspan="3">Cu nano-particles</td></tr>
</table>

Sample	Base glass	Colour	Opacity
 DR_BK5	Soda-silica-lime Natron-based Compositional category Egypt I	Black [NCS S 9000-N] L* 24.28 / a* 0.73 / b* 0.38 Cu nano-particles	 Cu nano-particles
 DR_G2	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 2060-G30Y] L* 47.65 / a* -11.95 / b* 15.5 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DR_G3	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 3060-G20Y] L* 44.93 / a* -22.83 / b* 15.34 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DR_G4	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 3060-G] L* 40.88 / a* -13.11 / b* 5.55 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DR_G5	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 2555-B80G] L* 32.2 / a* -11.95 / b* 2.29 Lead Tin Yellow II + copper	 Lead Tin Yellow II
 DR_G6	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 4040-B90G] L* 44.11 / a* -11.95 / b* 3.72 Lead Tin Yellow II + copper	 Lead Tin Yellow II

Sample	Base glass	Colour	Opacity
 DR_G7	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 2050-G20Y] L* 36.2 / a* -4.44 / b* 9.75 Lead Tin Yellow II + copper	 $PbSnO_3$
 DR_GR1	Soda-silica-lime Natron-based Compositional category Egypt I	Green [NCS S 4010-G10Y] L* 58.74 / a* -6.32 / b* 2.5 Copper	 Calcium Phosphate
 DR_GY1	Soda-silica-lime Natron-based Compositional category Foy-2	Yellow [NCS S 1050-G60Y] L* 56.35 / a* -7.48 / b* 29.22 Lead Tin Yellow II	 Lead Tin Yellow II
 DR_GY2	Soda-silica-lime Natron-based Compositional category Egypt I	Yellow [NCS S 1050-G70Y] L* 61.35 / a* -7.28 / b* 37.16 Lead Tin Yellow II	 Lead Tin Yellow II
 DR_LB1	Soda-silica-lime Natron-based Compositional category Egypt I	Blue/Green [NCS S 1515-B50G] L* 57.55 / a* -7.07 / b* 0.92 Copper	 Calcium Phosphate
 DR_R1	Soda-silica-lime Natron-based Compositional category Apollonia-type	Red [NCS S 6030-Y90R] L* 34.33 / a* 23.81 / b* 14.45 Cu nanoparticles	 Cu nanoparticles

Sample	Base glass	Colour			Opacity
 DR_R2	Soda-silica-lime Natron-based	Red [NCS S 4550-Y80R]			 Cu nanoparticles
	Compositional category Foy-2	L*	a*	b*	
		34.42	23.85	15.24	
		Cu nanoparticles			
 DR_T1	Soda-silica-lime Natron-based	Blue [NCS S 2055-B10G]			 Calcium Phosphate
	Compositional category Foy-2	L*	a*	b*	
		47.3	-11.8	-8.79	
		Copper			
 DR_T2	Soda-silica-lime Natron-based	Blue [NCS S 4550-B20G]			 Calcium Phosphate
	Compositional category Apollonia-type	L*	a*	b*	
		42.35	- 15.19	-9.36	
		Copper			
 DR_T3	Soda-silica-lime Natron-based	Blue [NCS S 2555-B20G]			 Calcium Phosphate
	Compositional category Apollonia-type	L*	a*	b*	
		50.26	- 13.07	-7.24	
		Copper			
 DR_T4	Soda-silica-lime Natron-based	Blue [NCS S 3060-B10G]			 Calcium Phosphate
	Compositional category Apollonia-type	L*	a*	b*	
		-	-	-	
		Copper			
  DR_Am1_Au	Soda-silica-lime Natron-based	Yellow (with golden leaf) [NCS S 2060-G90Y]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	-	-	
		Manganese			

Sample	Base glass	Colour			Opacity
 DR_Am2_Au	Soda-silica-lime Natron-based	Yellow (with golden leaf) [NCS S 0530-Y20R]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	-	-	
		Manganese			
 DR_Am3_Au	Soda-silica-lime Natron-based	Yellow (with golden leaf) [NCS S 0515-G90Y]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	-	-	
		Manganese			
 DR_Am4_Ag	Soda-silica-lime Natron-based	Yellow (with silver leaf) [NCS S 0540-G90Y]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	-	-	
		Manganese			
 DR_Am5_Ag	Soda-silica-lime Natron-based	Yellow (with silver leaf) [NCS S 0530-G90Y]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	--		
		Manganese			
 DR_Am6_Au	Soda-silica-lime Natron-based	Yellow (with golden leaf) [NCS S 0570-G90Y]			Translucent
	Compositional category	L*	a*	b*	
		-	-	-	
		Manganese			
 DR_G1_Au	Soda-silica-lime Natron-based	Green (with golden leaf) [NCS S 4550-G20Y]			Translucent
	Compositional category outlier	L*	a*	b*	
		-	-	-	
		Copper			

Sample	Base glass	Colour			Opacity
 **DR_Y1_Au**	Soda-silica-lime Natron-based	Yellow (with golden leaf) [NCS S 4050-G90Y]			Translucent
	Compositional category Foy-2	L*	a*	b*	
		-	-	-	
		Manganese			

Tab.6.11 Summary of results obtained by analyses carried out on tesserae from the Dome of the Rock. Note: when, for opaque tesserae, L*a*b* coordinates are missing, this is due to the irregular surface (or too small size) of the tesserae.

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Chapter 7

Looking glasses of mosaics of cultures: manufacturing technology and supply of tesserae under the Umayyad caliphate

In Chapter 3, discussion upon the ongoing enigma of the supply of mosaic glass tesserae under the Umayyad caliphate has drawn attention to results achieved by research conducted in the last years by Liz James and colleagues, summarised in the Leverhulme Database (http://www.sussex.ac.uk/byzantine/mosaic).

More exactly, it has been highlighted how the 5th and 6th century were the ages when wall and vault mosaics mainly made of glass tesserae met their major widespread across the Mediterranean Basin. This "golden age" was, then, followed by a noticeable decline between the 7th and 8th century, with a dramatic decrease in the amount of surviving mosaics: seventeen new mosaics are mapped for the 7th century and thirteen for the 8th century, compared to sixty-three attested in the 5th century and fifty-five in the 6th century (James 2017; James et al. 2013). Though a specific reason for this phenomenon still needs to be recognised, major political events may have affected such a decrease in the production of mosaic works, like the Arab conquest, the spread of Islam and the advent of Iconoclasm.

Nevertheless, this considerable decline is not the only important event occurred in the 7th 8th century in the history of mosaic. As, in fact, Liz James has recently stated: "*The most significant change between the fifth and the sixth centuries and the seventh, is that a new mosaic in Jerusalem was not the commission of a Christian emperor or patriarch. Instead, it is the first surviving example of Islamic mosaic, present (on a vast scale) in the building known as the Dome of the Rock. It was to be followed in the eighth century by the mosaics of the Great Mosque of Damascus*" (James 2017, p.254).

The above premise plays a key role in understanding the relevance of data achieved by the investigation of the three assemblages this research is focused upon, by putting further emphasis on the need of cross-linking data to outline (as far as possible) a broad picture on the manufacture and circulation of mosaic glass tesserae under the Umayyad caliphate, an age of transition between cultures.

The following pages are, therefore, aimed at providing a reasoned comparison between the assemblages from the *qasr* of Khirbat al-Mafjar, the Great Mosque of Damascus and the Dome of the Rock. Data achieved through scientific analyses, thoroughly examined and discussed in Chapter 6, will be considered and evaluated together, as well as further discussed on the basis of a punctual comparison with historical sources.

This will result in outlining some relevant conclusions on the supply of glass tesserae under the Umayyad caliphate in the Levant, and to hypothesise plausible manufacturing and supply models.

It will, thus, be shown how the way mosaic glass tesserae were manufactured and supplied needs to be detailly understood by taking two interconnected and undetachable issues into account: an in-depth and thought out analysis of the materials used and a comprehensive detailed comparison with historical sources.

Such a complex and multifaceted research needs to be conducted thinking from small to large scale. Only after having depicted inclusive scenarios of well-defined geographical areas and chronological spans, a comparison among them can effectively be addressed. Only at that point, a careful evaluation of both consistencies and inconsistencies will effectively result in piecing together the history of mosaics glass tesserae, from the provenance of materials to their circulation and supply.

7.1 The base glass: drawing inferences from data and sources

How was glass for mosaics made and how complicated was the technology involved? How was raw glass transformed into coloured tesserae?

These (and many other) questions concerning the manufacture of mosaic glass tesserae are still far from being provided with exhaustive answers.

As extensively discussed in chapter 2, it is nowadays widely accepted among scholars that in Roman and Medieval ages glass-making was a two-stage process: raw glass was made in one place (primary glass-making sites) and then shaped into things elsewhere (secondary glass-making sites).

Basically, once the melting was completed and glass cooled, the blocks were broken up and traded as lumps, to be melted down and made into objects.

Glass-making and glass-working were, hence, two distinct processes. According to sound evidence, in the late Roman and early Byzantine periods, glass-making occurred on a large-scale at primary production sites, while glass-working occurred on a small-scale, being, at the same time, a common practice both in large settlements and small centres (Gorin-Rosen 2000).

The upsurge of Islam and the Arab conquests of Egypt and the Levant between the 7th and 8th century do not seem to have transformed this model of production and movement of glass, as demonstrated by archaeological research undertaken at Tyre, Raqqa, Baghdad and other major Islamic centres. Further evidence from sites like Beirut and Jaffa suggest that glass-working continued in the Levantine region up to 12th century (Jacobi 2014).

Though, this (or any other) model has not been proved to occur in the manufacture of glass tesserae as well. Rather, recent research has stressed that the picture of large-scale raw glass production would have better fitted with a mosaic-making industry, dealing with the production of considerable quantities of coloured tesserae (James 2017).

Unfortunately, from the Roman and Medieval worlds, physical evidence has been underpinned neither for the existence of factories specialised in the production of mosaic glass tesserae, nor for a large-scale colouring and

opacifying of glass. This means that clear information about where mosaic glass tesserae were manufactured and how, are still lacking.
It can, however, be taken as an essential starting point that, in order to produce coloured glass tesserae, raw glass was needed.
EPMA and LA-ICP-MS data allowed to discriminate between different primary glass production groups among the sets of tesserae under study.
All the analysed samples have been classified as soda-lime-silica glass with low potassium and magnesium oxide contents, indicative of the use of mineral natron as fluxing agent (Fig.7.1).

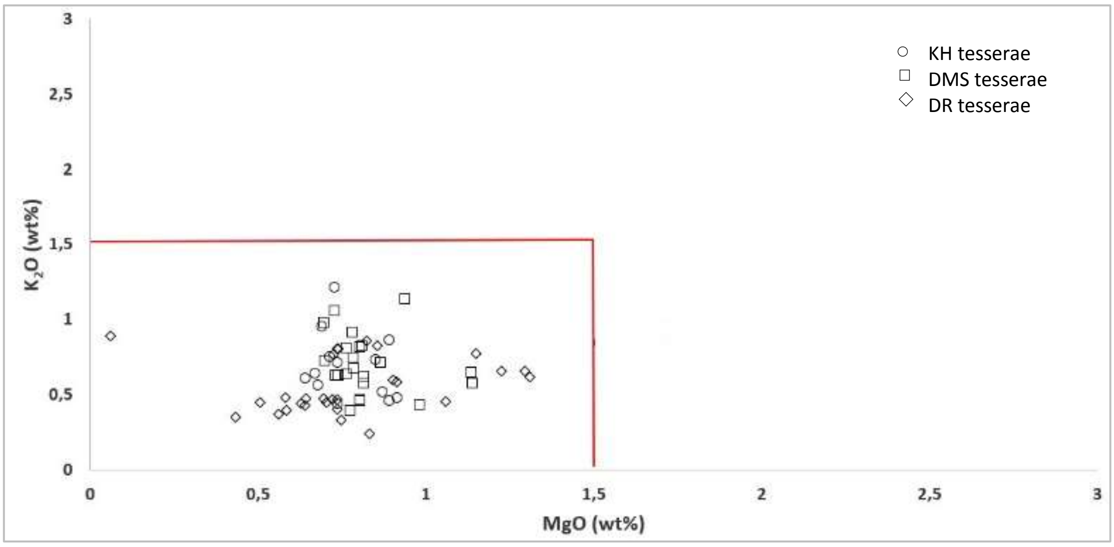


Fig.7.1 K_2O versus MgO bi-plot (for the opaque tesserae, reduced wt% are used).

Trace element patterns obtained by LA-ICP-MS demonstrated that different silica sources can be identified within the assemblages under study, according to the mineralogical components of the sands employed as vitrifying agent (Fig.7.2). Scatter plots in Fig.7.3-7.5 provide further information on the "recipes" of the base glasses, highlighting how tesserae under study split into diverse (and recurrent) compositional categories, identifiable through their chemical signature.

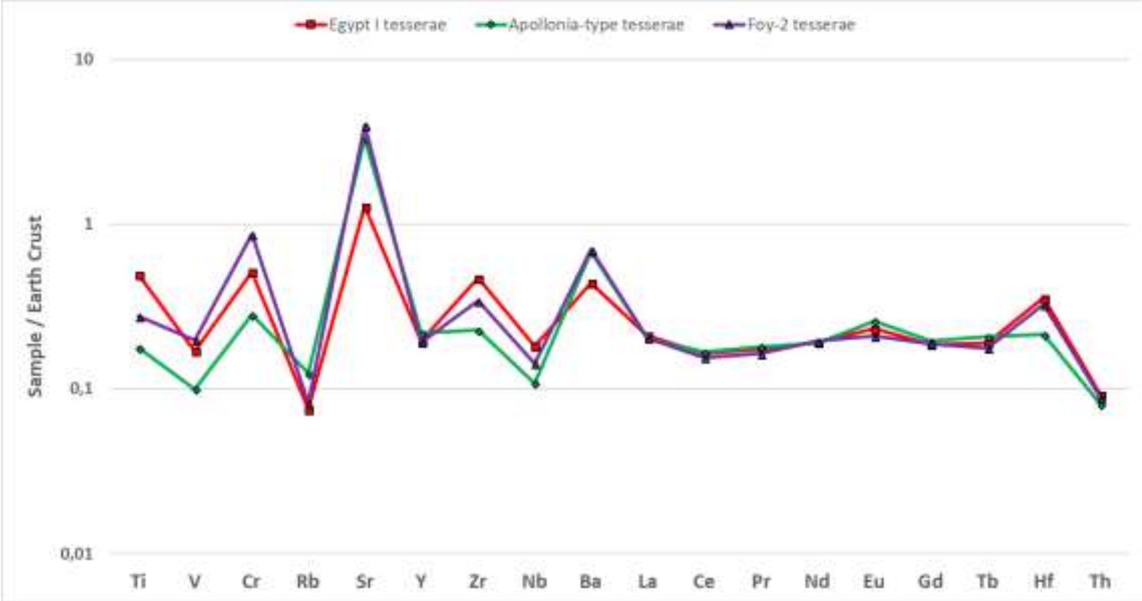


Fig.7.2 Comparison between trace elements patterns of Egypt I (red line), Apollonia-type (green line) and Foy-2 (purple line) tesserae, obtained by LA-ICP.MS. Averages are normalised to the mean values of the continental crust (Kamber et al. 2005).

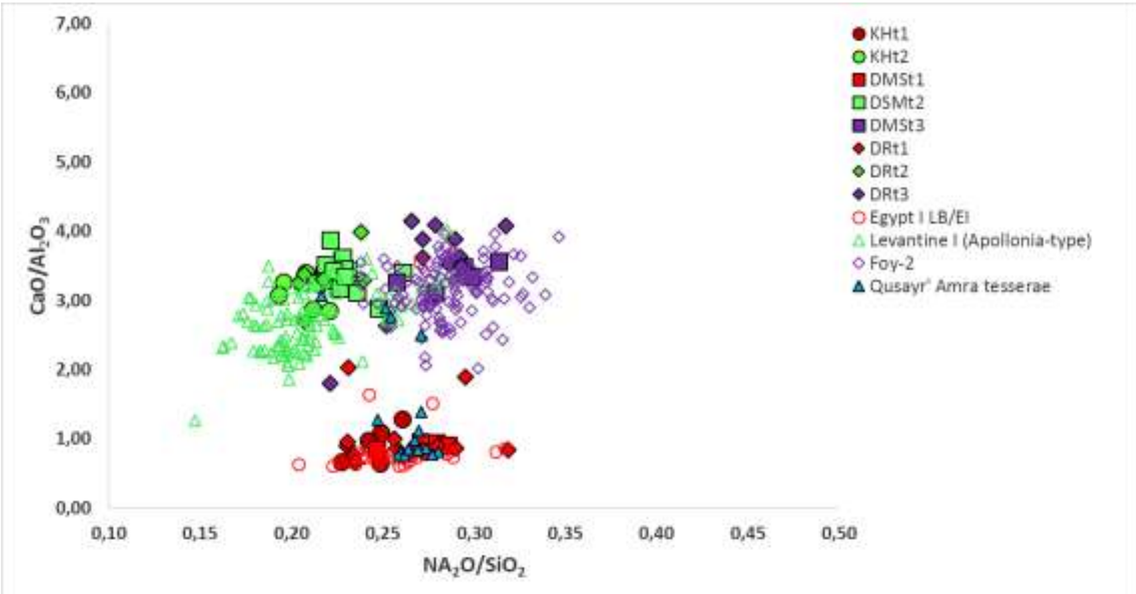


Fig.7.3 CaO/Al_2O_3 versus Na_2O/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). Apollonia-type references: Freestone et al. 2008; Tal et al. 2004; Phelps et al. 2016; Egypt I late Byzantine/early Islamic references: Bonnerot et al. 2016; Foy et al. 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Foy-2: Foy & Picon 2003; Conte et al. 2014; Bonnerot et al. 2016; Neri et al. 2017; Neri, Gratuze & Schibille 2017; Qusayr' Amra: Verità et al. 2017.

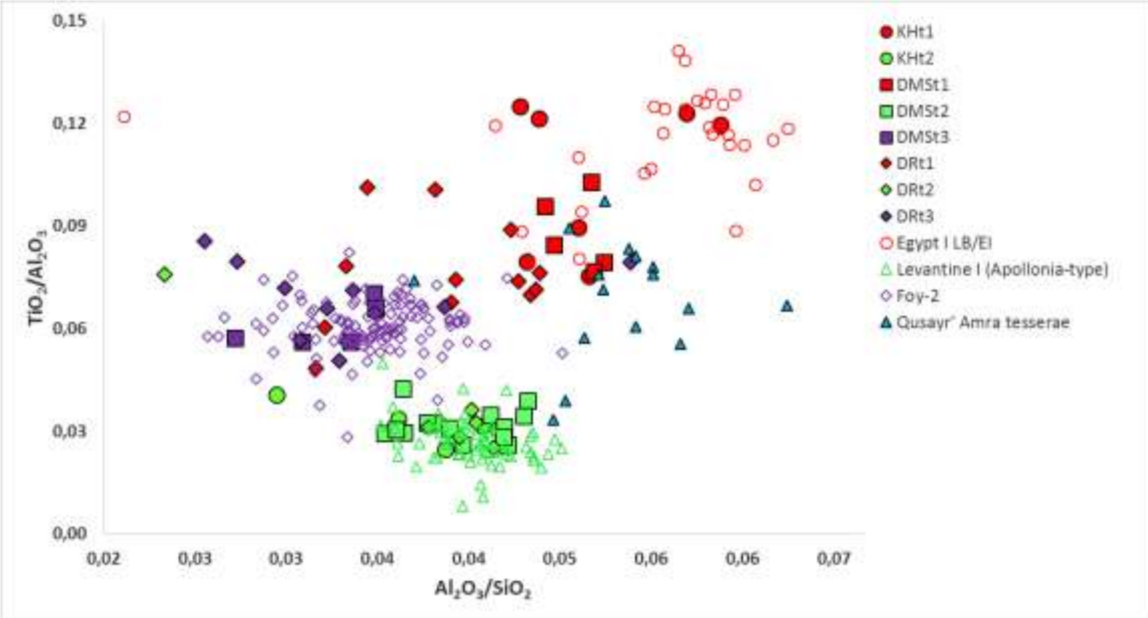


Fig.7.4 TiO_2/Al_2O_3 versus Al_2O_3/SiO_2 bi-plot (for the opaque tesserae, reduced wt% contents are used). Apollonia-type references: Freestone et al. 2008; Tal et al. 2004; Phelps et al. 2016; Egypt I late Byzantine/early Islamic references: Bonnerot et al. 2016; Foy et al. 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Foy-2: Foy & Picon 2003; Conte et al. 2014; Bonnerot et al. 2016; Neri et al. 2017; Neri, Gratuze & Schibille 2017; Qusayr' Amra: Verità et al. 2017.

