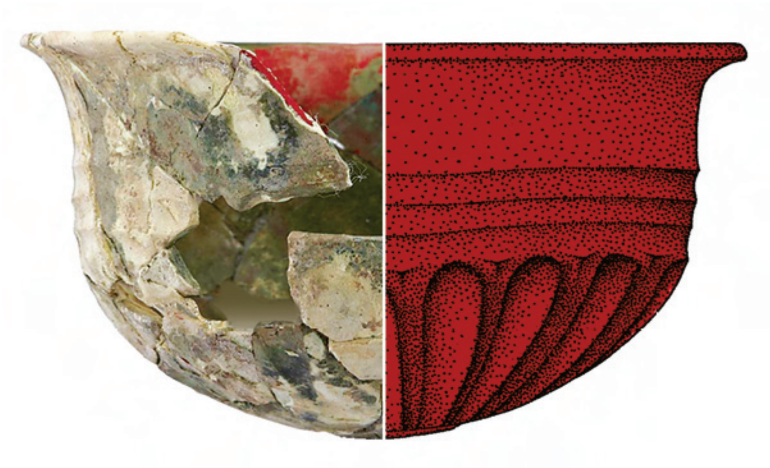
ANNALES



Thessaloniki 2009

du 18e CONGRÈS

de l'ASSOCIATION INTERNATIONALE
pour l'HISTOIRE du VERRE

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Editors
Despina Ignatiadou, Anastassios Antonaras

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Couverture / Cover illustration

The *haematinon* bowl from Pydna. Height 5.5 cm.
© 27th Ephorate of Prehistoric and Classical Antiquities, Greece.
The bowl (skyphos) is discussed in the paper by Despina Ignatiadou 'A *haematinon* bowl from Pydna', p. 69.

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PRÉFACE

Marie-Dominique Nenna

J'ai le grand plaisir de vous présenter les Annales du 18^{e} congrès de l'Association Internationale pour l'Histoire du Verre et je tiens à remercier tous ceux qui ont fait que cette publication paraisse dans les meilleurs délais, les auteurs au premier chef, le comité de lecture et surtout les éditeurs du volume, Despina Ignatiadou, vice-présidente, puis membre du bureau de l'AIHV durant les années 2006-2012 et Anastassios Antonaras.

Le 18^{e} congrès de l'AIHV s'est tenu à Thessalonique du 21 au 25 septembre 2009. Il a été dédié à Clasina Isings qui est venue, via une video, nous offrir ses meilleurs vœux au début des sessions. Tous nos remerciements vont d'abord au Musée archéologique de Thessalonique qui a organisé l'ensemble de cette manifestation et au Musée de la civilisation byzantine qui a accueilli nos sessions dans le tout nouveau auditorium, utilisé pour la première fois pour notre congrès. Remercions aussi les amis du Musée archéologique de Thessalonique qui ont soutenu ce congrès avec entre autres, le beau sac décoré de balsamaires-oiseaux ; la préfecture de Thessalonique qui nous ont accueillis à la fin de ces journées. Et enfin, du fond du coeur, tous nos remerciements vont à Despina Ignatiadou, Anastassios Antonaras et au comité d'organisation pour avoir réuni tous leurs efforts pour organiser ce congrès et nous offrir l'occasion de nous rencontrer une nouvelle fois pour partager nos découvertes et nos réflexions sur ce matériau qui nous passionne tous.

Durant les trente-trois sessions organisées en parallèle, 95 contributions orales et 55 posters ont été présentés, montrant ainsi la vitalité de la recherche sur l'Histoire du Verre dans l'ensemble du monde scientifique. Grâce au dynamisme du comité grec, après une découverte de la ville à l'orée de notre congrès, des promenades thématiques ont été organisées afin de mieux connaître les différents aspects de Thessalonique, ville hellénistique et romaine, ville byzantine, ville ottomane avec son importante communauté juive et ville du XX^{e} siècle. En outre, les excursions post-congrès ont permis aux participants de découvrir le cœur de la Macédoine avec les cités de Vergina et de Dion, ainsi que le lac de Pikrolimni, producteur de natron dans l'Antiquité et encore aujourd'hui, les villes d'Amphipolis et de Philippes ou encore de faire une croisière autour du Mont Athos.

Ce volume réunit 84 contributions qui couvrent un arc chronologique très vaste depuis le deuxième millénaire av. J.-C. jusqu'à nos jours, et touchent à tous les aspects de l'histoire du verre, avec une bonne interconnexion entre l'archéologie, l'histoire de l'art et l'archéométrie. Une part importante est réservée aux débuts de l'histoire du verre au II^{e} millénaire et au début du I^{er} millénaire av. J.-C. et à ses développements dans le monde hellénistique avec des communications portant sur le Proche-Orient, l'Égypte et le Soudan, la Grèce et la Turquie. Les mondes romain et byzantin sont abordés selon deux axes : étude de la production et de la consommation de la vaisselle et des ornements et étude en fort développement de l'emploi du verre dans les mosaïques pavimentales et pariétales. Les communications sur le monde islamique s'inscrivent dans la lancée inaugurée au 15e congrès et attestent la vitalité de la recherche dans ce domaine. La présentation de découvertes et études portant sur la Grande Bretagne, l'Italie, le Kosovo, le Montenegro, le Portugal, la Pologne, la Roumanie, la Serbie et la Tchéquie alimentent le débat sur le verre à l'époque médiévale et post médiévale en Europe. XVIIIe et XIXe siècles ne sont pas en reste, avec des communications sur le verre dans les toits, les fleurs de verre et le verre mosaïqué et on dispose aussi de communications sur le verre en Chine méridionale et en Afrique subsaharienne.

Lors de l'assemblée générale, le bureau de l'AIHV a été renouvelé. Jan Egbert Kuipers, trésorier et Ian Freestone, que l'on doit remercier pour leur dévouement et leur efficacité, ont présenté leur démissions. De nouveaux membres ont été élus : Irena Lazar, organisatrice du 19e congrès en 2012, comme vice-présidente et Huib Tijssens, comme trésorier. Déjà présents dans le bureau, Despina Ignatiadou a été élue comme membre, Jane Spillman a été réélue comme secrétaire général, David Whitehouse comme membre, et j'ai moi-même été réélue comme présidente. Le comité exécutif réunissant six membres élus ainsi que les représentants des associations ou comités nationaux a été en partie renouvelé, avec l'élection de Fatma Marii et de Yoko Shindo, tandis que Sylvia Fünfschilling, Lisa Pilosi, Marianne Stern et Maria Grazia Diani ont été réélues. Nous avons déploré le décès lors du congrès de deux de nos membres, Sarah Jennings d'Angleterre et Claudia Maccabruni d'Italie.

Les préparatifs pour le 19e congrès se déroulent sous la houlette d'Irena Lazar. Le congrès se tiendra à Piran en Slovénie du 17 au 21 septembre 2012 (www.aihv.org, www.zrs.upr.si). Après l'accent mis sur la Méditerranée orientale au congrès de Thessalonique, une nouvelle avancée vers les informations et les membres d'Europe Centrale sera effectuée à Piran.

PREFACE

Marie-Dominique Nenna

I have great pleasure in presenting you with the Annales of the 18th congress of the Association Internationale pour l'Histoire du Verre, and I wish to thank all those who have ensured that this publication appears with the least delay: principally the authors, the academic committee, and especially the academic editors of the volume, Despina Ignatiadou, vice-president, and member of the board of the AIHV for the years 2006-2012 and Anastassios Antonaras.

The 18th congress of the AIHV was held in Thessaloniki from September 21st-25th, 2009. It was dedicated to Clasina Isings, who came, via a video, to offer us her best wishes. Here we have to warmly thank the Archaeological Museum of Thessaloniki which has organized the whole manifestation, and the Museum of Byzantine Culture, which has hosted our sessions in the brand new auditorium of the Museum, used for the first time for our congress. All our warm thanks also to The Friends of the Archaeological Museum of Thessaloniki who supported the organization of the congress among the others with the nice bag decorated with bird-balsamaria, and The Prefecture of Thessaloniki, who has hosted us at the end of the congress. Last, but not the least, from the bottom of our heart, our thanks go to Despina Ignatiadou, Anastassios Antonaras and the Organizing committee for their hard work in organizing this congress and for offering us the opportunity to meet once again to share our discoveries and our thoughts on this wonderful material, glass, to which we are all dedicated.