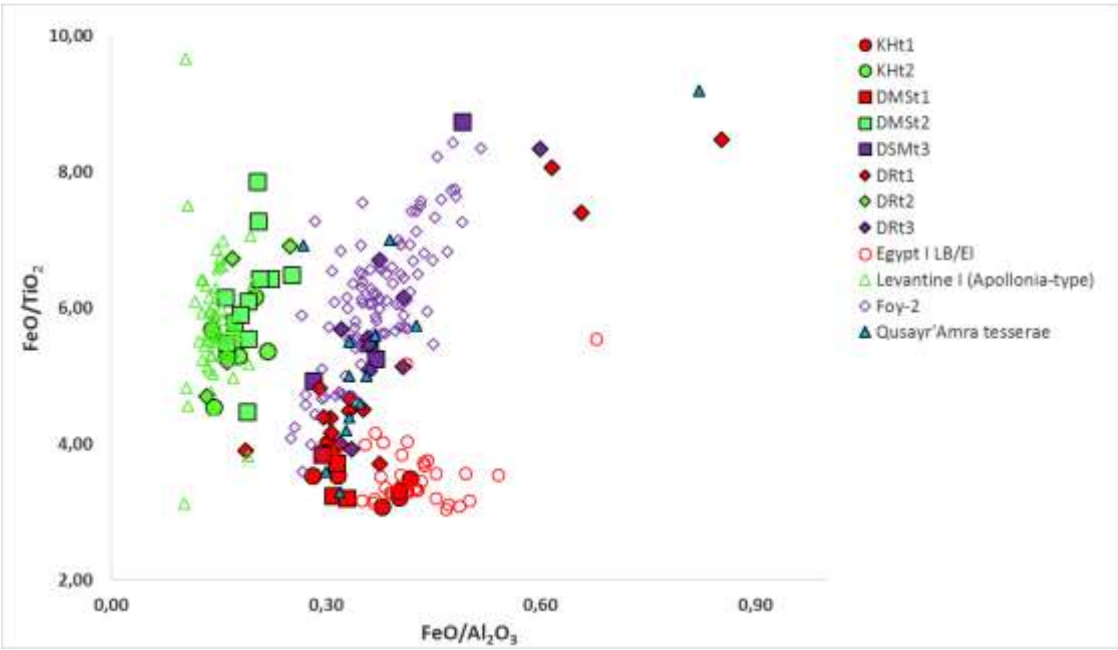


Fig.7.5 FeO/TiO_2 versus FeO/Al_2O_3 bi-plot (for the opaque tesserae, reduced wt% contents are used). Apollonia-type references: Freestone et al. 2008; Tal et al. 2004; Phelps et al. 2016; Egypt I late Byzantine/early Islamic references: Bonnerot et al. 2016; Foy et al. 2003; Gratuze & Barrandon 1990; Phelps et al. 2016; Foy-2: Foy & Picon 2003; Conte et al. 2014; Bonnerot et al. 2016; Neri et al. 2017; Neri, Gratuze & Schibille 2017; Qusayr' Amra: Verità et al. 2017.

EPMA and LA-ICP-MS data have shown, therefore, that tesserae from the Great Mosque of Damascus and the Dome of the Rock match Egypt I, Apollonia-type and Foy-2 compositional categories, while in the assemblage from Khirbat al-Mafjar only Egypt I and Apollonia-type glass groups were identified.

Before further discussing on the implications arising from the identified compositional categories, a brief restatement of the state of the art concerning the gathering of artisans and tesserae under the Umayyad caliphate needs to be done.

As emerged from the review addressed in chapter 3, several written sources seem to imply that the movement of tesserae and craftsmen around the Mediterranean was customary practice under the Umayyad caliphate.

A pivotal issue that has long bothered art historians is the current relationship between Umayyad and Byzantine mosaic manufacture and technology, with specific reference to both artisans and tesserae supply. Several Muslim literary sources[67] claim that Umayyad caliphs requested and got from the Byzantine emperor both workmen and mosaic cubes to construct and decorate religious buildings, like the Prophet's Mosque at Medina, the Dome of the Rock, the Great Mosque of Damascus and the Great Mosque of Cordoba.

Nevertheless, that of the sent tesserae is quite a thorny question, since the reliability - as well as the interpretation - of these sources has always been controversial among scholars: should these texts be read as propaganda pieces aimed at enlightening the power of the Muslim rulers or, on the contrary, could they imply that the trade of materials between Muslims and Byzantines went on despite their rivalry? (Cutler 2001; Gibb 1958; James 2006).

Though precise answers to these questions still need to be provided, Liz James has recently made some interesting reflections on the reliability of these Muslim accounts. According to James, "*the evidence for* Byzantine *mosaicists and materials being sent to the caliph has the ring of a* good story" (James 2017, p.267).

This statement essentially stems from two points: the absence of any mention in the Christian sources of Byzantine artists or mosaicists collaborating on the

[67] See chapter 3 for a detailed discussion upon them.

construction of the mosques (while Muslim texts take a different line), and the lack of any concrete material evidence for that.

Furthermore, it has to be reminded that, to date, no evidence exists for the making of raw glass in Constantinople at any time in its Byzantine history. As a direct consequence, it cannot be assumed that mosaic tesserae (or even the glass for tesserae) necessarily came from Constantinople or the Byzantine Empire.

It is, conversely, highly probable that there were large amounts of mosaic tesserae in ruined or dismissed Roman and Byzantine buildings that could have been recycled and reused. About the Prophet's Mosque at Medina, al-Tabari (9th-10th century) reports, for instance, that the Sultan of Rūm (the Greek Emperor), apart from sending gold, workmen and loads of mosaic to al-Walīd, also ordered a search for tesserae in ruined cities, which were sent to the caliph as well. It is likely that something analogous also happened for the construction of other Umayyad buildings.

In addition to that, thanks to recent research and surveys, it has also become discernible that mosaic was also more extensively used than suspected in the Muslim Levant, and not only restricted to the mosques (James et al. 2013).

It is reasonable to hypothesise that Umayyad caliphs were familiar with the buildings of the main cities of the Levant, and that they were inspired by what they saw in in the churches Syria, wanting to create something similar in mosaic. As the existence of mosaics in Antioch, Gaza, Lydda, Sergiopolis has been used to propose regional mosaic workshops operating between the 5th and the 6th century, it has also been hypothesised that these workshops continued to function in the following centuries and, thus, they might have provided the Umayyad caliphs with the materials and the mosaicists they needed, "local" Syrian workmen (James 2017).

The above digression works as indispensable prerequisite for a complete understanding and accurate contextualisation of the compositional data obtained by the analysis of the base glass.

Analytical data have been particularly helpful in determining the occurrence of specific compositional categories, whose span can be framed within a delimited geographical area in a quite well-defined chronological range by means of a punctual comparison with the literature.

In all the assemblages under study, the occurrence of tesserae matching Apollonia-type (Levantine I) compositional category has been demonstrated. According to the literature, tesserae manufactured by using an Apollonia-type raw glass have been found at different sites, often together with other compositional categories. Fig.7.6 provides a distributional map of these sites, located in the Mediterranean basin and mainly datable between the 5th and the 10th century (with the majority ascribable to the 6th century). More exactly: several monuments in Ravenna, Italy, as the Basilicas of St. Severo (Fiori 2011; Fiori 2013; Vandini et al. 2014), St. Apollinare Nuovo (Verità 2012), St. Vitale (Fiori et al. 2004) and the Neonian Baptistery (Verità 2011); the Chapel of St. Prosdocimus, inside the Basilica of St. Giustina in Padova, Italy (Silvestri et al. 2012; Silvestri et al. 2014); the Durres Amphitheatre, Albany (Neri, Gratuze & Schibille 2017); the Church of Hagios Polyeuktos at Constantinople, Turkey (Schibille & McKenzie 2014); the Baptistery of Tyana, Turkey (Serra et al. 2009); the Lower City Church at Amorium, Turkey (Wypyski 2005); the late antique church at Kilise Tepe, Turkey (Neri et al. 2017); Polis Chrysochous, Ayioi Pente, the Acropolis Basilica, Kalavasos-Kopetra and the Kourion, all sites located in Cyprus, Greece (Bonnerot et al. 2016); Huarte (Lahanier 1987); the Petra Church, Jordan (Marii 2013; Marii & Rehren 2009).

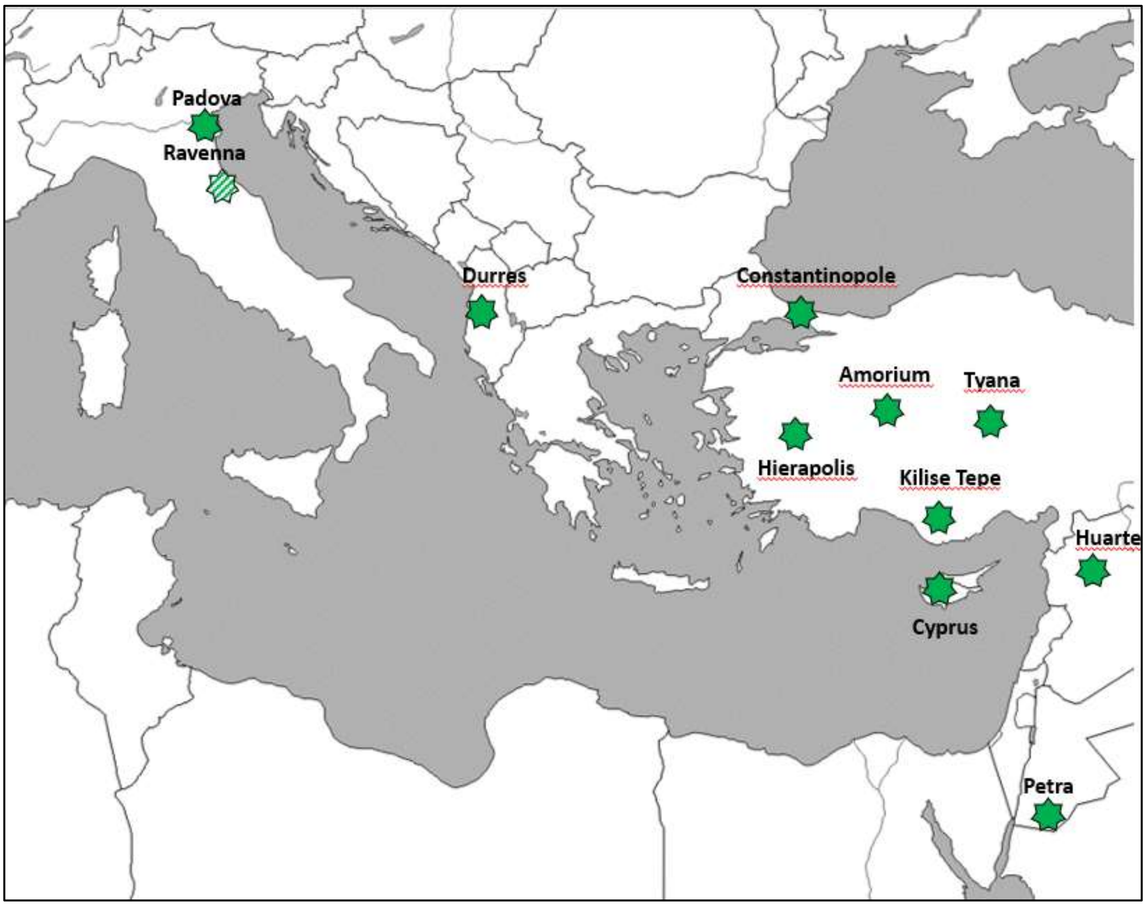


Fig.7.6 Sites where tesserae matching Apollonia-type compositional category were found. References: Padova, 6th century (Silvestri et al. 2012, Silvestri et al. 2014); Ravenna, 6th century (Fiori 2011; Fiori 2013; Fiori et al. 2004; Vandini et al. 2014; Verità 2011; Verità 2012) – site tag is filled in a different way because, in the references, the base glass is generically termed *Levantine* rather than *Levantine I*; Durres, 6th-8th century (Neri, Gratuze & Schibille 2017); Constantinople, 6th century (Schibille & McKenzie 2014); Hierapolis, 6th century (information provided in Neri et al. 2017); Amorium, 10th century (Wypysky 2005); Tyana, 5th century (Serra et al.2009); Kilise Tepe, 5th-6th century (Neri et al. 2017); Huarte, 5th century (Lahanier 1987); Cyprus, 6th century (Bonnerot et al. 2016); Petra, 5th-6th century (Marii 2013; Marii and Rehren 2009).

In the analysed assemblages from the Great Mosque of Damascus and the Dome of the Rock, tesserae matching Foy-2 compositional category were also found. Fig.7.7 shows the consumption sites where Foy-2 compositional category has been detected in assemblages of glass tesserae. More precisely, the sites are: the Chapel of St. Prosdocimus, inside the Basilica of St. Giustina in Padova, Italy (Silvestri et al. 2012, Silvestri et al. 2014); the Durres Amphitheatre, Albany (Neri, Gratuze & Schibille 2017); the Church of Hagios Polyeuktos at Constantinople, Turkey (Schibille & McKenzie 2014); the late antique church at Kilise Tepe, Turkey (Neri et al. 2017); Polis Chrysochous, Ayioi Pente, the Acropolis Basilica, Kalavasos-Kopetra and the Kourion, all sites located in Cyprus, Greece (Bonnerot et al. 2016).

It can be noticed that all sites are distributed across the Mediterranean basin, predominantly in the eastern area. Moreover, according to archaeological evidence, all assemblages are datable back between the 5th and the 8th century, with the majority being ascribable to the 6th century.

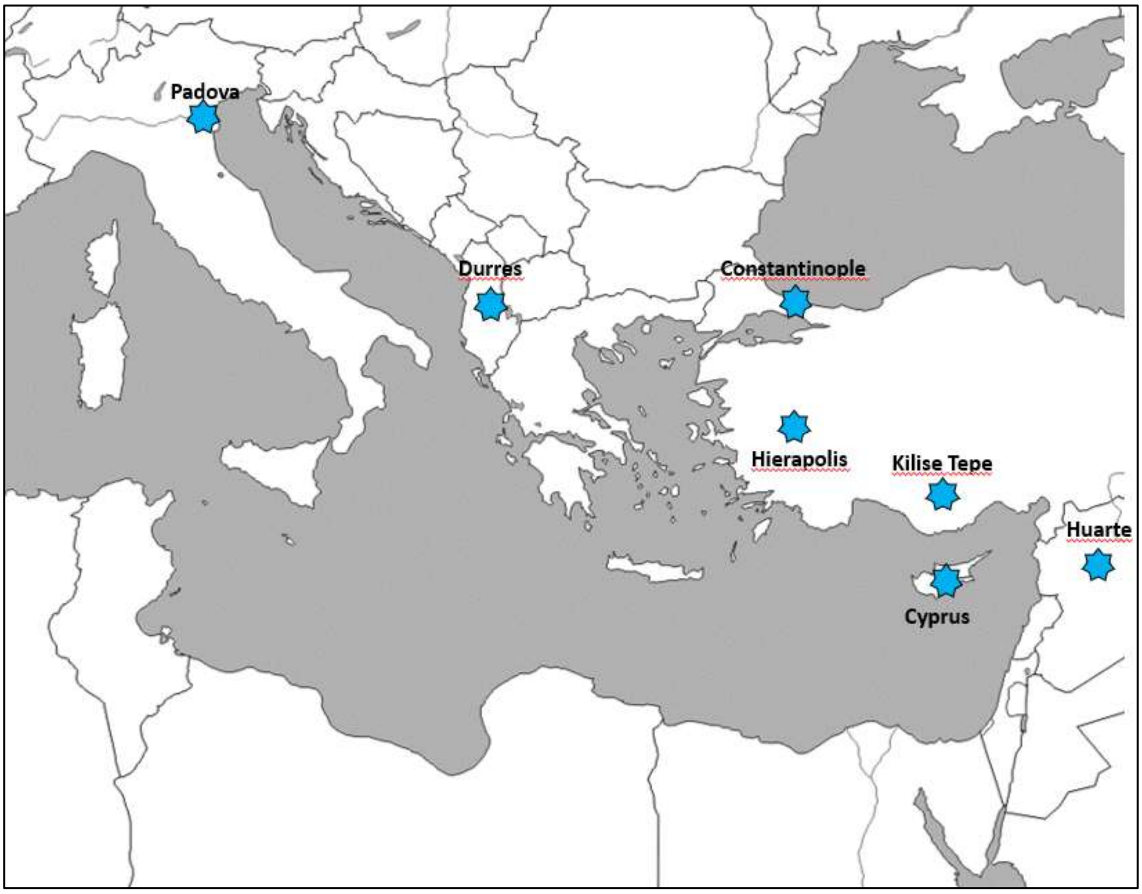


Fig.7.7 Sites where tesserae matching Foy-2 compositional category were found. References: Padova, 6th century (Silvestri et al. 2012, Silvestri et al. 2014); Durres, 6th-8th century (Neri, Gratuze & Schibille 2017); Constantinopole, 6th century (Schibille and McKenzie 2014); Hierapolis, 6th century (information provided in Neri, Jackson et al. 2017); Kilise Tepe, 5th-6th century (Neri et al. 2017); Huarte, 5th century (Lahanier 1987); Cyprus, 6th century (Bonnerot et al. 2016).

Maps in Fig.7.6 and 7.7 indicate that glass tesserae matching Apollonia-type and Foy-2 compositional categories were recovered from several sites located in the territories under the domain of the Byzantine emperor, datable back between the 5th and the 10th century and with a major amount in the 6th century.

Having detected both Apollonia-type and Foy-2 base glasses in all the Umayyad tesserae assemblages analysed in this research, points to a sort of continuity with the manufacture of mosaic glass tesserae in the late antique Levant.
Though scientific analyses cannot unequivocally ascertain whether Umayyad Apollonia-type and Foy-2 tesserae were freshly made (just before being used on site) or gathered from ruined and dismantled pre-existing monuments, further inferences can be drawn if data obtained by recent research on early Islamic glass vessels are also considered.
Plot shown in Fig.7.8 highlights how research undertaken by Phelps and colleagues (Phelps et al. 2016) demonstrated the existence of a high variability of glass typologies and recipe changes in the Umayyad period (661-750).

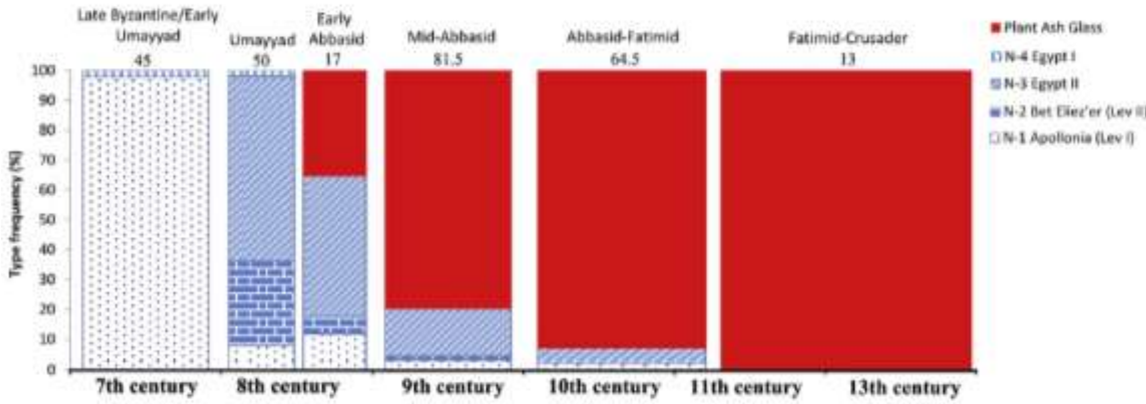


Fig.7.8 Histogram plotting percentage frequency of vessel compositional type against time (Phelps et al. 2016).

Two noteworthy information can be deduced by an accurate observation of the diagram: the complete absence of Foy-2 compositional category, both in the 7th and in the 8th century, and the decrease of Apollonia-type glass in the first half of the 8th century. As, contrariwise, Foy-2 and Apollonia-type glass are recurrent in Umayyad assemblages of mosaic tesserae, this datum could further support the hypothesis of tesserae recovered from dismantled sites, previously adorned with mosaics.