During the 33 parallel sessions, 95 oral communications and 55 posters were presented, displaying the vitality of research on the history of glass in the scientific world. Thanks to the energies of the Greek Committee, after a first glance at Thessaloniki at the beginning of our congress, thematic visits were organised to discover the different aspects of Thessaloniki· Hellenistic and Roman city, Byzantine city, Ottoman city with its important Jewish community, contemporary city. In the post-congress trips, the participants were able to visit the heart of Macedonia, with the cities of Vergina and Dion, and the Pikrolimni Lake, producing natron in Antiquity and still today, the ancient cities of Amphipolis and Philippi, or to make a cruise around Mount Athos.

This volume brings together 84 contributions, which cover a vast chronological span from the second millennium BC up to the present day, touching on all aspects of the history of glass with a good networking between archaeology, history of art and archaeometry. An important part is devoted to the beginnings of the history of glass in the second millennium and the beginning of the first millennium BC, and the developments in the Hellenistic world with papers covering the Near East, Egypt and Sudan, Greece and Turkey. The Roman and Byzantine worlds are approached from two directions: the study of the production and consumption of vessels and ornaments and the expanding study on the glass in mosaic pavements and walls. The papers on the Islamic world build on the start made at the 15th congress and show the vitality of research in this area. The presentation of discoveries and research coming from the Czech Republic, Great Britain, Italy, Kosovo, Montenegro, Portugal, Poland, Romania and Serbia, fuels the debates about glass during the medieval and post-medieval period in Europe. The 18th and 19th centuries are not ignored, with papers dealing with glass in roofs, glass flowers and mosaic glass and there are also studies dealing with African and Asian glass.

During the General Assembly the board of the AIHV changed. Jan Egbert Kuipers (Treasurer) and Ian Freestone, to whom we extend all thanks for their work, submitted their resignations. The newly elected members were Irena Lazar, organizer of the 19th Congress in 2012, as Vice President, and Huib Tijssens, as Treasurer. Already present in the board, Despina Ignatiadou was elected member, were re-elected Jane Spillman as General Secretary, David Whitehouse as member, and I as President. The executive committee which assembled six elected members as well as the presidents of the national Associations or Committees, was partly renewed, with the election of Fatma Marii and Yoko Shindo; Sylvia Fünfschilling, Lisa Pilosi, Marianne Stern et Maria Grazia Diani were re-elected. We mourned during the congress the recent death of two long time members, Sarah Jennings from England and Claudia Maccabruni from Italy.

The preparations for the 19th congress are progressing under the guidance of Irena Lazar. The congress will be held at Piran (Slovenia) from September 17th to September 21st 2012 (www.aihv.org, www.zrs.upr.si). After the wider opening towards eastern Mediterranean members effectuated during the Thessaloniki Congress, we will receive in Piran more information and members coming from Central Europe.

TECHNOLOGICAL AND TYPOLOGICAL INVESTIGATION OF LATE ROMAN GLASS MOSAIC *TESSERAE* FROM ANCIENT MESSENE, GREECE

Metaxia Papageorgiou, Nikolaos Zacharias, Konstantinos Beltsios

I. Introduction

The present paper aims at investigating Late Roman mosaic *tesserae* excavated in 2008 at the sanctuary of Isis and Sarapis, an archaeological site of ancient Messene situated in the south-western Peloponnese region of Greece. In order to further understand the production of *tesserae* during Roman times, both archaeological and scientific aspects will be considered, however, emphasis will be placed on the scientific analysis of the *tesserae* this in turn, leading to concrete findings which can further contribute to existing studies.

II. Brief Archaeological Background

The use of mosaics in architectural embellishment was general practice long before the Roman period. The form of elements used for mosaic manufacture follows evolutionary stages which distinguish the various types of mosaics.

A turning point of this evolution during the third century BC was the invention of mosaics whose design consisted of *tesserae*[1]–shaped cubes between 0.5 and 1.5 cm. Their pebble predecessors could not satisfy the increasing desire of the Hellenistic society for variety in colour, detailed and complex designs which closely imitated paintings.