There is, however, a crucial element that distinguishes Umayyad mosaic tesserae assemblages from any other. Together with Apollonia-type and Foy-2 base glasses, the occurrence of Egypt I compositional category has also been found in all the assemblages under study.

The importance of having found this glass group is linked to two main reason: on the one hand, it is the first time that the use of Egypt I compositional category is documented for mosaic glass tesserae; on the other hand, it provides a tangible proof of the existence of legacies other than Levantine in the manufacture of Umayyad mosaics.

The comparison between compositional data achieved for Umayyad Egypt I tesserae and those reported in the literature for Egypt I from the primary production site of Wadi Natrun (Egypt) seems, moreover, to show that these categories have dissimilar compositional features and, therefore, they could be interpreted as distinct groups, probably made by using different recipes and, presumably, different sands[68].

The contribution of Egypt to the construction and decoration of Umayyad mosques is reported in several historical sources. At the end of the 9th century, al-Balādhurï wrote that al-Walīd sent money, mosaic, marble and eighty Rumī and Coptic craftsmen, inhabitant of Syria and Egypt to the Governor of Medina to aid in the construction of the Prophet's Mosque. An analogous inference is made by al-Maqdisī, who states that craftsmen of Syria and Egypt were brought to Mekka for working at the construction and decoration of the Mosque (Gautier-van Berchem 1969).

Information about workmen and materials being sent from Egypt to collaborate on the construction of the al-Aqsa Mosque and of the Great Mosque in Damascus are reported in the so-called "Aphrodito papyri", an official correspondence written in Greek and preserved as letters on papyrus found at Kom Ishqaw, Upper Egypt (Bell 1910; Bell 1911; Creswell 1969).

The theory supported by Mab van Lohuizen-Mulder, who suggested that the mosaics decorating the Great Mosque in Damascus were the product of

[68] Reasons underpinning this statement have already been discussed in Chapter 6.

Alexandrian mosaicists with the contribution of Syrian workmen in 1995 seem, thus, plausible (van Lohuizen-Mulder 1995).

The presence of a possible Alexandrian component in the mosaic of the Great Mosque has further been explored by Judith McKenzie (McKenzie 2013), who has focused her studies on a re-evaluation of the depiction of Alexandrian architecture in the Landscape Panorama (the largest intact area of mosaic dating back to the Umayyad decoration of the mosque) and has devoted a specific attention to the boat on the river depicted on the north arcade. This boat shows, according to McKenzie, distinctive typological features and elements that allow characterising it as a Nile boat and its occurrence in the original Umayyad decorative programme could provide additional evidence for the presence of an Alexandrian legacy in the making of the mosaics of the Great Mosque in Damascus.

Fig.7.9 summarises all is known, to date, on the base glass used in the manufacture of mosaic tesserae under the Umayyad caliphate in the Levant.

Fig.7.9 Glass groups identified among assemblages of tesserae datable to the Umayyad period. Materials from Qusayr' Amra are not part of this research, and shapes are differently filled as the identification of these specific compositional categories is not reported in the published paper (Verità et al. 2017), but has been made by the candidate.

In spite of their above discussed significance, data on the base glass are not sufficient to provide a complete scenario on mosaic glass tesserae manufacture and supply under the Umayyad caliphate, as at least one further (and awkward) question needs to be answered: were tesserae transported as an already finished product, or were they delivered as raw glass to be coloured and opacified either on site or in secondary workshops, probably located near the consumption sites?

7.2 Colouring and opacifying glass tesserae: what information from archaeometry?

Colouring and opacifying glass was probably the most challenging step in the making of tesserae, and when and where this occurred is still unknown.
According to recent research, the hypothesis of imported raw glass to be coloured on the site of the mosaic seems the most unlikely, as it would have implied the presence of skilled mosaicists or on-site glassworkers. In addition, adequate storage space for glass and tesserae would have been required, as well as room for furnaces and fuel, like enough workmen to cut the tesserae and sort the colours (James 2017).
Though sound archaeological evidence is still lacking, the most reliable hypothesis is that glass for tesserae was coloured in secondary workshops, perhaps by specialists either in colouring or in making a range of colours or even one specific colour. The idea that the making of certain colours was the preserve of individual craftsmen has long been popular among academia, but whether a specific glassmaker was ever attached to a mosaic workshop is unknown.
Regardless the historical period or the geographical area, our current knowledge of colouring and opacification technologies is extremely fragmentary. As detailly discussed in Chapter 4, apart from the tangible scarcity of data in the literature, the lack of a tailor-made analytical protocol is among the primary issues to be faced.
It must be reminded that, when dealing with the study of mosaic glass tesserae, it is impossible to benefit from the support of typological studies, that is, conversely, commonplace for glassware. Therefore, the definition of a methodical analytical protocol needs to be accurately evaluated, since archaeometry can play a fundamental role in unravelling the mysteries that concern manufacturing technology and circulation of tesserae.
In chapter 6, data on colourants and opacifiers have been reported and discussed in detail, and it has been shown how the micro-structures of mosaic glass tesserae can be highly inhomogeneous and particularly demanding to investigate. This high degree of complexity means that, most of the time, the

use of only one or a narrow range of analytical techniques is not sufficient to provide us with the information necessary for an in-depth understanding of the materials and the technologies used.
In this research, specific attention has been, thus, payed to the definition of what can be defined as a *best practice* analytical protocol to be applied on coloured mosaic glass tesserae, with the aim of gathering exhaustive and comparable data helpful in outlining a reliable picture on manufacturing processes and supply of this peculiar material category. In the following pages, some discussion upon the limits encountered in the use of one or another analytical technique will also be provided, to further stress the importance of choosing the most suitable techniques on the basis of the micro-structure and the micro-texture of the tesserae under investigation.
As the chromatic shades and the degree of opacity are the only features we can use when describing and selecting mosaic glass tesserae to be further investigated, the exact classification of the colours of the tesserae on an objective basis has been the first problem, to avoid any subjective description and to provide a reliable criterion for the selection of tesserae to be analysed.
All coloured tesserae were first divided into chromatic macro-categories defined in accordance with the second part of their NCS-notations, describing the hue (see chapter 4). Among the assemblages under study, four macro-categories were identified: red, black, blue, yellow and green. Then, on the opaque coloured tesserae, VIS-RS was carried out, to gain the numerical coordinates describing the colour shades.
Fig.7.10 shows reflectance curves of tesserae belonging to NCS-Red macro-category. It can be noticed that all of them display a very flat behaviour in the wavelength range between 400 and 580 nm, followed by an increase of reflectance intensity for the wavelengths above 580 nm (the red region of the visible spectrum). SEM-EDS analyses demonstrated that the micro-structure of these RED tesserae is characterised by the presence of nanometric rounded particles of copper dispersed into the glassy matrix, and XRPD allowed to exactly characterise these particles as metallic copper, responsible for the red hue as well as for the opacity. For the red tesserae, micro-Raman did not

provide suitable data in the identification of the colouring/opacifying agent, both for the type of laser used and for the extremely exiguous dimensions of the particles, impossible to be observed at the magnifications obtained by using a Raman microscope.

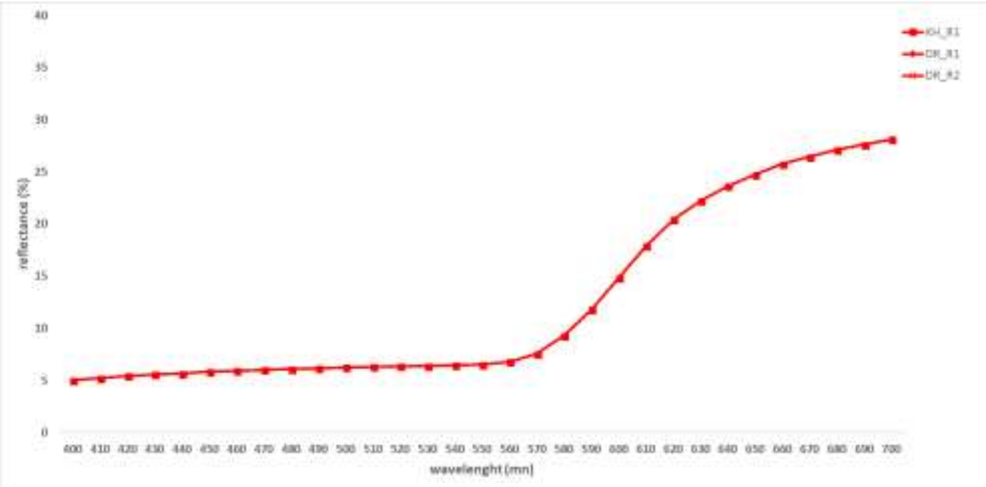


Fig.7.10 Reflectance curves obtained by VIS-RS measurements on opaque red tesserae.

Reflectance curves of tesserae belonging to NCS-Black macro-category are reported in Fig..7.11: all of them show a display an entirely flat behaviour in the wavelength range 400-700 nm, consistent with the absorption of all the visible radiation responsible for the apparent black colour.

As more extensively discussed in chapter 6, the comparison between compositional and micro-structural features seems to suggest that black tesserae are the result of a “failed” red colouration.

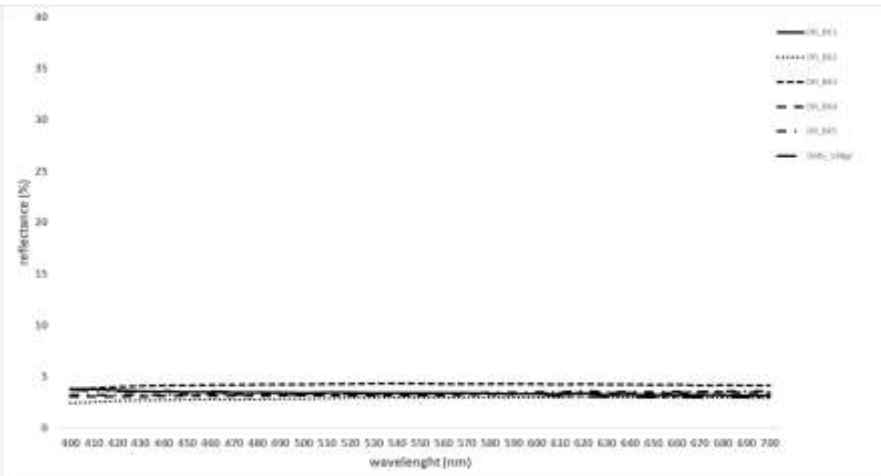
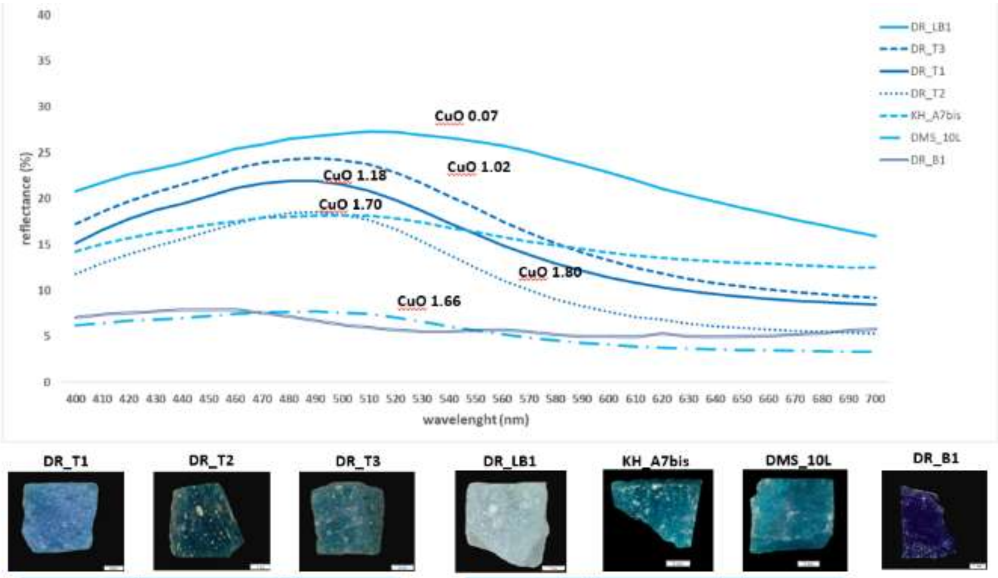


Fig.7.11 Reflectance curves obtained by VIS-RS measurements on opaque black tesserae.

Fig.7.12 shows reflectance curves obtained by VIS-RS on tesserae belonging to NCS-Blue macro-category.



Tessera	CuO	PbO
DR_T1	1.18 wt%	0.17 wt%
DR_T2	1.80 wt%	0.34 wt%
DR_T3	1.02 wt%	0.13 wt%

Tessera	CuO	PbO
DR_LB1	0.07 wt%	0.74 wt%
KH_A7bis	1.70 wt%	0.26 wt%
DMS_10L	1.66 wt%	0.56 wt%

Fig.7.12 Reflectance curves obtained by VIS-RS measurements on opaque blue tesserae.

Different profiles are observable: DR_T1, DR_T2 and DR_T3 have well-defined bell-shaped curves with a reflectance peak between 440 and 540 nm (the blue and the green zones of the visible spectrum); this bell shape is less pronounced for tesserae DR_LB1, DMS_10L and KH_A7, also showing easily noticeable variations in the reflectance percentages (Fig.7.13).

The different profiles of the curves can be related to some compositional features of the tesserae. DR_LB1 has higher PbO content compared to all other opaque NCS-Blue tesserae (0. 74 wt%); this is responsible for an increase of the lightness (L*) of the tessera, resulting in a higher reflectance percentage (Fig.7.12, 7.13). Compared to DR_LB1, tesserae DMS_10L and KH_A7 have lower PbO (0.56 and 0.26 wt%), but higher CuO contents (being respectively 1.66 and 1.70 wt%). Hence, the profiles of their curves more closely match those observed for samples DR_T1, DR_T2 and DR_T3, having CuO contents ranging between 1.02 and 1.80 wt%. However, slightly lower reflectance percentages can be observed for tesserae KH_A7bis and DMS_10L, and histogram in Fig.7.13 allows to relate this decrease to the lower lightness.

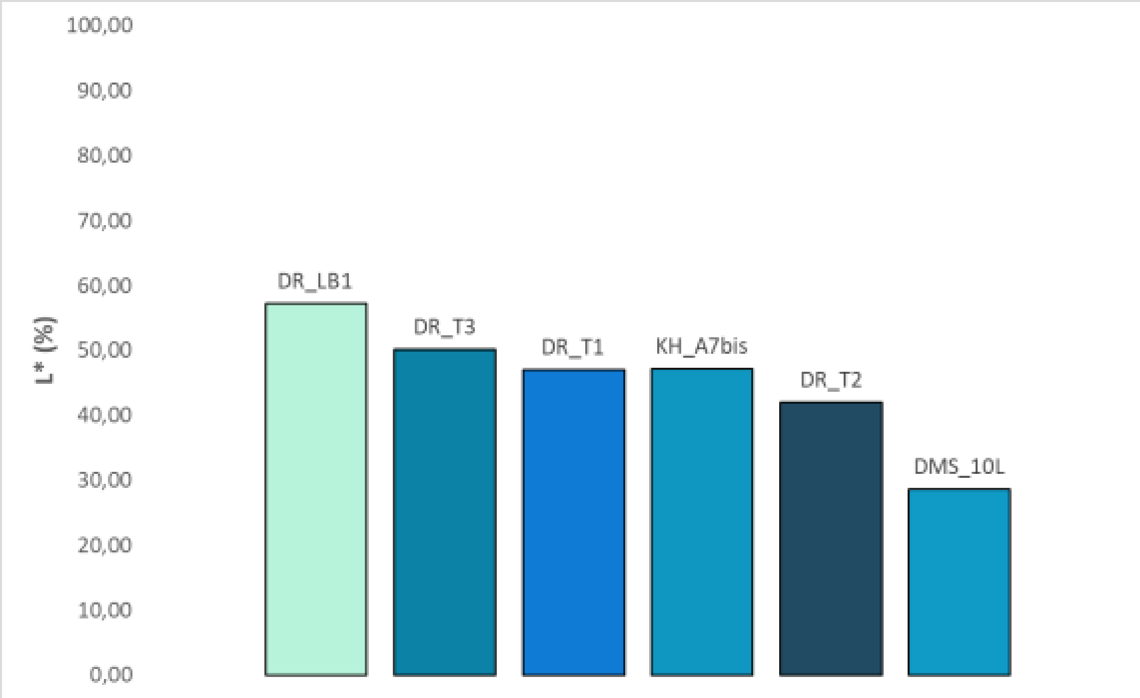


Fig.7.13 Luminosity (L*) percentages of the blue tesserae, obtained by VIS-RS.

Last, the region where the reflectance peaks of all the NCS-Blue tesserae is located (440-540 nm) is consistent with the presence of copper acting as colouring agent; moreover, a decrease of reflectance is intensity occurs when copper concentration increases (Galli et al. 2006; Galli et al. 2007).

It can, thus, be stated that, for the NCS-Blue tesserae, different profiles of the curves and different percentages of reflectance can be related to the contents of copper in the glassy matrix, responsible for the chromatic shades, and the presence of lead, enhancing the brilliance of the tesserae and, therefore, resulting in higher lightness (L*). Finally, it can be observed that DR_B1 tessera (dark blue colour) shows a completely different reflectance curve, consistent with those reported in the literature for tesserae coloured by the addition of cobalt (Galli et al. 2006; Galli et al. 2007).

A combined SEM-EDS and micro-Raman approach allowed an in-depth analysis of the micro-structures of the tesserae belonging to NCS-Blue macro-category, and results demonstrated that all but DMS_10L tessera were opacified with bone ash (see chapter 6). Achieved analytical data also allow to add further considerations on the opacification technology of these tesserae. The presence of reaction rims surrounding the core of P-based inclusions has only been observed in tesserae from Khirbat al-Mafjar. As, in the rims, the occurrence of β-rhenanite has been demonstrated, whose formations occurs at temperatures around 650°C (Silvestri et al. 2016), an addition of bone ash to the glass melt at lower firing temperatures can be hypothesised for tesserae in which these rims are lacking.

The addition of bone ash acting as an opacifying agent has been detected in several assemblages of mosaic glass tesserae: late antique church at Kilise Tepe, Turkey (Neri et al. 2017); the Baptistery of Tyana, Turkey (Silvestri et al. 2016); Polis Chrysochous, Ayioi Pente, the Acropolis Basilica, Kalavasos-Kopetra and the Kourion, all sites located in Cyprus, Greece (Bonnerot et al. 2016); the Petra Church, Jordan (Marii 2013; Marii and Rehren 2009); the Chapel of St. Prosdocimus, Padova, Italy (Silvestri et al. 2012, Silvestri et al. 2016); the Baths of Qusayr ‘Amra, Jordan (Verità et al. 2017); the Lower City Church at Amorium, Turkey (Wypyski 2005).

Interestingly, it seems to emerge that the use of bone ash as opacifier is not attested before the 5th century. In addition to that, the majority of the study cases cited above concern mosaic glass tesserae coming from archaeological sites mainly located in the eastern Mediterranean basin, as shown in Fig.7.14[69].

[69] This map (as the following related to the geographical distribution of other colourants/opacifiers) is based on the present state of the art. Though explicative, it can be considered neither conclusive nor exhaustive, as it is impossible to exclude that further data from forthcoming studies on the occurrence of specific colourants/opacifiers in one or another geographic area could led to a different picture.

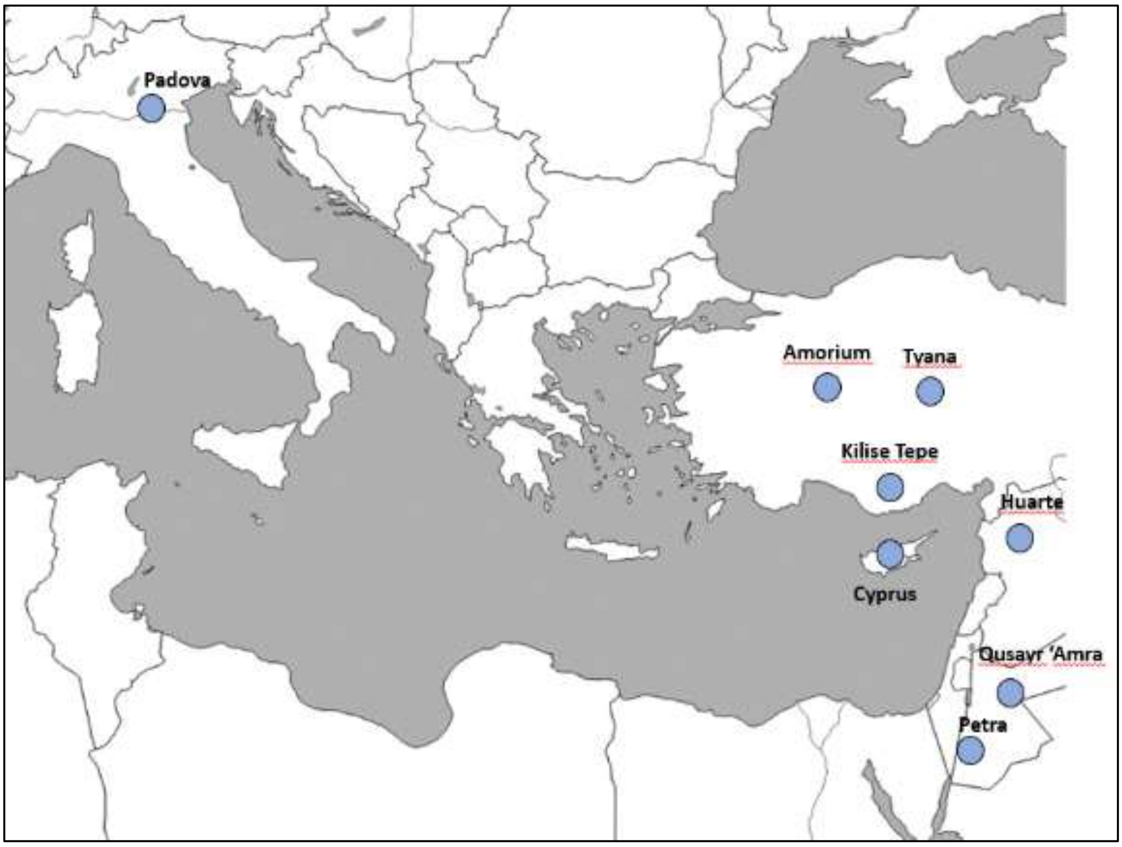


Fig.7.14 Map with the indication of sites where tesserae containing phosphorus-based opacifiers were detected. References: Padova, 6th century (Silvestri et al. 2012, Silvestri et al. 2016); Amorium, 10th century (Wypysky 2005); Tyana, 5th century (Silvestri et al. 2016); Kilise Tepe, 5th-6th century (Neri et al. 2017); Huarte, 5th century (Lahanier 1987); Cyprus, 6th century (Bonnerot et al. 2016); Petra, 5th-6th century (Marii 2013; Marii and Rehren 2009).

Reflectance curves of tesserae belonging to NCS-Yellow macro-category are reported in Fig.7.15. An increase of reflectance intensity for the wavelengths above 480 nm is always observed. DMS_7G shows a slightly higher reflectance percentage, confirmed by a higher lightness (L*=71.13 %).

The curve obtained by VIS-RS on NCS-Yellow tesserae closely match those reported by Cloutis and colleagues for powdered lead-tin oxides-based yellow pigments (Cloutis et al. 2016). More precisely, the closest similarity occurs with standard PIG818, a Lead-Tin Yellow type II. Though all lead-tin oxides-based yellow pigments have broadly similar reflectance spectra, consistent with their similar compositions, PIG818 shows the shallowest absorption edge, closely resembling the profiles of the curve acquired on NCS-.Yellow tesserae

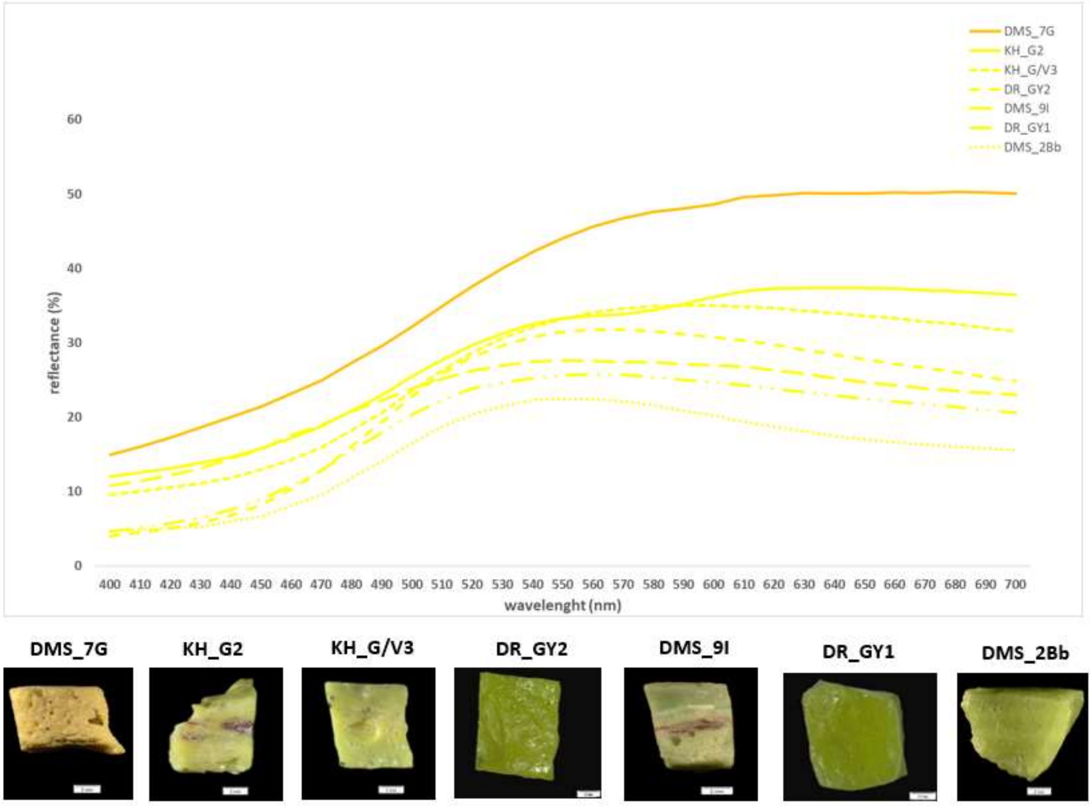


Fig.7.15 Reflectance curves obtained by VIS-RS measurements on opaque yellow tesserae.

SEM-BSE inspection of all yellow tesserae demonstrated the occurrence of extremely heterogeneous micro-structures, characterised by differently shaped crystals precipitated into the glassy matrix and mainly found as aggregates. After preliminary SEM-EDS elemental analysis, micro-Raman and XRPD measurements were carried out to provide an exact characterisation of the molecular and mineralogical signatures of these inclusions, and achieved data indicate that Lead Tin Yellow type II was added to the base glass to obtain the yellow colour (see chapter 6).

The same lead-tin-based compound was used to colour (and opacify) the majority of tesserae belonging to NCS-Green macro-category, the ultimate green shades being conferred by the combination between Lead Tin Yellow type II and copper.

Fig. 7.16 a-c show reflectance curves of all tesserae belonging to NCS- Green macro-category. Some differences can be observed in terms of both reflectance intensity and profiles of the curves, linkable to the different shades of green encountered inside the green macro-category and ascribable to the compositional features of the tesserae (more precisely, to the colouring and opacifying agents identified by means of SEM-EDS, micro-Raman and, when necessary, XRPD).

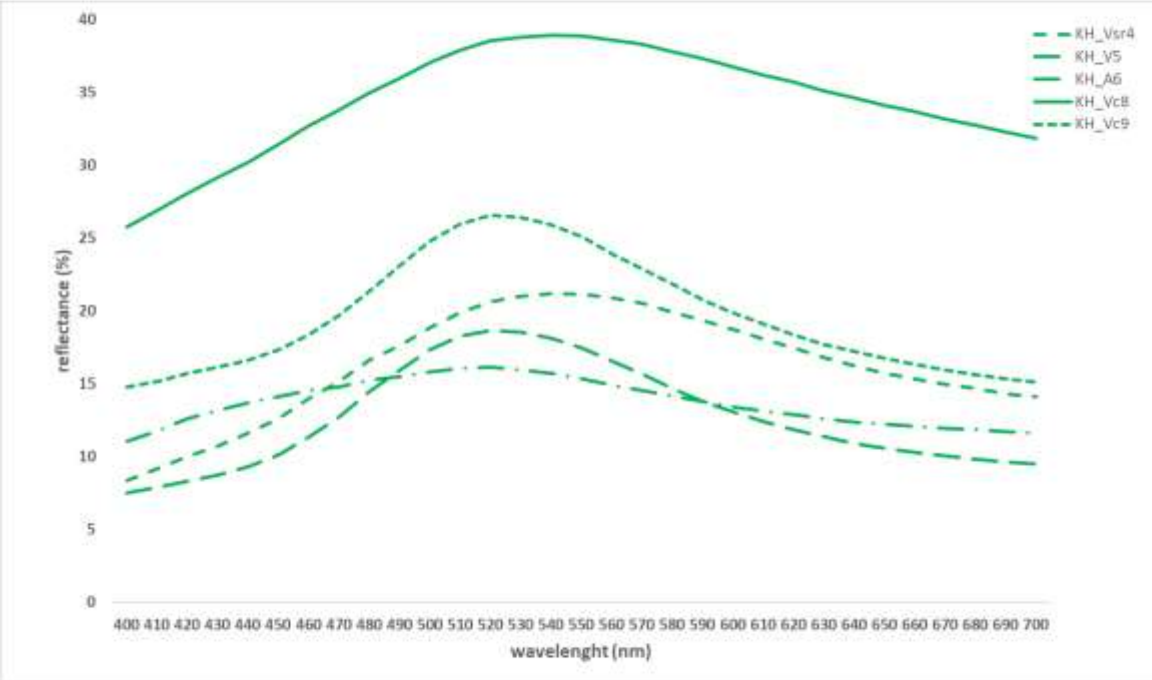


Fig.7.16a Reflectance curves obtained by VIS-RS measurements on opaque green tesserae from Khirbat al-Mafjar.

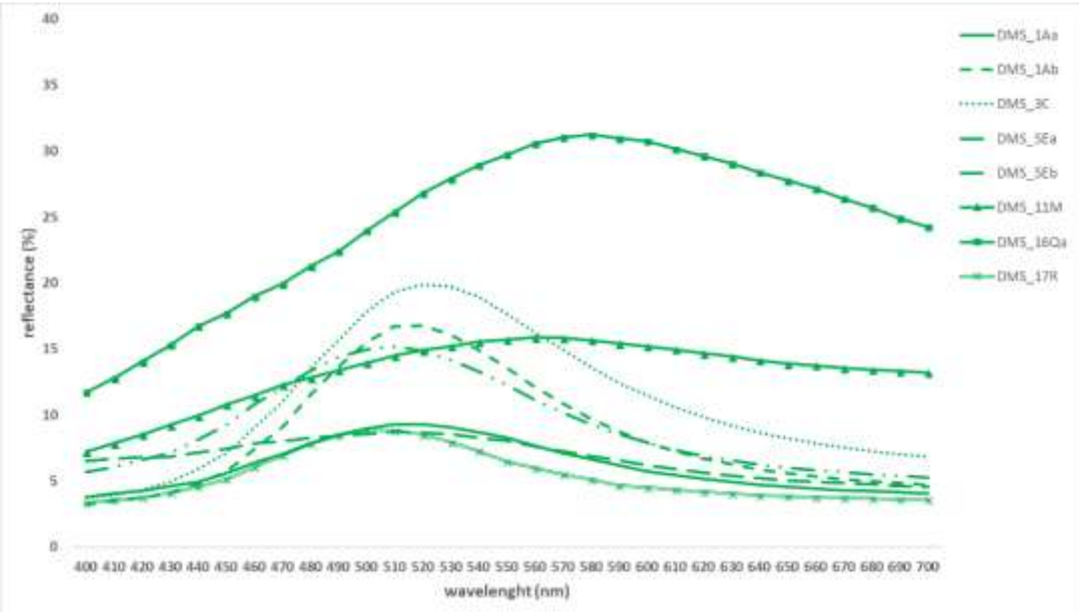


Fig.7.16b Reflectance curves obtained by VIS-RS measurements on opaque green tesserae from the Great Mosque of Damascus.

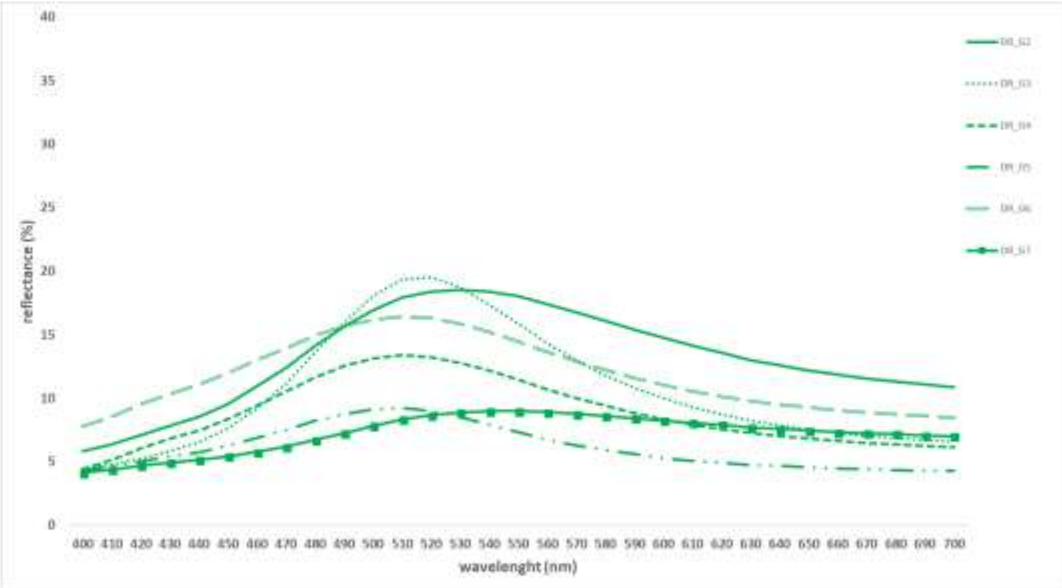


Fig.7.16c Reflectance curves obtained by VIS-RS measurements on opaque green tesserae from the Dome of the Rock.

Reflectance curves of NCS-Green tesserae whose colour shades and opacity degrees are ascribable to the addition of Lead Tin Yellow type II and copper are displayed in Fig.7.17a, while in Fig.7.17b NCS-Green tesserae opacified with cassiterite and coloured by copper are shown.

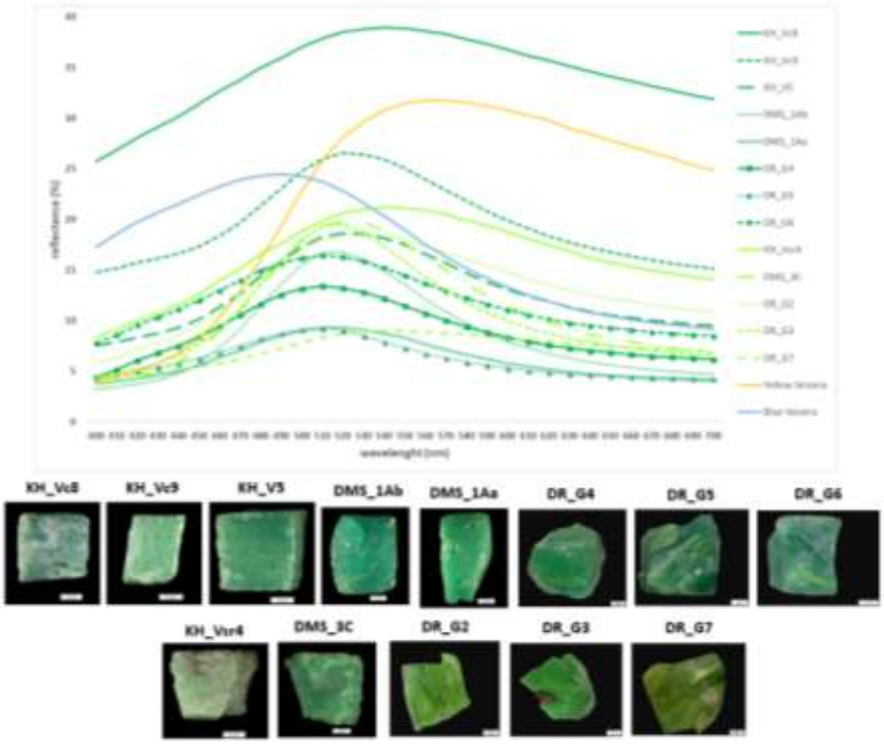


Fig.7.17a Reflectance curves obtained by VIS-RS measurements on opaque green tesserae coloured and opacified with Lead Tin Yellow type II and copper.

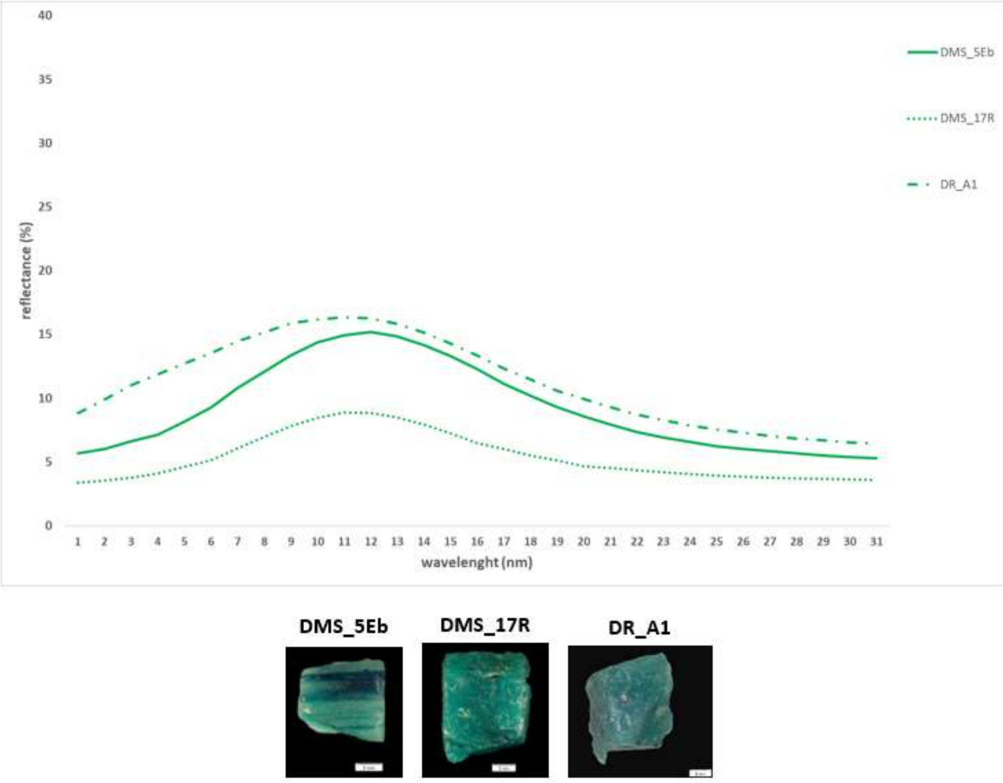
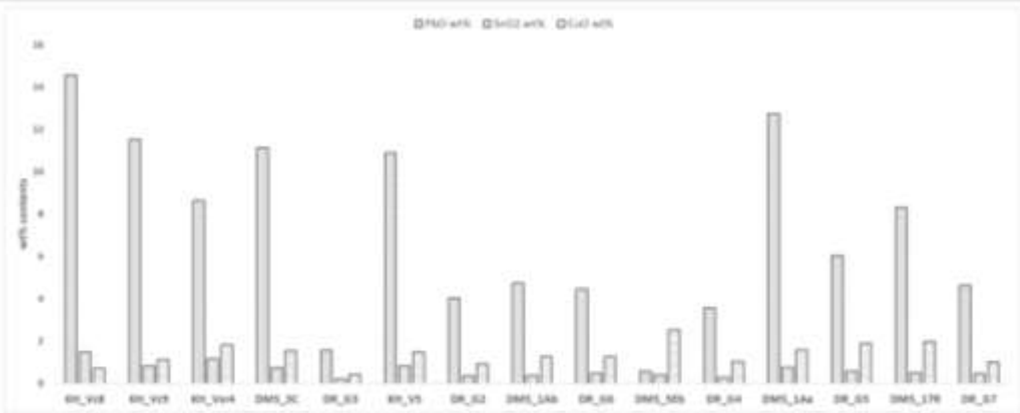


Fig.7.17b Reflectance curves obtained by VIS-RS measurements on opaque green tesserae coloured with copper and opacified with cassiterite.