Mosaic *tesserae* were cut from various materials including glass. The advantages of glass *tesserae* versus stone or ceramic material was the ability to offer a range of colours and a glittering quality which could heighten bold contrasts in pictorial representations. Due to its less durable nature, glass was the most common material employed in wall and vault mosaic decoration, whereas it was less often used for floor adornment, and only in instances where bright colours were required. Indeed, according to Pliny, the pavements of theatres, basilicas and the domestic quarters of noble Romans were dressed in *tessellatae* or marble *sectile* work whereas the walls were embellished with glass ornamental entities that included both pictorial imagery and geometric patterns[2].

Despite the fact that glass *tesserae* were in use as far back as the first century BC, their widespread use in mosaics is significantly noticed as of the mid-first century AD and onwards[3]. However, the earliest evidence for the use of glass *tesserae* in the Greek area was identified on the island of Delos, dating back to the second century BC[4].

It has been reported that in Italy glass *tesserae* were obtained from glass cakes[5]. In fact, a fragmentary stele from Ostia dated to the beginning of the fourth century AD supports this assumption as it depicts mosaicists obtaining *tesserae* by hammering blocks[6]. Moreover, Giorgio Vasari gives a description of the preparation of mosaic cubes in Medieval times: "…When the glass was sufficiently melted and fused, it was ladled out… onto a metal table and pressed into circular cakes…the solidified glass was then annealed, cooled and cracked into tesserae…"[7]. However, it has been suggested that in Delos and Alexandria *tesserae* were cut from glass rods[8]. Therefore, the leading Roman glassworking technique, glass blowing, was not employed in the production of the *tesserae*, which suggests that older manufacturing techniques were in use when needed.

The *tesserae* were embedded as closely together as possible on a surface layer of fine cementing material. It has been observed in finds from the Mediterranean that the finishing touch on the surface of the tessellat-

1. Ling 1998, 24.

2. Pliny XXXVI, i.
3. Dunbabin 1999, 280.
4. Guimier-Sorberts and Nenna 1995, 529-563.
5. Boschetti 2008, e-22.
6. Dunbabin 1999, 281, fig. 287.
7. G. Vasari (1511-1571) in Newton and Davison 1996, 89.
8. Guimier-Sorberts and Nenna 1995, 529-563.

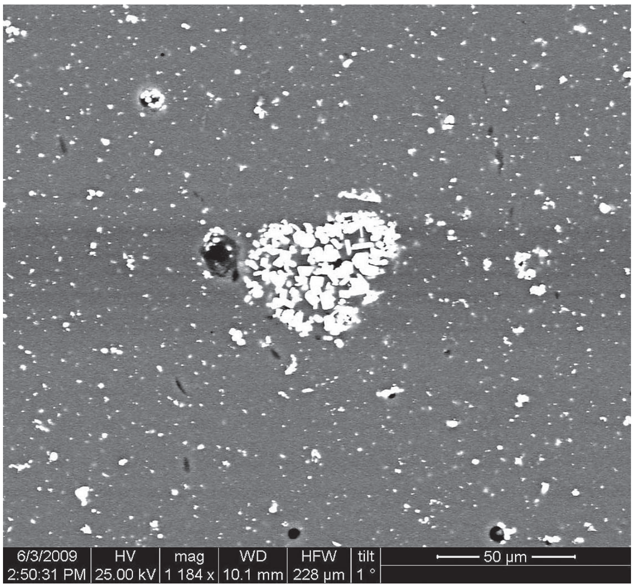

Fig. 1a: BEI image on SEM of calcium antimonate particles and crystal in the glass matrix of a white *tessera*.

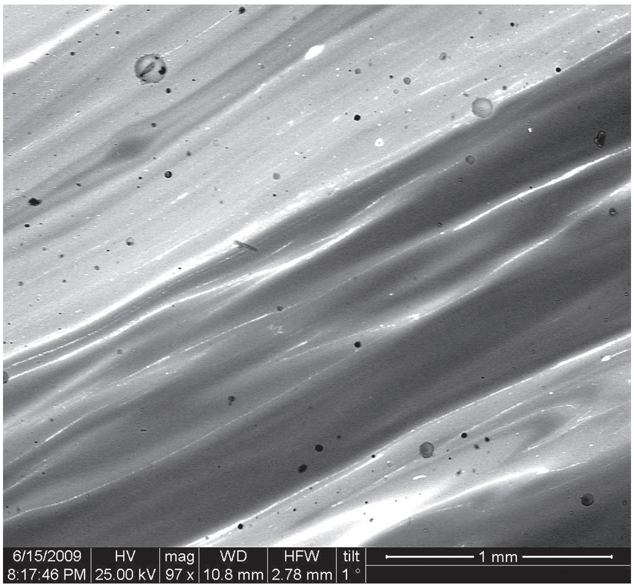

Fig. 1b: BEI image on SEM of striations rich in the yellow antimonate colourant in a yellow opaque *tessera*.

ed work was the application of a painted layer in order to reduce the appearance of the mortar joints[9].