It can be noticed that the profiles of the curves in Fig.7.17a look like a combination between those of a copper-coloured blue tessera and a Lead Tin Yellow type II-coloured yellow one: a peak is observable between 480 and 560 nm, followed by a reflectance decrease above 550 nm. Conversely, the profiles of the curves displayed in Fig.7.17b more closely resemble those of NCS-BLUE tesserae coloured by copper (Fig.7.12).

In addition to that, NCS-Green tesserae whose colour shades are more turned towards a yellowish-green (KH_Vsr4, DMS_3C, DR_G2, DR_G4, DR_G7) show trends of the reflectance curves more similar to those of the yellow tesserae (Fig.7.17a). Conversely, NCS-Green tesserae whose colour shades are more turned towards a proper green hue show trends of the reflectance curves more similar to those of the blue tesserae coloured by the addition of copper.

In the case of NCS-Green tesserae opacified and coloured by Lead Tin Yellow type II and copper, no correlation was found between copper contents and reflectance: decrease of reflectance is not always observed when copper contents increase. Lead and tin oxides contents do not seem to impact on the reflectance as well (Fig.7.18). It can only be stated that the higher reflectance percentages of tesserae KH_Vc8 and KH_Vc9 are linked to slightly higher lead contents, responsible for a higher brilliance and lightness.



Tessera	PbO (wt%)	SnO_2 (wt%)	CuO (wt%)
KH_Vc8	14.56	1.47	0.7
KH_Vc9	11.53	0.81	1.12
KH_Vcr4	8.83	1.16	1.82
DMS_3C	11.14	0.74	1.53
DR_G3	1.56	0.19	0.41
KH_V5	10.89	0.82	1.47
DR_G2	4.04	0.36	0.92
DMS_1Ab	4.74	0.38	1.26
DR_G6	4.45	0.47	1.26
DMS_5Eb	0.58	0.4	2.53
DR_G4	3.58	0.28	1.03
DMS_1Aa	12.72	0.75	1.6
DR_G5	6.03	0.38	1.89
DMS_17R	8.32	0.49	1.98
DR_G7	4.63	0.45	1

Fig.7.18 Histogram showing PbO, SnO_2 and CuO contents (wt%) in opaque green tesserae opacified by the addition of Lead Tin Yellow II and copper.

Lead Tin Yellow type II belongs to the category of tin-based colourants, started being systematically used from the 4^{th} century to replace antimony-based ones, probably either to face a breakdown in the supply of antimony or consequently to the establishment of closer relations between the Roman Empire and India (Tite et al. 2008). Regarding mosaic glass tesserae, a conspicuous number of study cases attest the use of tin-based phases, especially in the Mediterranean basin: the Durres Amphitheatre, Albany (Neri, Gratuze & Schibille 2017); the late antique church at Kilise Tepe, Turkey (Neri et al. 2017); Polis Chrysochous, Ayioi Pente, the Acropolis Basilica, Kalavasos-Kopetra and the Kourion, all sites located in Cyprus, Greece (Bonnerot et al. 2016); the Petra Church, Jordan (Marii 2013; Marii and Rehren 2009); the Baths of Qusayr'

Amra, Jordan (Verità et al. 2017); the Lower City Church at Amorium, Turkey (Wypyski 2005); the Catacomb of San Gennaro, Naples (Schibille et al. 2018); the Basilica of St. Peter, Rome (Arletti, Vezzalini et al. 2011); the Florences's Baptistery (Arletti, Conte et al. 2011); the Basilicas of St. Vitale (Fiori et al. 2004) and St. Severus (Fiori 2011; Fiori 2013; Vandini et al.2014) in Ravenna, Italy; the Chapel of St. Prosdocimus, Padova (Silvestri et al. 2012, Silvestri et al. 2014); the Baptistery of St. Giovanni alle Fonti in Milano, Italy (Neri et al. 2013); the Casa delle Bestie Ferite, Aquileia (Maltoni & Silvestri 2018)[70].

Fig.7.19 provides a distributional map of assemblages of tesserae where the presence of tin-based phases (cassiterite and lead stannate) has been detected; interestingly, it can be noticed that most of the sites are located in the eastern area of the Mediterranean basin and datable between the 6th and the 8th century.

[70] Tin-based phases were also used from the 5th to the 9th century to produce yellow and white beads in Anglo-Saxon England (Bayley & Wilthew 1986), Ireland (Henderson 1988) and Germany (Heck & Hoffmann 2000), Islamic white and yellow enamels in the 12th century (Mason 2004; Mason & Tite 1997) and Venetian glass in the 13th century (Freestone & Bimson 1995).

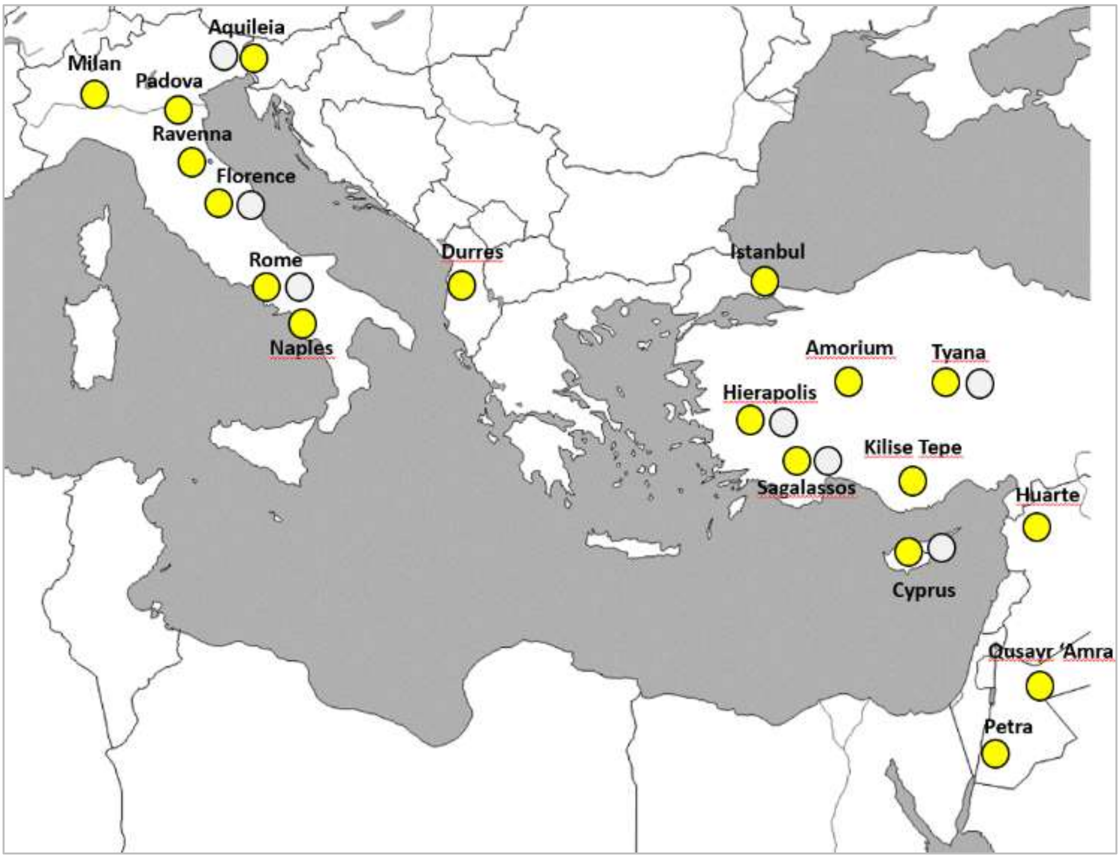


Fig.7.19 Map with the indication sites where tesserae containing tin-based phases were detected (lead stannate in yellow, cassiterite in white). Data from: Kilise Tepe, 5th-6th century (Neri et al. 2017); Durres, 6th-8th century (Neri, Gratuze & Schibille 2017); Istanbul, 6th century (Schibille & McKenzie 2014); Cyprus, 6th century (Bonnerot et al. 2016); Sagalassos, 6th century (Schibille et al. 2012); Amorium, 10th century (Wypyski 2005); Hierapolis (information reported in Neri et al. 2017); Huarte, 5th century (Lahanier 1987); Qusayr 'Amra, 8th century (Verità et al. 2017); Petra, 5th-6th century (Marii 2013; Marii and Rehren 2009); Tyana, 5th-6th century (Serra et al. 2009); Naples, 4th-9th century (Schibille et al. 2018); Rome, 16th century (Arletti, Vezzalini et al. 2011); Florence, 13-14th century (Arletti, Conte et al. 2011); Ravenna, 5th-6th century (Fiori et al. 2004; Fiori 2011; Fiori 2013; Vandini et al. 2014); Padova, 6th century (Silvestri et al. 2012, Silvestri et al. 2014); Milano, 5th-6th century (Neri et al. 2013); Aquileia, 4th century (Maltoni & Silvestri 2018) .

Some further considerations upon colouring technology. Though the use of Lead Tin Yellow type II (whichever the stoichiometry) has here been detected in both yellow and green tesserae, accurate study of the micro-textures highlighted some differences. Yellow tesserae show a higher abundance of anhedral crystals in the glassy matrices, mainly found as aggregates; in the green-shaded tesserae a higher distribution of acicular-shaped crystals, whose composition is consistent with SnO_2, can be observed, while anhedral inclusions are more sporadic and often found as isolated crystals. As the persistence of cubic lead-stannate (responsible for the yellow colour) is mainly dependent upon temperature (Matin et al. 2018; Tite et al. 2008), it can be here hypothesised that different firing temperatures were used to achieve the different chromatic shades: lead-tin-oxide type II crystals are, in fact, stable at up to temperatures between 750°C and 1000°C; at higher values, crystals begin to decompose and re-crystallise as SnO_2. As a consequence, it is likely that green tesserae where produced at higher furnace temperatures than yellow, as they show a relatively high abundance of SnO_2 crystals in the glassy matrix.

Some NCS-Green tesserae were opacified by the addition of bone ash and coloured by means of copper dissolved into the glass. These samples show reflectance curves resembling those recorded for NCS-Blue tesserae, with peaks between 440 and 540 nm (Fig.7.20). A different profile can be observed for tessera DMS_16Qa, with a higher reflectance percentage compared to other yellow tesserae and a shifted peak, occurring at about 570-580 nm. These differences can be linked to compositional features, as 16Qa tessera is characterised by a PbO content of 2.33 wt%. The higher reflectance percentage can, thus, be due to the addition of lead oxide to the base glass responsible for an increase in the brilliance and, therefore, of the reflectance of the surface.

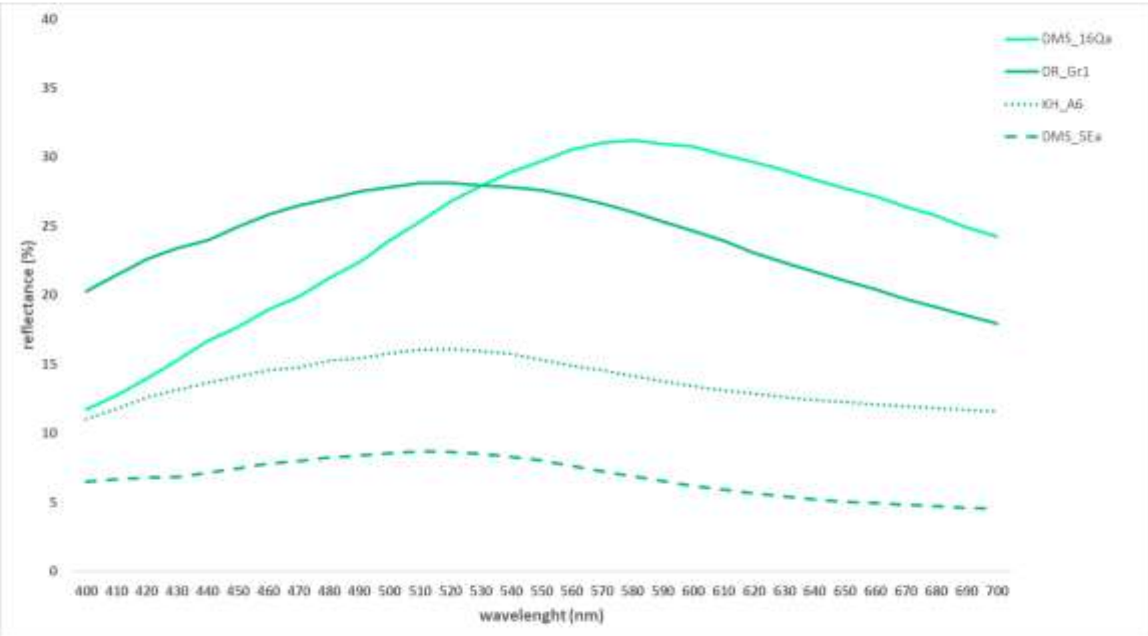


Fig.7.20 Reflectance curves obtained by VIS-RS measurements on opaque green tesserae opacified with bone ash and coloured with copper.

If data obtained from scientific analyses performed to characterise the materials used to achieve the desired colour shades and opacity degrees are viewed in their entirely, two main conclusions can be made: first, the same materials were employed for colouring and opacifying diverse types of raw glass used in the manufacture of tesserae; second, these materials are consistent with those found among assemblages of tesserae from sites located across the Mediterranean basin, especially in its eastern area.

Now can this information, compared with results obtained from the study of base glass and interfaced with data reported in the historical sources, be useful in terms of defining a framework for manufacturing technology and supply of mosaic glass tesserae under the Umayyad caliphate?

7.3 Plausible hypotheses upon manufacture and supply models

It can be affirmed that a definitely intriguing scenario has emerged from the archaeometric characterisation of the tesserae under study, in terms of both raw materials and colouring/opacifying technology.

The first data deserving specific attention has been the occurrence of different types of base glass, pointing to several suppliers.

But suppliers of *what*? Here we go back to what can be defined as the crucial question affecting the manufacture of mosaic tesserae: were they supplied as an already finished product or was glass traded as raw glass to be coloured and opacified either in secondary workshops or on site?

It has been shown that, in the Umayyad assemblages under study, colouring and opacifying technology do not correspond to differences in the base glass compositions. In other words, tesserae belonging to the same chromatic groups do not have the same base glass, but the same materials were employed for colouring and opacifying both Levantine and Egyptian raw glass used in the manufacture of tesserae (Tab.7.1a,b).

Having found tesserae made of different base glass but coloured and opacified with the same materials could imply that (plausible) secondary workshops specialised in the production of either one or several colours supplied glass from different primary production centres.

Other manufacturing and supply models need, however, to be considered.

It has been demonstrated that analyses carried out to characterise the base glass allowed to distinguish between a Levantine and an Egyptian manufacture of the base glass employed in the production of the tesserae, since Apollonia-type, Foy-2 and Egypt I compositional categories were identified.

Though this double supply of raw glass matches the picture emerged from a recently carried out research on glass vessels datable back to the Umayyad period (Phelps et al. 2016), one thought-provoking difference can also been noticed: the complete absence of glass matching Foy-2 and Egypt I compositional categories, both in the 7th and in the 8th century Umayyad glass vessels assemblages. In addition to that, another datum deserving attention is the noticeable decrease of Apollonia-type glass in the first half of the 8th century.

	Site	N.	Sample	Base glass	Colourant	Opacifier
Red	Khirbat al-Mafjar (KH)	1	R1	Egypt I	Cu nano-particles	Cu nano-particles
	Great Mosque of Damascus (DMS)	0				
	Dome of the Rock (DR)	2	R1	Apollonia-type	Cu nano-particles	Cu nano-particles
			R2	Foy-2	Cu nano-particles	Cu nano-particles
Yellow	Khirbat al-Mafjar (KH)	2	G2	Apollonia-type	Lead Tin Yellow II	Lead Tin Yellow II
			G/V3	Egypt I	Lead Tin Yellow II	Lead Tin Yellow II
	Great Mosque of Damascus (DMS)	5	2Ba	Apollonia-type	Lead Tin Yellow II	Lead Tin Yellow II
			2Bb	Egypt I	Lead Tin Yellow II	Lead Tin Yellow II
			7G	Foy-2	Lead Tin Yellow II	Lead Tin Yellow II
			9I	Apollonia-type	Lead Tin Yellow II	Lead Tin Yellow II
			14O	Apollonia-type	Iron (?)	Ca-Si-based
	Dome of the Rock (DR)	2	GY1	Foy-2	Lead Tin Yellow II	Lead Tin Yellow II
			GY2	Egypt I	Lead Tin Yellow II	Lead Tin Yellow II
Green	Khirbat al-Mafjar (KH)	6	Vsr4	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			V5	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			A6	Egypt I	Copper	Calcium Phosphate
			Vc8	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			Vc9	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			Ga10	Egypt I	Iron (?)	Calcium Phosphate
	Great Mosque of Damascus (DMS)	10	1Aa	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			1Ab	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			3C	Apollonia-type	Lead Tin Yellow II + copper	Lead Tin Yellow II
			5Ea	Apollonia-type	Copper	Calcium Phosphate
			5Eb	Apollonia-type	Copper	Cassiterite
			11M	Apollonia-type	Lead Antimonate + copper	Lead Antimonate
			13Nv	Apollonia-type	Iron	Ca-Si-based
			16Qa	Apollonia-type	Copper	Calcium Phosphate
			17R	Egypt I	Copper	Cassiterite
			20U	Egypt I	Copper	Cassiterite
	Dome of the Rock (DR)	8	A1	Apollonia-type	Copper	Cassiterite
			G2	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			G3	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			G4	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			G5	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			G6	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			G7	Egypt I	Lead Tin Yellow II + copper	Lead Tin Yellow II
			GR1	Egypt I	CuO	Calcium Phosphate
Blue	Khirbat al-Mafjar (KH)	2	A7	Apollonia-type	Copper	Calcium Phosphate
			A7bis	Apollonia-type	Copper	Calcium Phosphate
	Great Mosque of Damascus (DMS)	1	10L	Egypt I	Copper	Cassiterite
	Dome of the Rock (DR)	6	B1	Foy-2	Copper	Cassiterite
			LB1	Egypt I	Copper	Calcium Phosphate
			T1	Foy-2	Copper	Calcium Phosphate
			T2	Apollonia-type	Copper	Calcium Phosphate
			T3	Apollonia-type	Copper	Calcium Phosphate
			T4	Apollonia-type	Copper	Calcium Phosphate
Black	Khirbat al-Mafjar (KH)	0				
	Great Mosque of Damascus (DMS)	1	13Ngr	Foy-2	Cu nano-particles	Cu nano-particles
	Dome of the Rock (DR)	5	BK1	Outlier	Cu nano-particles	Cu nano-particles
			BK2	Apollonia-type	Cu nano-particles	Cu nano-particles
			BK3	Egypt I	Cu nano-particles	Cu nano-particles
			BK4	Egypt I	Cu nano-particles	Cu nano-particles
			BK5	Egypt I	Cu nano-particles	Cu nano-particles

Tab.7.1a Summary of data on base glass, colourants and opacifiers acquired on all opaque coloured tesserae.

	Site	N.	Sample	Base glass	Colourant/Decolourant
Yellow	Khirbat al-Mafjar (KH)	4	Am/Au11	Beth Eli'ezer-type	Manganese
			Am12	Outlier	Iron
			G/V13	Apollonia-type	Iron
			Am14	Apollonia-type	Manganese
	Great Mosque of Damascus (DMS)	3	6Fs	Apollonia-type	Manganese
			18S	Foy-2	Manganese
			19T	Apollonia-type	Manganese
	Dome of the Rock (DR)	7	Am1_Au	Foy-2	Manganese
			Am2_Au	Foy-2	Manganese
			Am3_Au	Foy-2	Manganese
			Am4_Ag	Foy-2	Manganese
			Am5_Ag	Foy-2	Manganese
			Am6_Au		Manganese
			Y1_Au	Foy-2	Manganese
Green	Khirbat al-Mafjar (KH)	0			
	Great Mosque of Damascus (DMS)	1	8H	Apollonia-type	Copper
	Dome of the Rock (DR)	1	G1_Au	Outlier	Copper
Blue	Khirbat al-Mafjar (KH)	1	A15	Outlier	Iron
	Great Mosque of Damascus (DMS)	1	4D	Foy-2	Cobalt
	Dome of the Rock (DR)				
Transparent	Khirbat al-Mafjar (KH)	0			
	Great Mosque of Damascus (DMS)	2	6Fc	Apollonia-type	Mn-decoloured
			15P	Foy-2	Mn-decoloured
	Dome of the Rock (DR)				

Tab.7.1b Summary of data on base glass and colourants/decolourants acquired on all translucent and transparent tesserae.

The use of Apollonia-type and Foy-2 recipes has been attested among several assemblages of mosaic glass tesserae found across the Mediterranean basin (especially in the eastern area), respectively between the 5^{th}-10^{th} century and the 5^{th}-8^{th} century. Interestingly, according to the literature, materials used as colourants and opacifiers also match those detected in Umayyad glass tesserae. Therefore, it is also a plausible hypothesis that Apollonia-type and Foy-2 tesserae were recovered from dismantled sites, previously adorned with mosaics, and re-used in the decorations of newly built Umayyad mosques and civil buildings.

Nonetheless, together with Apollonia-type and Foy-2 glass groups, the occurrence of Egypt I compositional category has also been found in all the assemblages under study. The relevance of this result is striking, since it provides a tangible proof of the existence of legacies other than Levantine in the manufacture of Umayyad mosaics. More precisely, it attests the veracity of sources mentioning skilled workmen and materials being sent from Egypt to collaborate on the construction of the mosques (Gautier-van Berchem 1969; McKenzie 2007; McKenzie 2013; James 2017).

Whether the tesserae were imported from Egypt as either a finished product or still in the form of raw glass, it is impossible to definitively ascertain.

The fact that the base glass types of the analysed sets are clearly distinct and perfectly matching the category of Egyptian and Levantine glasses, could indicate there was no mixing of types. Since the mixing is likely to have occurred at secondary workshops if they had worked different raw glass, the hypothesis of "ready-made" tesserae imported from Egypt is, on the one hand, plausible and it cannot be univocally excluded.

On the other hand, two main results must be taken into account: the use of the same colourants and opacifiers independently from the compositional category of the base glass and the fact that these materials have mainly been attested in assemblages from the eastern Mediterranean basin. Considered together, these data seem to better support the hypothesis of raw glass travelling with craftsmen and, then, turned into tesserae locally by the workmen themselves, by using materials available on site to gain the desired chromatic shades. A further possibility is that the raw glass was coloured and opacified in geographically different areas (i.e. Egypt and the Syrian-Palestinian area), but with the same techniques, like following specific recipes.

It has been highlighted that colouring and opacifying glass was probably the most challenging step in the making of tesserae, and when and where this occurred is still unknown. Nowadays the most popular hypothesis among academia is that glass for tesserae was coloured in secondary workshops, perhaps by specialists either in colouring or in making a range of colours or even one specific colour. However, sound archaeological evidence able to verify and ascertain this production model is still lacking. The possibility of imported raw glass to be coloured on the site of the mosaic has been considered the most unlikely, as it would have implied the presence of skilled mosaicists or on-site glassworkers, as well as adequate storage space for glass and tesserae and room for furnaces and fuel.

In the case of the Great Mosque of Damascus and the Dome of the Rock, the presence of skilled craftsmen from Egypt is attested by historical sources and analyses demonstrated that these workmen brought materials with them as well. It is undisputable that adequate storage space for glass and tesserae was necessary on site, as well as room for furnaces; however, it is likely that all these facilities could have easily been available, as the mosaic decorations were made at the same time when the mosques were constructed and, thus, when there was a real construction site in progress with different tools and equipment the craftsmen might have needed.

That of tesserae travelling with skilled workmen as raw glass to be coloured on site is, therefore, a reasonable hypothesis to be considered for the assemblages and the sites under study.

In the previous paragraphs, hypotheses have been formulated upon the manufacture and supply of tesserae under the Umayyad caliphate and several inferences have been drawn, in light of a careful and persistent comparison between analytical data and historical sources.

On the one hand, it is certain that Egypt was thrown into the mix as a supplier of not only craftsmen, but materials as well. On the other hand, the actual state of knowledge does not allow to univocally identify "Levantine" tesserae and workmen as coming from Byzantium rather than being Syrian. The gathering of tesserae from dismantled building is a concrete possibility, together with Levantine artisans (either from Byzantium or Syria) collaborating with Egyptian craftsmen.

Discussing upon Islamic mosaics, Liz James has recently affirmed that they "*were no more* Byzantine *than the mosques of the seventh and eight centuries were* really *churches*" (James 2017, p.269).

According to what emerged from this research, this statement can easily be adapted to Umayyad mosaics as well. Though some questions are still open, no other expression could better define Umayyad mosaics as "mosaics of cultures". They tell us the fascinating story of workmen and materials coming from different places for collaborating together on the mosaic decoration of Umayyad mosques and "castles in the desert", depicting the scenario of Levantine artisans sharing the work with their Egyptian colleagues. It is highly plausible that mosaic gained a specific significance under the Umayyad caliphate, through the “appropriation” of a Byzantine (and Roman) medium and its insertion in a far-reaching Umayyad sphere of culture.

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Chapter 8

Something material, something methodological. Further developments of the research

The importance of the role played by material culture in understanding an age of transition, namely the Byzantine-Umayyad transition, has been the starting point of this research, followed by an excursus on the present state of knowledge about glass (its manufacture, consumption and supply) under the Islamic domain in the East, with a specific focus on the Umayyad period.
The ongoing enigma concerning the gathering of glass tesserae for the mosaic decoration of Umayyad mosques has been thoroughly discussed, with the aim of introducing reasons underpinning the choice of the materials selected for this research. The need for a *tailor-made* archaeometric approach for mosaic glass tesserae has been, then, evaluated, and a "best practice" protocol has been suggested (although with possible improvements). Results obtained by the analyses of three assemblages of glass tesserae from Umayyad sites have been presented and discussed. Achieved data have been framed in a broaden scenario and compared to historical sources, with the aim of unravelling the mysteries concerning the gathering and supply of tesserae under the Umayyad caliphate.
As it is commonplace for every research, this is the moment to think about its potential and appropriate further developments.
The title of this chapter, *Something material, something methodological*, points to two main directives, carefully evaluated by considering, on the one hand, further assemblages to be studied and, on the other hand, the necessity of taking steps forward in terms of data evaluation and processing.
About the part inherent to the materials, planned research will focus on the mosaics of Ravenna, for two main (and interrelated) reasons. Though in the last decades studies have been conducted to unravel the mysteries related to the production technology of mosaic glass tesserae employed in Ravenna and where they were made, even a preliminary scenario is still lacking. Despite

that, mosaics decorating 5^{th} and 6^{th} CE monuments in Ravenna have always been defined as masterpieces of Byzantine art and craftsmen: a statement of this kind must be made with the necessary caution, for the reasons thoroughly discussed in the previous chapters and in accordance with recent research.

Concerning the part related to the methods, in parallel to the assessment of a *tailor-made* protocol for the study of coloured mosaic glass tesserae (dictated by the reasons widely discussed in chapter 4), a study aimed at evaluating the application of exploratory statistical methods to the available dataset has also been undertaken. Exploration of data by PCA and HCA was, in particular, aimed at a systematic background comparison with the recalculation and normalisation processing of compositional data of the base glass. Although preliminary, achieved results can be considered as a starting point for future developments of the application of these exploratory statistical methods to assemblages of coloured tesserae, with a view to possibly evaluate, by future research, a method for eliminating any degree of subjectivity from the processing of compositional data.

8.1 Ravenna and its mosaics: unravelling the mysteries of a black hole?

8.1.1 How far can we go with available data? Evaluating the need for a thoroughgoing re-assessment

In 402 AD, Ravenna became the Capital of the Western Roman Empire. On this occasion, the city underwent extensive makeover to meet the needs of the Imperial Court. Many palaces and churches were built between the 5^{th} and the 6^{th} CE, characterised by an extensive use of mosaic as decorative and celebrative medium.

The fine and extensive use of glass tesserae, as well as being a distinctive characteristic of Ravenna itself, has always been (and it still is) an intriguing research topic.

Though several studies have been undertaken in order to understand something more about the production technology of mosaic glass tesserae employed in Ravenna and, above all, where they were made, a complete and explicative scenario is far from being outlined and only some fragmentary preliminary data can be found in the literature.

In the last few decades, especially on the occasion of conservative interventions, cognitive investigations have been carried out on the vitreous tesserae collected from the mosaic decorations of several monuments in Ravenna, looking for clues on the technological level of the production workshops and their geographical location.

A group of 136 coloured tesserae was collected during the restoration works of the basilica of St. Vitale (6^{th} CE), both from original portions of the mosaic decoration, and from remakes. Chemical analyses demonstrated that the tesserae were mainly made of a silica-soda-lime glass, with natron as fluxing agent. The concentrations of alumina and lime also allowed identifying two main compositional categories: Roman and Levantine I (Fiori et al. 2004). Different materials were used in order to achieve the desired shades of colour and degrees of opacity (Tab.8.1).

Analyses performed on a set of opaque coloured tesserae from the Neonian baptistery (5^{th} CE) demonstrated the use of a silica-soda-lime natron-based glass, opacified and coloured by means of different materials (Tab.8.1). In particular, tesserae have been suggested to split into two main compositional categories: one still from the Roman tradition (natron glass opacified with antimony), and the other (natron glass opacified with bone ash) more closely matching Levantine assemblages from the eastern Mediterranean basin (Verità 2011). Four transparent tesserae (three with gold leaf and one with a silver foil) were collected and analysed during the restoration of the mosaics adorning the basilica of St. Apollinare Nuovo (6th CE). Data on the base glass showed consistent similarities with those achieved by the analyses of tesserae from other monuments in Ravenna. Interestingly, the use of a decolouring agent was not detected only in the tessera with silver foil, a datum that has been linked to a specific practice to obtain characteristic chromatic effects (Verità 2012).

Mosaic glass tesserae from the archaeological area known as St. Severus (Classe, Ravenna) have also been investigated. Tesserae found inside the basilica, datable to the 6th CE (Fiori 2011; Fiori 2013), the *sacellum*, first nucleus of the monumental area, dated to the second half of the 5th CE, and the monastery, whose construction started at the end of the 9th CE (Vandini et al. 2014) were analysed. According to compositional data, they were all manufactured by using a silica-soda-lime natron-based glass: Levantine I was the compositional category tesserae from the basilica more closely match, whilst those found in the sacellum and the monastery split into Levantine I and Roman glass groups. Again, differences have been detected related to the materials used for the opacification and colouration of the tesserae (Tab.8.1).

Two sources for the glass or the tesserae have, thus, been hypothesised. These tesserae were apparently set indiscriminately next to each other, as their source probably made no difference to the mosaicists (James 2017).

Such a homogeneous framework, specifically linked to the preferential use of two main glass recipes, has often led scholars to question a possible local manufacture for the tesserae of Ravenna.

Site	Century	Base glass	Colourants and Opacifiers										Analyses	References
			Yellow	Green	Red	Blue	Turquoise	Amber	Purple	Black	White	Colourless		
St. Vitale basilica (Ravenna, Italy)	6th century	Roman, Levantine I	$PbO + Sb_2O_3$	$PbO + SnO_2 + CuO$	Iron oxide + copper	CoO	Copper oxide/iron oxide		MnO				XRF, ICP-AES, AAS	Fiori et al. 2004
St. Severus basilica (Classe, Ravenna, Italy)	6th century	Levantine I	Lead antimonate	Lead antimonate + copper	Copper							Antimony	XRF-WDS, SEM	Fiori 2011
		Between Roman and Levantine	Lead and antimony	Lead stannate and copper	Copper	Cobalt (+ antimony)	Copper (+ antimony)		Manganese and iron	Manganese and iron	Calcium antimonate	Antimony	XRF-WDS, EPMA	Fiori 2013
		Roman, Levantine I, weak HIMT		Pb, Sn-based opacifier + copper	Cu_2O	Cobalt (+ calcium antimonate)	Copper (+ calcium antimonate)					Antimony	EPMA, SEM-EDS, XRPD	Vandini et al. 2014
St. Apollinare Nuovo basilica (Ravenna, Italy)	6th century	Roman, Levantine										Antimony	SEM-EDS	Verità 2012
Neonian Baptistery	5th century	Foy-2, Roman, Levantine I	Lead antimonate and lead stannate	Lead antimonate and/or lead stannate with copper	Metallic Cu or cuprite	Cobalt	Copper				Calcium antimonate or calcium phosphate		SEM-EDS	Verità 2011

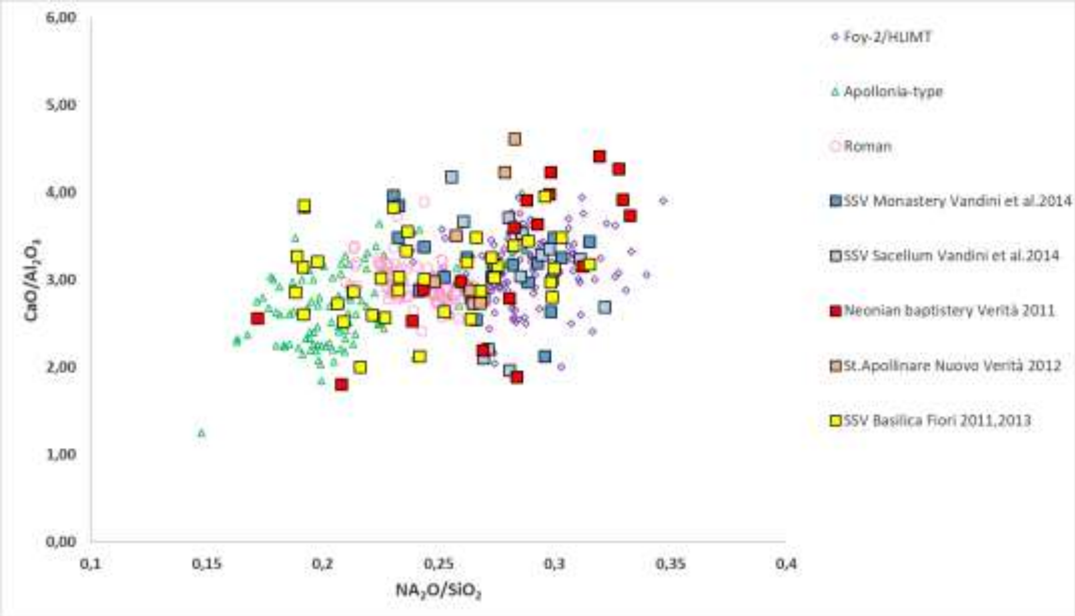
Tab.8.1 Summary of published data for mosaic glass tesserae from 5th-6th century monuments in Ravenna.

Nevertheless, before making any hypothesis, some considerations are necessary. Data achieved by archaeometric analyses carried out on assemblages of glass tesserae from Late Antique monuments in Ravenna are scarce and not easily comparable. Some of the assemblages were analysed more than ten years ago, when even a preliminary approach for the study of mosaic glass tesserae was lacking. In addition to that, analyses on the base glass were performed using different methods (without provenance analysis for raw materials), while the microstructure was only investigated by SEM-EDS.

For these reasons, before designating any, albeit preliminary, scenario on the manufacture of Late Antique mosaics in Ravenna and the manufacture/supply of glass tesserae, a consistent revision of the available data must be carried out, together with a highly recommended integration with further sets of materials. Scatter plots in Fig.8.1 are striking in proofing the need for an extensive revision of available datasets. They were drawn by taking all published data on mosaic glass tesserae assemblages from Ravenna as reference, after having calculated the reduced compositions and normalised to 100 (see chapter 4). Plots clearly show that, within all analysed assemblages, compositional categories Roman and Foy-2 can be identified, whilst Levantine I glass group seems to be lacking.

This contrasts with the literature (see above), where tesserae have always been said to split into Levantine I and Roman compositional categories.

Although these preliminary observations cannot be considered exhaustive, they further emphasise the need for a careful review of the available data, carefully evaluating the integration with other analytical techniques in order to obtain a more precise characterization of the samples and, above all, comparable data.



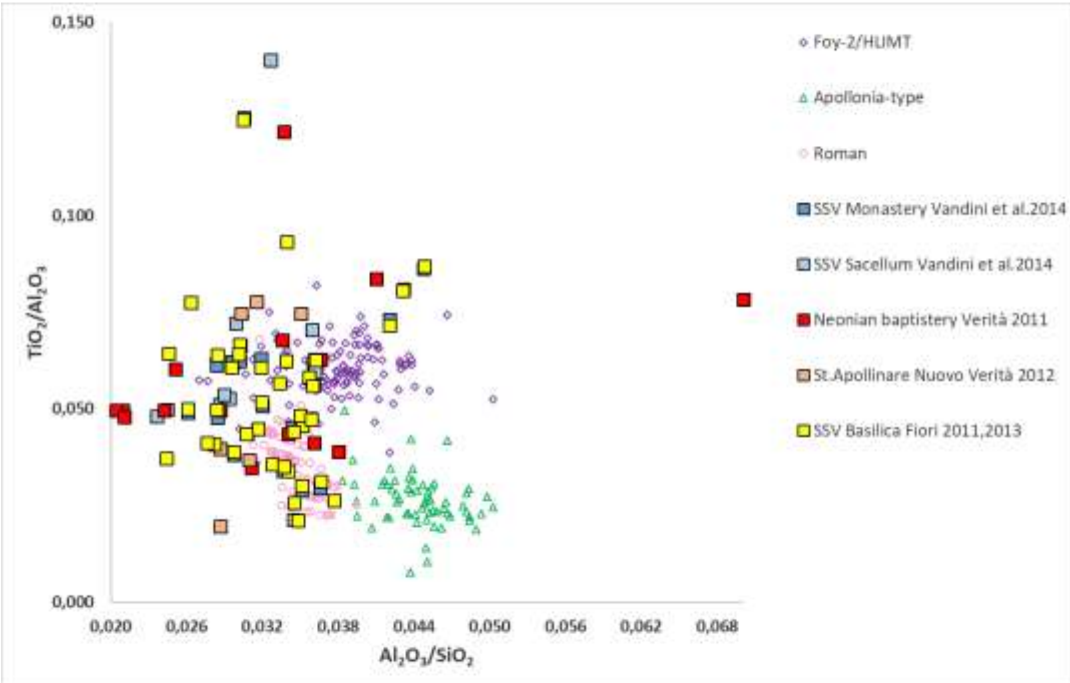


Fig.8.1 Scatter plots encompassing all compositional data on glass tesserae from Ravenna from the literature. Refernces: Verità 2011; Verità 2012; Fiori 2011; Fiori 2013; Vandini et al.2014.

8.1.2 The archaeological area of Saint Severus (Classe, Ravenna): a thought-out re-starting point

As far as addition of further assemblages is concerned, the starting point will be represented by the study of mosaic glass tesserae from the archaeological area of St. Severus, located in the suburb of Classe, Ravenna.

Nothing more than a rural area before the 5th CE, Classe grow into a proper city when Ravenna became capital, with all the typical settings and structures of Late Antique urban centres. Of all these elements, only a few traces survive, recovered thanks to archaeological research conducted through decades of collaboration between the University of Bologna (Ravenna Campus), the Superintendence for the Archaeological Heritage of Emilia Romagna and the *RavennAntica* Foundation.

Currently subject to archaeological excavations by the University of Bologna (Augenti 2006a; 2006b; Augenti et al. 2006; Augenti et al. 2012), the site of Classe is divided into two separate sections, representing two distinct archaeological areas a few kilometres apart: the commercial and productive area of the town, and the religious area occupied by the St. Severus basilica and monastery.

The site is highly stratified due to its multifaceted history, strictly linked to that of the imperial town Ravenna (Augenti 2012). The archaeological area of Saint Severus began to be occupied in the 1st century BC by a Roman villa, whose planimetry is still not completely understood. During the second half of the 5th CE a new building was erected in the site of the villa: a *sacellum*, that Andrea Agnello's *Liber Pontificalis* testifies titled to St. Rufillo. A change in the outline of the area occurred at the end of the 6th CE, when a major basilica dedicated to Saint Severus was erected, consecrated in either 592 or 593 AD. Firstly cited in written sources in the mid-10th CE, the Benedictine monastery of Saint Severus was constructed at the end of the 9th CE along the southern wall of the basilica (Augenti 2012; Augenti et al. 2012). The ecclesial complex went through important restoration works in the 13th and 15th CE, when the precarious state of conservation made it necessary to tear down parts of the basilica with the inevitable loss of the mosaic decorations. However, the monastery remained active until the year 1512, when the monks left the site.