III. The Context of the Glass *Tesserae*

All the buildings of ancient Messene, which Pausanias mentions in his *Description of Greece*, have by now been uncovered except for one—the sanctuary of Isis and Sarapis. However, recent excavations conducted to the south of the ancient theatre have brought to light the remains of a large underground Π-shaped vaulted portico that was incorporated in a building yet to be uncovered. It is believed that this building is part of a complex, which, based on Pausanias, belongs to the *Iseum* and *Serapeum*[10]. Each side of the aforementioned portico was forty meters in length and in Late Antiquity this construction was used as a deposition area. The remains excavated so far include collapsed debris, sherds of domestic pottery, fourth century lamps, tiles, fragments of architectural elements, and statues[11]. It is important to note that the discovery of ceramic lamp moulds proves that in this area, not only were elements from domestic contexts deposited, but also elements from workshops.

During the excavation period of 2008 a large number of scattered glass *tesserae,* in various colours and shades, were discovered along the eastern side of this underground construction. They are securely dated to the third century but it is not clear whether they were part of a wall or floor decoration due to the fact that they were found scattered.

IV. Results and Discussion

The average size of the 28 samples selected for scientific investigation was 7 × 5 × 7 mm and their weight was approximately 1.5 grams. The slight variation in size allows for the production of different shapes (square, rectangular, trapezoidal) suggesting that the examined specimens were cut according to the area which they were intended to decorate. Moreover, their small size points to a very detailed mosaic surface.

The main colours identified were different hues of blue, turquoise, yellow, green, white, purple, and two specimens of black *tesserae* which represent in reality dark purple and dark green shades. The latter, along with three olive green samples, are translucent, whereas all the rest of the glass *tesserae* were opaque.

Glass is an overall homogeneous material and even small fragments may generate secure results for the chemical composition of a finished product. However, mosaic *tesserae* are often more complex in nature; several phases can be identified in the glass matrix of a single specimen.

In fact, optical microscopy examination revealed areas in the samples that contrast in brightness which points to the compositional difference between the base glass that interacts with the visible inclusions within the *tesserae*.

9. Boschetti *et al.* 2008, 1085-1090.
10. '…Not far from the theatre is a sanctuary of Sarapis and Isis'. Pausanias 4.32.6, Themelis 2002, 33 and Themelis 2003, 29 fig. 23b.
11. Themelis 2002, 34.

Furthermore, backscatter electron imaging (BEI) revealed different methods of colour generation from sample to sample. Colourants are present either in the form of scattered pigment particles or striations (Fig.1a-1b). It should be mentioned that in the green and red samples, the presence of copper-containing inclusions associated with tin and sulfur respectively were also detected (Fig. 2). As far as opacity is concerned, it was achieved either by the even distribution of microcrystalline opacifying agents or by their aggregates. (Fig. 1a).

Finally, most of the samples contain silica inclusions which were not dissolved (at least completely) and which exhibit various shapes and sizes. Nevertheless, the latter particles do not suffice for the generation of opacity.

Methodology

Micro destructive sampling was performed by dry cutting. The samples were washed in deionised water in an ultrasonic bath and were dried. Next, they were embedded in epoxy resin molds. The resulting polished blocks were ground and polished in cross section and the resulting polished surfaces were carbon coated. Both the base glass composition (by multiple area analysis) and the identification of characteristic inclusions were carried out at the Institute of Materials Science of "N.C.S.R. Demokritos" using a FEI Inspect scanning electron microscope equipped with an energy dispersive spectrometer (SEM-EDS). The analysis was performed using an acceleration voltage of 25 kV and a working distance of 10 mm. ZAF correction was employed to normalize the standardless analyses. Backscattered electron imaging was employed because it has the advantage of yielding images of compositional variation[12].

The base glass

The base glass compositions show a homogeneous assemblage of the soda-silica-lime type, which is the ordinary glass type of the Roman period, containing high SiO_2 concentrations ranging from 60.51 % to 70.33 %, Na_2O values from 13.43 % to 17.26 % and CaO from 5.0 % to 7.02 %. Our data confirm that the lowest levels of CaO appear in the glasses that contain elevated amounts of lead (5.96 %-7.43 %). It has been stated that calcium oxide can be reduced due to the direct addition of lead oxide (5.96 %-7.43 %); it is known

12. Henderson 2000, 18.

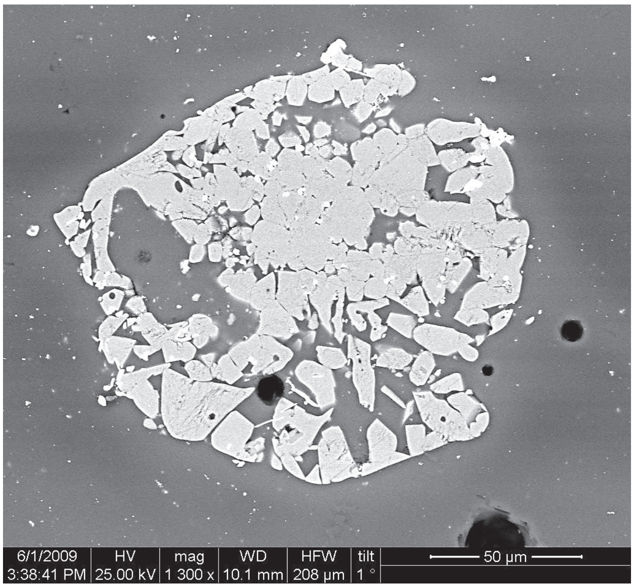

Fig. 2: BEI image on SEM of a copper inclusion associated with tin in a green opaque *tessera*.

already from antiquity (at least in practice)[13] that in silica-based glasses calcium and lead oxides are to a certain extent interchangeable.

Moreover, the Al_2O_3 content is moderate (average: 2.38 %) but constant over the whole glass assemblage; this might be due to the employment of a particular type of calcareous sand containing feldspar contaminants[14]. This assumption is compatible with our finding that our glass artefacts often contain particles with SiO_2 (52.64 %), CaO (38.69 %) as the major components and Al_2O_3 (1.68 %) and Na_2O (3.74 %) as minor components. The latter particles contain K_2O below the limits of detection and, hence, if sand contains feldspar contaminants the latter are possibly of the plagioclase type and certainly not of the orthoclase type.

Furthermore, low concentrations of K_2O, MgO (below 1 %) and P_2O_5 (average: 0.08 %) suggest that these pieces were produced with natron as flux[15]. In the Imperial Age natron was extracted from the Wadi Natrum, Egypt, where there were deposits of carbonates, sulfates and chlorides of sodium[16]. Thus, the presence of SO_3 at around 0.81 % and Cl_2O at around 1 % in the glass batch of the *tesserae* is further evidence of the employment of natron as flux.

Finally, when the concentrations of TiO_2 and MnO and Fe_2O_3 are below 0.5 % it is suggested that they result from impurities in the sand[17]. On the other hand,

13. Henderson 2000, 28.
14. Freestone 1994; Arletti 2006, 28.
15. Sayre and Smith 1961; Henderson 1985; Lilyquist and Brill 1995.
16. Shortland *et al.* 2006, 524.
17. Henderson 1985; Jackson 1996, 300.

enhanced levels of Fe_2O_3 and MnO most often reflect deliberate additions aiming at glasses of particular colors; the key exception is the case of elevated manganese oxide originating from alkali sources employed in Europe during medieval times.

Colourants and opacifiers

Although the colouring and opacifying of glasses requires knowledge and technical ability, a degree of uniformity in recipes was achieved in the Roman world. Thus, the technology used to colour and render opaque the *tesserae* from ancient Messene is similar to the techniques employed for the same reason in other ancient Roman sites[18].

Hence, all blue, turquoise, white, red and purple *tesserae* were opacified by calcium antimonate crystals, whereas lead and antimony compounds acted both as colouring and opacifying agents for yellow and green specimens.