During recent excavation surveys, many glass finds have been brought to light: glass vessels, lamps, mosaic tesserae, together with production markers (raw glass, semi-manufactured products, and glass waste), were found in huge amounts both in the productive and commercial areas of Classe and close to the monastery (Cirelli & Tontini 2010; Tontini 2006).

The existence of one or more areas of glass working in the Late Antique Classe is no longer just a hypothesis. In 2001, archaeologists unearthed a small circular structure pointing to the occurrence of activities linked to glass manufacture (Cirelli & Tontini 2010; Tontini 2006). The small furnace was located inside one of the warehouses (Building 6), in the southern corner of the excavation area; its structural features, together with the presence of fragments of raw glass, clearly refer to a so-called "secondary type" production (Chinni, in press). Within the same environment, 1538 finds were recovered between blocks of rough glass, production waste and glass scrap. These objects were below the walking surface, probably reused to raise the floor level, with an unparalleled solution. The reasons for this condition may be related to a fire that affected Building 6 between the end of the 5th and the beginning of the 6th CE: probably damaged, the glass material was deemed no longer suitable for production and, therefore, reused in this peculiar way (Cirelli & Tontini 2010).

To understand what kind of objects were manufactured in this small atelier, and to clarify the scope of this production as well, a selection of the findings was submitted to both crono-typological and archaeometric investigation.

The research was conducted by a joint team of the University of Padua and Bologna, as part of the PRIN 2009 Ministerial Project "Continuity and discontinuity between the Adriatic glassmaking productions between the 9th century BC and the 15th century AD". Achieved data allowed to formulate the hypothesis of a secondary processing of Class glass, from raw glass blocks imported from the Syro-Palestinian and Egyptian coast, with the main purpose of creating consumption products within the port (Chinni, in press; Maltoni et al. 2015;).

Whether this atelier also produced mosaic glass tesserae, is still unknown. Only twenty-five tesserae made of opaque blue and green glass were found in Building 6, of which only half are in phase with the furnace. Given the paucity of the finds, it seems unlikely that this small structure also functioned as a supplier of mosaic tesserae for the churches of Ravenna (Chinni, in press).
During the excavation campaigns carried out between 2010 and 2014, in the area south of the Basilica of Saint Severus 11903 glass fragments were recovered, of which 4364 ascribable to specific forms and typologies[71]. Significant is also the number of fragments referable to glass windows and mosaic tesserae, made of both opaque and translucent glass (Fig.8.2): the former show chromatic shades ranging from blue and green, to red, yellow, white, grey and black; the latter are mainly made of colourless glass, with only a few examples of light green glass. Some of these tesserae also show traces of metal foils.

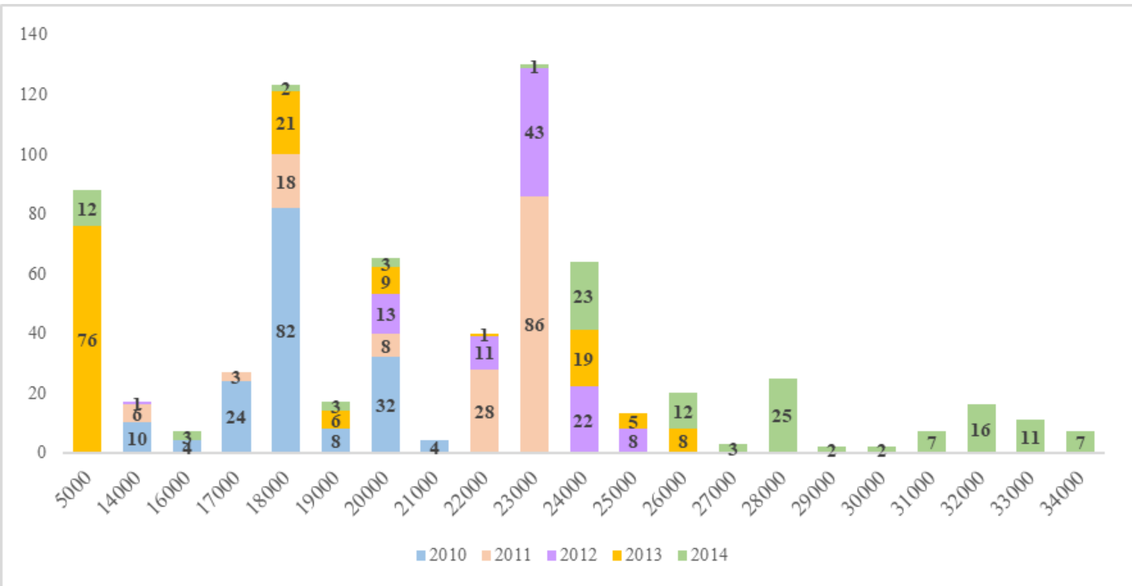


Fig.8.2 Distribution of opaque and transparent mosaic glass tesserae found at Saint Severus during the excavation campaigns conducted between 2010 and 2014 (Chinni 2017, p. 154).

Although they were collected over the entire extension of the *cenobium*, tesserae were found in more conspicuous amounts in: the area corresponding to the Chapter Hall (sector 23000); the area south of the Chapter Hall, along

[71] The entire assemblage has recently been the subject of study by Dr. Tania Chinni, whose doctoral thesis in Histories and Cultures (*Produzione e circolazione dei manufatti in vetro in Romagna nel Medioevo, V-XV sec.*), is referred to for further details (Chinni 2017).

the east wing of the cloister (perhaps the *scriptorium*) (sector 18000); the area located south of the vestibule of the late antique Basilica (sector 5000) (Fig.8.3).

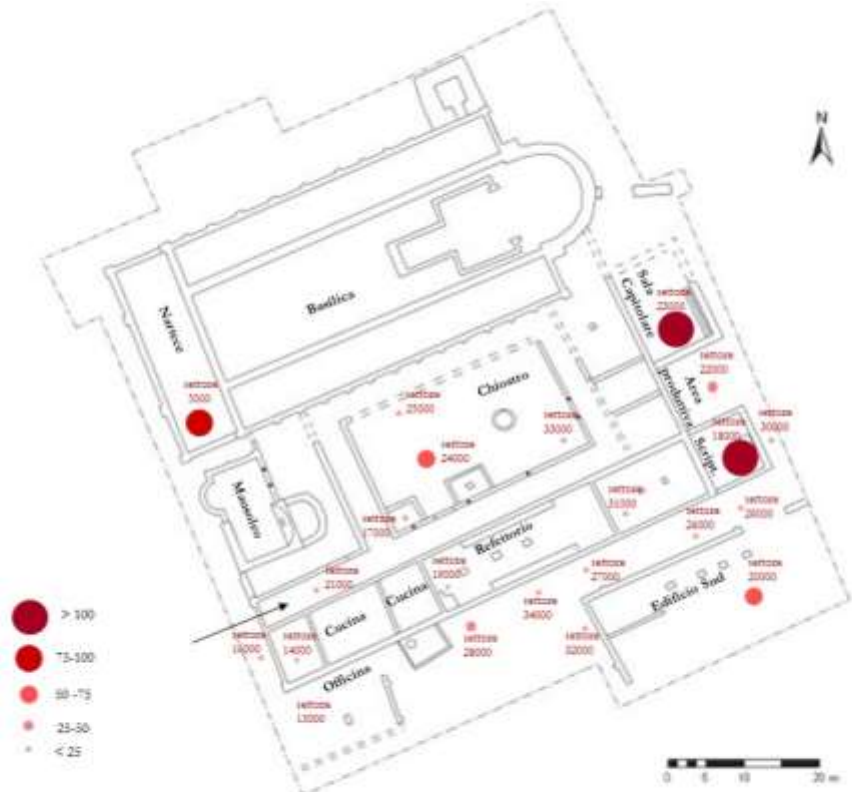


Fig.8.3 Distribution map of mosaic glass tesserae found at Saint Severus during the excavation campaigns conducted between 2010 and 2014 (Chinni 2017, p. 155).

It seems, therefore, highly probable that mosaic decoration only adorned the three most ancient and important areas of the entire complex (the Basilica, the *scriptorium* and the Chapter Hall), and that the loose tesserae recovered from the remaining areas are actually due to the numerous restructuring phases the complex underwent between the 10^{th} and the 17^{th} CE.

Tesserae from these areas of the monastery will be submitted to archaeometric analyses in accordance with the methodological approach proposed in this research. This will lead to the collection of a conspicuous amount of compositional data regarding both the base glass(es) and the materials used as colourants and opacifiers, essential premise for the creation of a database conceived as a comparison tool between these data and those that will be, at a second stage, collected by means of a comprehensive re-examination of previously studied tesserae from late antique monuments in Ravenna.

8.2 Evaluating potentialities of statistical methods for exploring glass tesserae

In 2008 the journal *Archaeometry* celebrated the anniversary of the 50 years since its foundation. On that occasion, Micheal Baxter published an essay aimed at reviewing the developments in the use of mathematics and statistics in archaeometry over the past 50 years.

In his paper, Baxter highlights, paraphrasing with a sense of humour and critical spirit the comment made by one of the referees on his manuscript, how archaeometry, and the use of mathematics and statistics within this discipline, has been "*living within its own little self-contained bubble*" (Baxter 2008).

The application of statistical methods to data generated by archaeometric analyses began to have a serious impact after the work published by Bieber and colleagues in 1976 (Bieber et al. 1976). This paper practically set the basis for a particular approach to archaeometric data treatment, refined in later years.

Scholars have, however, long debated about the application of mathematical and statistical methods to archaeology and archaeometry. Though strong attacks of some (Shank and Tilley 1992) have countered solid answers of others (Orton 1999; Ringrose 1993), the difficulty of finding, especially in the archaeometric literature, papers that have engaged with this debate, is tangible.

Baxter concludes his review underlining how, rather than looking for new and, presumably, more informative methodologies aimed at demonstrating the efficiency of the application of statistical methods, more attention should be given to the questions themselves, as it would be more suitable to address archaeologically interesting questions with appropriate methodology. Proper data collection should, therefore, be considered just as important as addressing data in an appropriate statistical manner.

It can be affirmed that the most relevant, complete and extensive contributions to the definition of statistical approaches for the exploration of archaeological and archaeometric data on glass assemblages have been given by the studies conducted by Micheal Baxter and his colleagues. A first methodological note on the use of multivariate analysis of data on glass compositions was published in

1989 (Baxter 1989), followed by some empirical studies on principal component and correspondence analyses of glass compositions (Baxter 1991, Baxter 1992) A slightly later study (Cool and Baxter 1999) was aimed at identifying the major influences that could impact on differences and heterogeneity within assemblages of glass vessels, in the attempt of developing an approach able to progressively analyse data to remove the effect of the dominant factor. These pivotal papers highlighted how, though a systematic comparison of archaeological glass assemblages could be a powerful tool, attention had to be payed to several issues to be taken into account, fist the comparability of sites and the nature of materials to be compared.

Following research was carried out on variable selection in artefact compositional studies (Baxter and Jackson 2001) and on statistical modelling of artefact compositional data (Baxter 2001). Several studies were, then, dedicated to the evaluation of compositional variability of Romano-British glass vessels, from a typological and compositional perspective (Cool and Baxter 2002, Baxter, Cool and Jackson 2005). Of a specific interest is the paper published in 2006 (Baxter, Cool and Jackson 2006), addressing the thorny issue of comparing and combining compositional data on naturally coloured and Mn-decoloured glass vessels obtained from analyses undertaken with the same technique, but at different times. The study demonstrated that, while the correlation between measurements was generally high among "old" and "new" data, agreement was not usually good, this precluding the combination of different data sets without statistical adjustment. In his very last works, Micheal Baxter has provided notes on quantitative archaeology (Baxter 2015), introductions to the methods methods of multivariate analysis most commonly used in archaeometric data exploration (Baxter 2016), and a ground-breaking book intending to encourage archaeologists to give more thought to the statistical graphics that they use (Baxter and Cool 2016).

In addition to already quoted research, two recently published papers by Matt Phelps and colleagues (Phelps 2018; Phelps et al. 2016) have extensively explored the possibility of defining groups against a range of comparative data, accurately selected from a spread of geographical locations with an emphasis on sites with high-quality data, of comparable chronological ranges, and from which glass compositional groups had previously been identified.

According to these studies, iterative processes of HCA and further data exploration by PCA can properly allow to distinguish between different compositional categories for both natron-based and plant ash-based glasses, by identifying the oxides responsible for the highest variance. In the case, for instance, of plant ash-based glasses, six major oxides have resulted being the most effective in separating analysed samples on the basis of both the fluxing (P_2O_5, MgO and CaO) and the vitrifying agent (Al_2O_3,Fe_2O_3, ZrO_2).

However, if we move to deeply coloured glasses in general, and to mosaic glass tesserae in particular, the application of statistical exploratory methods is at a very early stage: to date, only one paper can be found in the literature dealing with an attempt of applying PCA to a set of coloured glass tesserae from Hagia Sophia, Constantinople (Moropoulou et al. 2016). As stated by the authors, PCA analysis was here based on the concentrations of alumina, silica, calcium, sodium and potassium oxides, as they characterise the base glass used for the production of the tesserae and, therefore, are considered to be less subjective to significant concentration changes due to the addition of opacifiers and colourants. Several sets of previously analysed mosaic glass tesserae (i.e. St. Prosdocimus, Padova; Hagios Demetrios, Thessaloniki; the Cross Church, Jordan) were included in PCA analysis, in order to evaluate similarities between them and the samples from Hagia Sophia. However, for glass tesserae from Hagia Sophia, PCA was performed on semi-quantitative SEM-EDS data acquired on non-prepared samples and without preliminary recalculation and normalization for major and minor oxides (see chapter 4).

A fixed point stemmed from this PhD research is the high degree of heterogeneity that characterises glass tesserae and their micro-structure. As a consequence, in order for it to be functional, the application of statistical methods to the exploration of archaeometric data acquired on mosaic tesserae must be carefully evaluated, taking into strict consideration the heterogeneity of their material features. Because an analogous degree of heterogeneity is hardly found when dealing with naturally-coloured glasses, approaching a statistical exploration of data acquired on deeply coloured tesserae moving from the same queries and arguments could be uninformative. If the challenge is to make the application of statistical methods efficient, the first step to be done is, thus, evaluating the possibility that different categories of materials (with different chemical features and signatures) could necessitate different approaches for an instructive use of statistical methods.

Multivariate statistical analysis for the interrogation of the data was performed in R (Version 3.1.2). Hierarchical cluster analysis (HCA) was carried out according to Ward's method, which utilises the error sum of the squares with the distance between the points represented by squared Euclidian distance (Baxter2003; Shennan 1997). For principal component analysis (PCA), components with eigenvalues above 1 were used (Shennan, 1997), by preferring those principal components (PC) describing the most variation.

Fig.8.4 provides a comparison between cluster dendrograms obtained by HCA applied, respectively, on raw and recalculated EPMA data. It can be noticed that dendrogram with recalculated data show a well-defined split of the tesserae into two main clusters, consistent with Egypt I and Apollonia-type compositional categories. Furthermore, tesserae matching Foy-2 group show closer affinity with Apollonia-type rather than Egypt I samples, the only exception being DR_LB1.

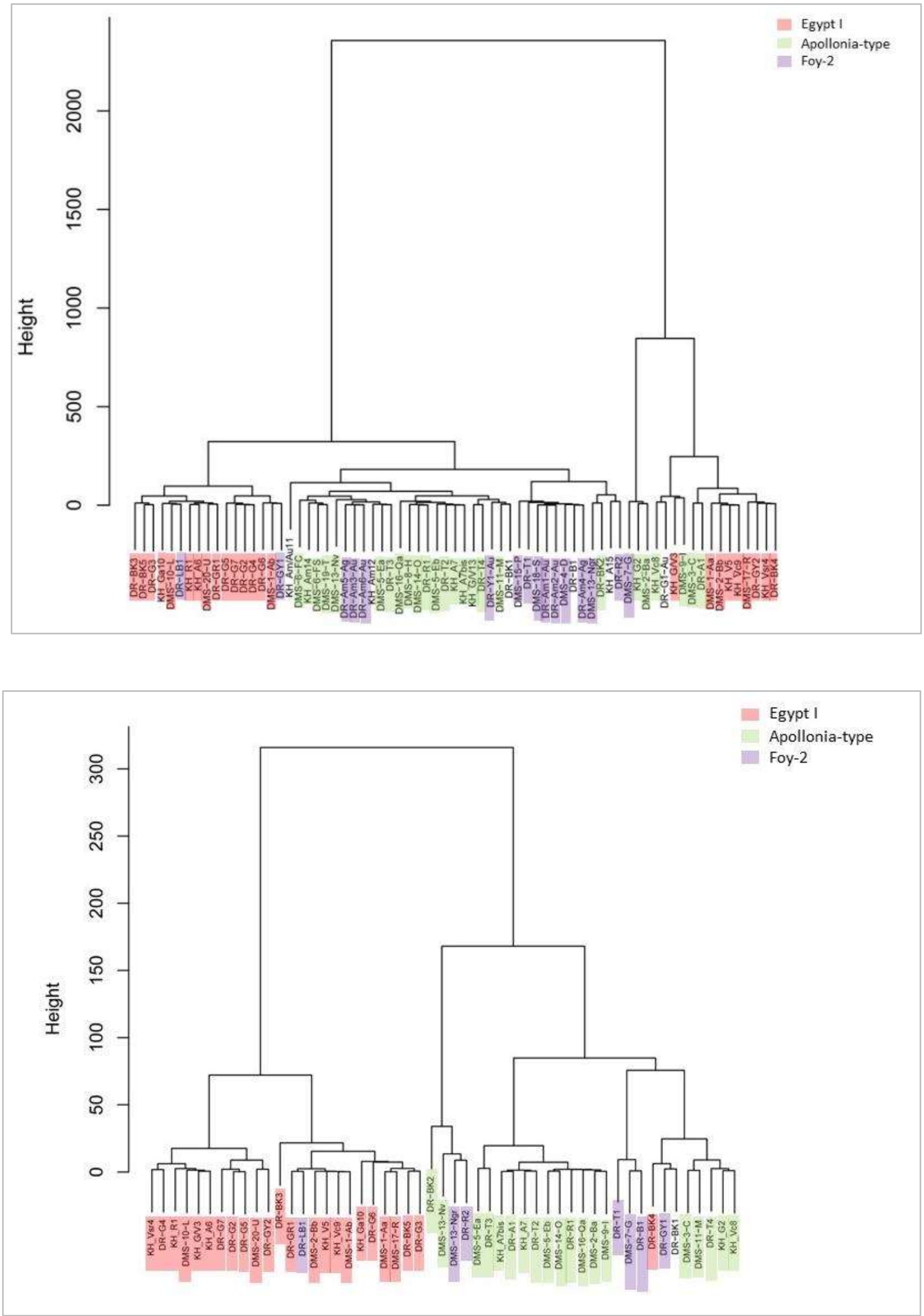


Fig.8.4 Cluster dendrograms obtained on a) raw data and b) recalculated data.

A similar situation occurs when PCA is performed on raw and recalculated datasets respectively: if raw EPMA data are utilised, an overlapping between tesserae matching Apollonia-type and Foy-2 compositional categories occurs; conversely, the two groups separate from each other when recalculated data are taken into account (Fig.8.5).