Calcium antimonate crystals may be present in Roman samples either in the $CaSb_2O_6$ form or in the $Ca_2Sb_2O_7$ form[19]. Although it has been proven that they sometimes coexist in the same sample[20], the mosaic *tesserae* under investigation contain calcium antimonate in its hexagonal $CaSb_2O_6$ form (CaO: 14.5 %, Sb2O3: 79 %, average EDS analysis), which states that the *tesserae* were manufactured at temperatures higher than 1000 °C[21]. The origin of calcium antimonate from stibnite or roasted stibnite is well documented in literature[22]. Moreover, lead and antimony compounds are usually associated with the mineral bindheimite $Pb_2Sb_2O_7$, whose presence in opaque glasses has been validated in recent studies[23]; alternatively the same compound might result from separate lead and antimony additions. Overall, antimony-based opacifiers were in use up to the 4^{th}-5^{th} centuries, when they were largely replaced by tin oxide[24].

The *white* colour and opacity of one sampled vitreous *tessera* is linked to white calcium antimonate crystals. Furthermore, the *blue colour* was achieved by the strong chromophore cobalt. Cobalt-bearing minerals are often associated with copper. The existence of

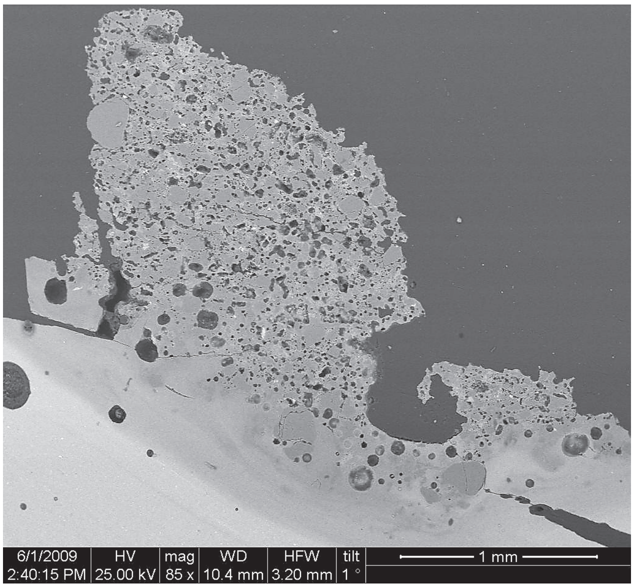

Fig. 3: BEI image on SEM of the "Si+Al" substance attached to a green opaque *tessera*.

copper in the blue *tesserae* might indicate *trianite* as a possible mineral source[25]; however, there are numerous examples of ancient blue glasses that contain copper and cobalt largely originating from separate sources. In our case, it is not possible to ascribe the examined blue samples to any of the potential cobalt sources considered by Gratuze and co-workers[26], because other trace elements that have been related by the latter authors to Co-bearing sources, such as zinc, nickel and arsenic, have not been detected by our SEM analyses.

The different tinges of the *turquoise tesserae* seem to be correlated to the amounts of copper and antimony. In addition, tin oxide occurs in some calcium antimonate aggregates. These tin particles may be a core around which large calcium antimonate compounds were developed[27]. In addition, a copper content is also detected in the same aggregates pointing to the use of bronze scrap for the addition of copper.

Samples that appear *green* owe their colour to the simultaneous presence of yellow lead antimonate and copper. It should be mentioned that copper inclusions are associated with tin, suggesting the use of a tin bronze as the raw material of the colourant[28]. Moreover, tin is also found to coexist with lead antimonate compounds, suggesting the possible use of bronze

18. Arletti *et al.* 2006a; Arletti *et al.* 2006b; Verità *et al.* 2008; Colomban 2003; Galli *et al.* 2004; Gedzeviciute 2009; van der Werf *et al.* 2009.
19. Mass *et al.* 1998.
20. Ricciardi *et al.* 2009, 2553.
21. Lahlil *et al.* 2009, 574.
22. Bimson and Freestone 1983; Henderson, 1991; Mass *et al.* 1997; Shortland 2002; Foster and Jackson 2005.
23. Ricciardi *et al.* 2009, van der Werf *et al.* 2009; Bouchard and Smith 2003; Colomban *et al.* 2001.
24. Tite *et al.* 2008.

25. Henderson 2000, 30.
26. Gratuze *et al.* 1992, 97-108.
27. van der Werf *et al.* 2009, 2630.
28. Mirti *et al.* 2001, 2002; Shortland and Tite 2000.