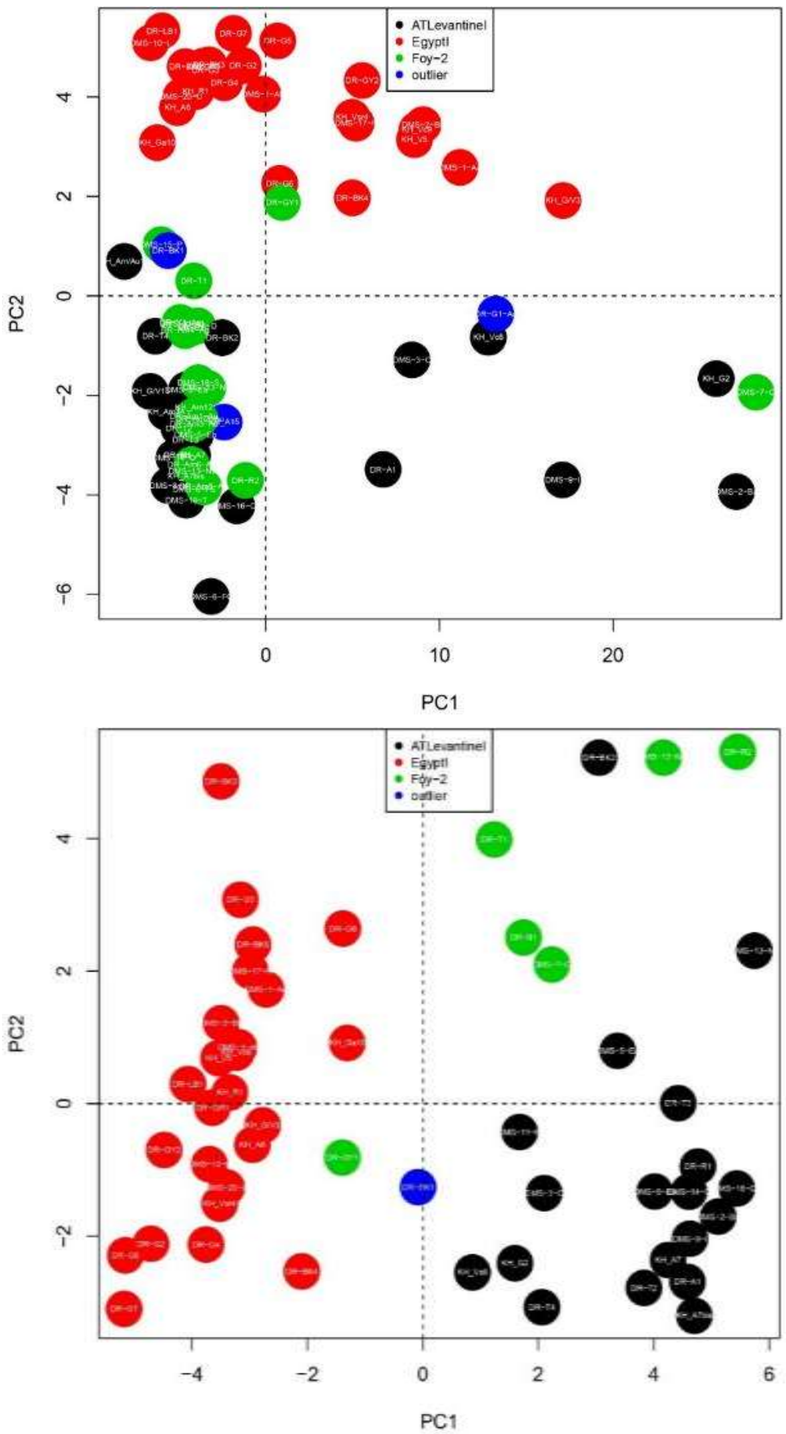


Fig.8.5 PCA bi-plots obtained on a) raw data and b) recalculated data.

Though results are still preliminary and further research is undoubtedly needed (and ongoing), the application of exploratory statistical methods like HCA and, especially, PCA, has provide further univocal and convincing evidence of the necessity to recalculate EPMA compositional data, to minimize interferences due to the addition of colourants and opacifiers. As stressed in chapter 4, the practice of recalculating compositional data when dealing with the study of deeply coloured glasses is still far from being widespread, and only in a few studies is this method of data processing adopted. Achieved results provide further evidence for the fact that the addition of materials aimed at obtaining specific chromatic shades of the tesserae involves a proper "contamination" of the base glass which, if not adequately taken into consideration, might result in an incorrect identification of the compositional categories of the base glass. As shown in Fig.8.4 and 8.5, this is particularly evident if Levantine and Foy-2 glass groups are taken into account.
However, someone might argue that the main concern associated with the recalculation method could be the following: when the recalculation procedure is carried out, how can we be sure not to incur in arbitrary subtractions?
Previously performed in-depth characterisation of colouring and opacifying phases can provide a considerable help in avoiding any subjective subtractions, as this information can guide in the recalculation of data. Ongoing research is aimed at further exploring the potential of other methods of statistical analysis, in particular the Analysis of Molecular Variance – AMOVA (Excoffier, Smouse & Quattro 1992), in verifying the correlation between the oxides associated with the addition of colourant and opacifiers and, eventually, assessing how much they can impact on compositional variations of the glass matrix. This could result in the evaluation of an entirely scientific-based and objective method for their subtraction, avoiding any eventual subjective influence in decision-making.
A further development of the research will then be to apply the same type of explorative analysis to trace elements data associated with the addition of colouring and opacifying agents. The evaluation of any traceable correlation between specific elements could, in fact, allow to obtain useful information to

shed new light on the possible provenance of raw materials used as colourants and opacifiers and, by extension, deepen the current knowledge about processes and technology of production of these peculiar glass-made objects.

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Conclusions

As is commonplace for all the stories, we now come to the end.
It is said that the purpose of a storyteller is not to tell you how to think, but to give you questions to think upon…and I think that, together with some captivating answers, intriguing questions to think upon also emerged from this research.

When addressing a critical state of the art upon the issue of the actual relationship between Umayyad and Byzantine mosaic manufacture and technology, I closed by quoting the words used by Judith McKenzie at the end of her opinions on the contribution of Byzantine, Egyptian and Syrian influences on the making of mosaic decorations adorning Umayyad religious buildings:

"*Whether the mosaic cubes were imported from Constantinople or manufactured in Egypt or Syro-Palestine is something which it should now be possible to ascertain by chemical analysis*" (McKenzie 2007, p.367).

At the end of this research, it is possible to state that archaeometry has really been useful for this purpose, as well as helpful in shedding new light on the subject.
The scenario that has come to light is intriguing and, to some extent, surprising. The occurrence of three "recipes" of base glass, matching three different compositional categories, has been demonstrated: Apollonia-type, Foy-2 and Egypt I. Detailed comparison with the literature has shown that glass tesserae matching Apollonia-type and Foy-2 compositional categories had previously been recovered from several sites located in the territories under the domain of the Byzantine emperor and datable back between the 5th and the 10th century (with major occurrence in the 6th century).
Though scientific analyses cannot unequivocally ascertain whether Umayyad Apollonia-type and Foy-2 tesserae were "freshly made" or gathered from ruined

and dismantled pre-existing monuments, comparison with both historical sources and available data from recent research dealing with glass recipe changes in the late Byzantine and early Islamic period seem to better support the hypothesis that these tesserae were recovered from dismantled sites rather than freshly made.

Having detected both Apollonia-type and Foy-2 base glasses in the assemblages analysed in this research, points, on the one hand, to a sort of continuity with the manufacture of mosaic glass tesserae in the late antique Levant.

There is, on the other hand, a key element that distinguishes Umayyad glass tesserae assemblages from any other: the occurrence of Egypt I glass type. Never found before among assemblages of mosaic tesserae, this type of glass provides a tangible proof of the existence of legacies other than Levantine in the manufacture of Umayyad mosaics. More specifically, it supports the veracity of sources mentioning skilled workmen and materials being sent from Egypt to collaborate on the construction and decoration of the mosques.

The occurrence of different types of base glass, ascertained by archaeometric analyses, points to several suppliers of tesserae. Now the query is whether these tesserae were supplied as an already finished product or traded as raw glass to be coloured and opacified either in secondary workshops or on site.

Different hypotheses have been formulated, graphically summarised in Fig.9.1-9.3.

The first hypothesis (Fig.9.1) points to tesserae travelling as already finished products, ready to be placed on site: Apollonia-type and Foy-2 tesserae could have been recovered from dismantled sites, previously adorned with mosaics, while Egypt I tesserae travelled with craftsmen who, according to historical sources, were sent from Egypt to collaborate on the construction and decoration of the mosques.

Fig.9.1 Hypothesis n.1: tesserae travelling as ready products.

This possibility seems to be supported by the fact that the base glass types of the analysed assemblages are clearly distinct and exactly match categories of Egyptian and Levantine glasses, suggesting that there was no mixing of types. Since the mixing is likely to have occurred at secondary workshops if they had worked different raw glass, the hypothesis of "ready-made" tesserae imported, on the one hand, from Egypt and gathered, on the other hand, from dismantled sites in the Levantine area, cannot be excluded.
For the analysed tesserae, the use of the same colourants and opacifiers independently from the compositional category of the base glass could also imply that raw glass intended to be turned into tesserae was coloured and opacified in geographically different areas (i.e. Egypt and the Syrian-Palestinian area), but with the same materials and methods, like following specific recipes. Interestingly, such a model would be analogous to what has recently been demonstrated about the production of lead-tin opacified early

Islamic glazes: a production that started in the 8th century in Egypt and the Levant by following the same "recipes" and, then, continued through to Mesopotamia, Northern Iran and Central Asia[72].

Further studies on the provenance of colourants and opacifiers are, therefore, planned, as they could result in shedding light on this issue.

Other hypotheses cannot, however, be excluded, pointing to glass travelling as raw material to be turned into coloured tesserae either on site (Fig.9.2) or in secondary workshops (Fig.9.3) presumably located in the nearby of the consumption sites, and supplying glass from different primary production centres.

Fig.9.2 Hypothesis n.2: glass travelling as raw glass to be turned into tesserae on site.

[72] Matin, M, Tite, M & Watson, O 2018, "On the origins of tin-opacified ceramic glazes: New evidence from early Islamic Egypt, the Levant, Mesopotamia, Iran, and Central Asia", *Journal of Archaeological Science*, vol. 97, pp. 42-66, https://doi.org/10.1016/j.jas.2018.06.011.

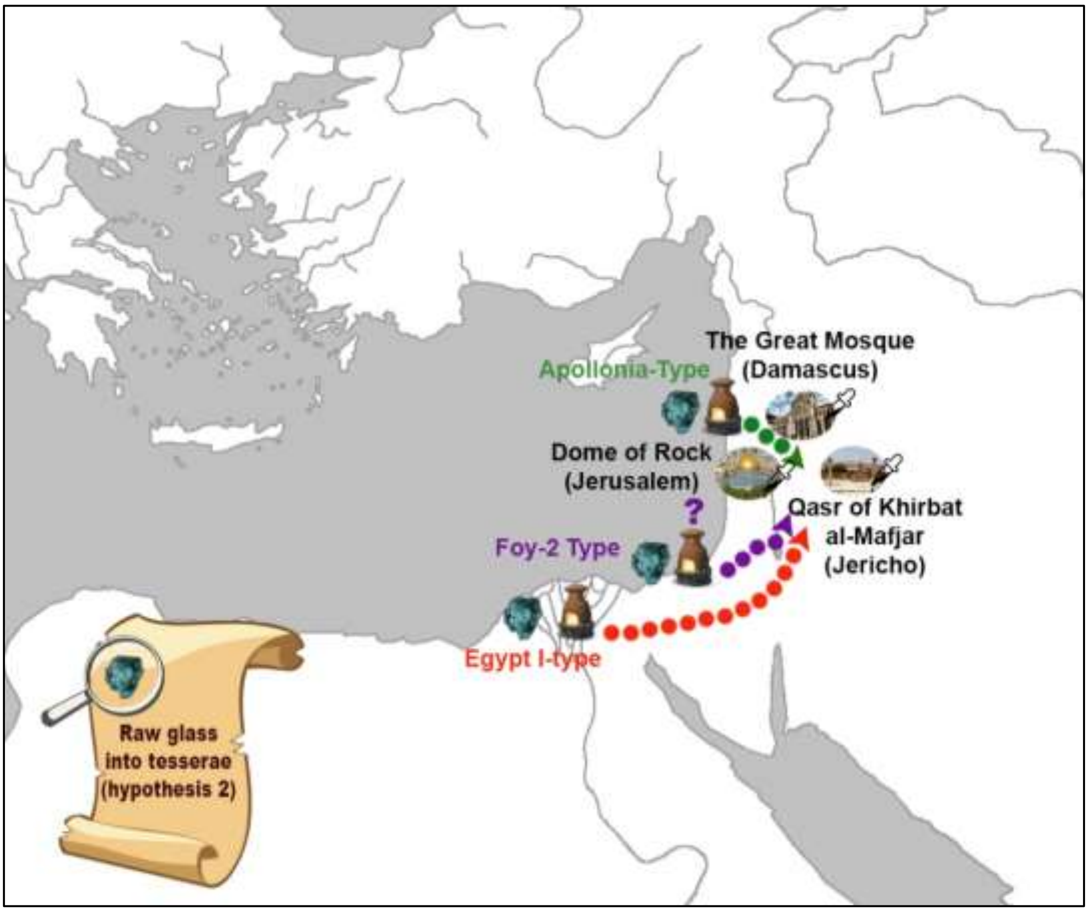

Fig.9.3 Hypothesis n.3: glass travelling as raw glass to be turned into tesserae in secondary workshops.

However, the use of the same colourants and opacifiers independently from the compositional category of the base glass and the fact that the employed materials have frequently been attested in several assemblages from the eastern Mediterranean basin (see chapter 7), makes the hypothesis of raw glass travelling with craftsmen and, then, turned into tesserae locally, equally reliable. Furthermore, it remains impossible to univocally ascertain whether raw glass was coloured in secondary workshops or directly on sites by the workmen themselves.

The initial stage of this research was focused on understanding if and to what extent had material culture been useful to shed light on the intricate period of the Byzantine-Islamic transition.

Changes in urban settlements and architectural planning, the monetary reform, as well as ceramic production point to an initial dependence upon previously established models, then progressively abandoned and replaced by new, independent schemes and varieties.

Glass industry was not different. Shapes and decorative features gradually evolved into new models, destined to evolve, subsequently, into something markedly Islamic.

Probably the saying "*something old, something new*" best describes what happened in the making of Umayyad mosaics. Truly mosaics of cultures, they tell us the story of workmen and materials coming from different places for collaborating together on the mosaic decoration of Umayyad buildings, depicting the scenario of Levantine artisans sharing the work with their Egyptian colleagues.

In introducing this research, I stated that a further goal of the research was trying to define a "persistent methodology", to be intended as a "best practice" archaeometric protocol for the study of mosaic glass tesserae.

An in-depth and critical analysis of the literature concerning the study of mosaic glass tesserae through scientific investigations has shown how, to date, we are still suffering from the lack of a shared protocol between the different research groups dealing with this specific field of study.

There are, rather, several multi-analytical approaches based upon the integration of different analytical techniques. Although these techniques can be suitable for characterising individually considered assemblages, if the aim is to move from single case studies to research by comparing and contrasting several assemblages in order to define a broaden picture, some difficulties can be encountered in terms of data comparisons.

As colour and opacity are the only two criteria of selection for glass tesserae, their objective and exact definition has been put as starting point.

The use of NCS System has proved to be particularly suitable for a preliminary selection among opaque coloured tesserae: since NCS-coordinates describe the hue of the tesserae, they can provide a first split of the tesserae into what can be defined as chromatic macro-categories (i.e. green, blue, red, black), avoiding any subjective classification and denomination of the colours.

Then, by carrying out VIS-RS measurements, further information on optical properties related to different chromatic shades among tesserae belonging to the same chromatic macro-category can be achieved. The potentiality of VIS-RS seems, however, to go far beyond the description of colour by means of numerical coordinates (i.e. L*a*b*). The shapes of the reflectance curves in the visible spectrum and the percentages of reflectance themselves have, in fact, proved to be able to provide preliminary qualitative information relating to the colouring and opacifying agents used.

Thought further research is needed, a comparison between NCS System and VIS-RS data could effectively work in at least two directions: the definition of an entirely objective criterion of chromatic description of the tesserae under study (as well as a more precise classification according to colours); the possibility of achieving preliminary qualitative information about the colouring and opacifying phases, this resulting extremely useful when dealing, for instance, with conspicuous assemblages of tesserae to be analysed, where preliminary selection is mandatory.

For the assemblages under study, micro-structural and micro-textural features of the tesserae were investigated before the composition of the base glass. Such an approach is highly recommended especially for opaque coloured tesserae, as they generally have extremely heterogeneous micro-structures. Therefore, their in-depth investigation before that of the base glass can be very helpful in avoiding interferences, mistakes and misunderstandings in data evaluation.

After sampling, embedding and polishing, SEM-EDS analyses were the starting point. BSE observations allowed to investigate and document the different morphologies of the crystals precipitated into the glassy matrix, and EDS spot measurements ascertained their elemental composition. SEM-EDS is undoubtedly suitable to carry out high-resolution morphological inspection of the inclusions dispersed in glassy matrix, as well as a qualitative and semi-quantitative analysis of their elemental composition.

However, in order to provide a more in-depth characterisation of these inclusions, necessary to identify raw materials responsible for the colour and opacity of the tesserae, SEM-EDS inspection needs to be integrated with other techniques.

At the current state of research, it is still quite challenging to define *what* is (if *there* is) the most suitable analytical technique for providing a full characterisation of the inclusions.

As far as the results of this research are concerned, it would be more correct to claim that there is not only one. The choice of the technique/s seems, in fact, to be highly dependent upon the nature of the inclusions that we want to investigate. It has, for instance, been demonstrated that Raman microscopy can be extremely suitable in investigating the composition of phosphorus-based inclusions, but the same cannot be said when dealing with lead-tin based phases or with Cu-based nanoparticles, where mineralogical analyses (as, for instance, XRPD) can be more informative.

An integration of at least one molecular and one mineralogical analysis is, therefore, always recommended, as it seems an appropriate compromise in order to achieve a thorough characterisation of the inclusions.

In-depth examination of the micro-structure needs to be followed by a determination of the bulk chemistry of the tesserae under study.

Major and minor oxides, whose measurement is aimed at identifying both the fluxing agent and the "recipes" used in the glass-making process, have been analysed by EPMA. LA-ICP-MS analysis was carried out for determining trace elements, to draw inferences on the provenance of the sands used as vitrifying agents.

Especially in the last few years, the use of EPMA is gradually being replaced by LA-ICP-MS for the determination of minor and major oxides, calculated by difference given a known oxide (generally SiO_2). Despite the fact that, according to recent research, close correspondence can be observed between EPMA and LA-ICP-MS data, it has also been stated that EPMA data show better precision when considering specific oxides that, especially when dealing with natron-based glasses, are of a particular relevance in the identification of the compositional categories (see chapter 4). Therefore, further research on reasons

underlying these differences should be conducted before going toward a complete dismission of EPMA.
In order to identify, with as much precision as possible, the compositional categories of the base glass the tesserae belong to, EPMA data should always be recalculated (and normalised) to minimise any effect caused by any other intentionally added compound. A characterisation of the colouring and opacifying agents carried out prior to the analysis of the base glass will, therefore, also allow avoiding (or at least minimising) any subjective subtraction.
The relevance of this data treatment is also confirmed by preliminary results obtained from an exploratory application of PCA and HCA to the sets of tesserae under study. Both seem, in fact, to show that colours (and, therefore, oxides relatable to colouring and opacifying agents) represent a highly incident variable on the groupings of opaque coloured glass tesserae.
A concluding ethical remark is, at this point, necessary.
The proposal for a *tailor-made* and shared analytical approach is far from being a criticism of what has been done so far in the field of archaeometric analysis for the study of mosaic glass tesserae.
At several points in this thesis, a lot has been, in fact, discussed upon the unanswered questions still affecting the actual knowledge of mosaic glass tesserae manufacturing technology and supply.
To answer them, future research could really benefit from a consensual sharing of a well-defined archaeometric approach.
This does not mean that it must necessarily be, point by point, the approach proposed here; it can, rather, be considered a re-starting point, susceptible to more implementations and variations evaluated on two fundamental criteria:

- material features of the tesserae under study, which will never be identical to one another, as they are the product of ancient technologies and not of industrial processes;

- technological advancement and all that the progress of research will offer us which could be suitable to further deepen our knowledge of this peculiar material category.

Though it may seem a commonplace, I learned a lot in these three years of study and research, and not only in terms strictly connected to my specific subject.
I learned to enhance my knowledge, to listen to suggestions and to turn criticisms into new beginnings to improve myself and my research.
But, above all, I learned to question what I did.
And I believe that, whatever the field of research, time must come when a research community stops, and questions applied methods and results so far achieved.
Such a questioning will represent a fundamental premise to formulate the principles of research, to maximise its quality and robustness, and, to a later stage, to reach its prime, shared motivation:
"Research is the quest for knowledge obtained through systematic study and thinking, observation and experimentation.
While different disciplines may use different approaches, they share the motivation <u>*to increase our understanding of ourselves and the world in which we live*</u> [...]*".*

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