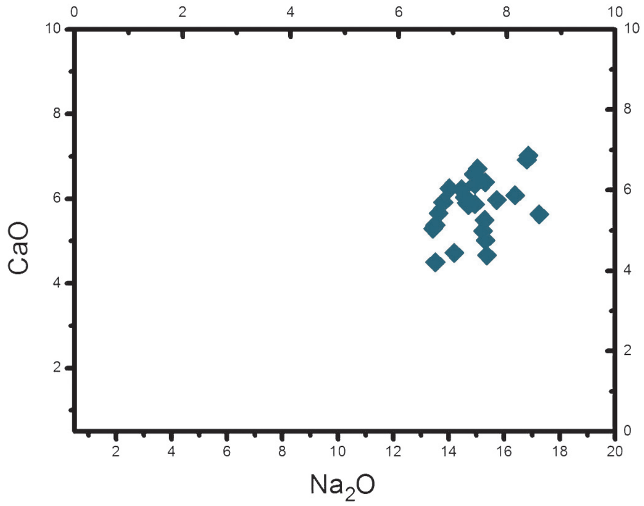

Fig. 4a: Concentrations of soda and lime (wt %) in the glass matrix of the *tesserae*.

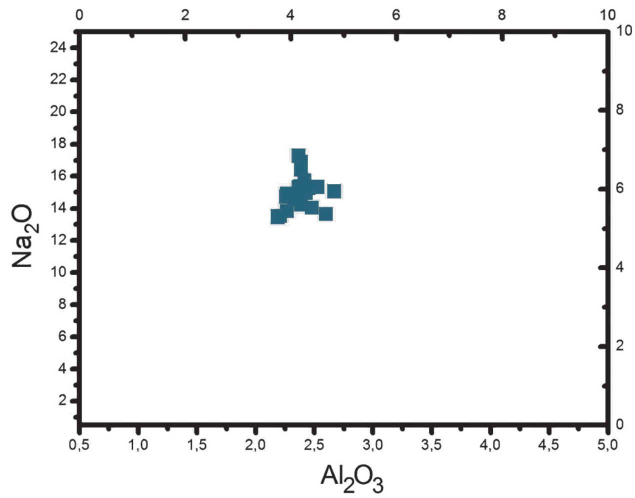

Fig. 4b: Concentrations of soda and alumina (wt %) in the glass matrix of the *tesserae*.

scale for the introduction of copper to the melt[29]. Finally, the presence of iron either isolated or combined with lead antimonate has already been discussed[30].

Yellow samples exhibit high levels of tin and antimony and are coloured and opacified with $Pb_2Sb_2O_7$. Tin particles were again identified, but, this time, their occurrence may be attributed to the presence of a yellow pigment prepared from a mixture of lead, tin, and antimony[31]. However, it is admitted that this is a puzzling issue to be further investigated.

In addition, the *purple* colour was obtained by adding manganese oxide (1.8 %) to the glass batch. Noteworthy are the manganese-containing compounds identified (MnO: about 70 %) associated with iron (Fe_2O_3: about 4 %).

Two analyzed *red tesserae* are classified as "low-copper and low-lead" representing the so-called ruby-red glasses. This red colour is obtained by a combination of copper, iron, and lead. Copper was present in its elemental and/or oxidized state[32]. Iron creates darker hues of red and along with significant amounts of lead it promotes the development of metallic copper particles[33]. Finally, residues of "Cu+S" were also identified whose chemical composition is comparable to chalcocite group minerals[34]; in addition to chalcocite and other copper sulfide minerals, chalcanthite can not be excluded as a possible raw material.

The translucent olive green samples were decolourized with manganese, while their colour is due to the interaction of iron and manganese. The aforementioned oxides were responsible for the black mosaic *tesserae* as well. Nevertheless, elevated amounts of copper were also determined in these glass matrices: 0.94 % (deep green colour) and 0.28 % (deep purple colour).

Finally, the base glass composition along with the biplots (Fig. 4a-b) of some major elements are indicative of the use of a single sand source, the controlled amounts of the raw materials to produce the base glass, and overall to the implementation of a standardized manufacturing procedure. The homogeneity of the base glass all over the Roman Empire confirms the existence of specialized glassmaking workshops that acted as suppliers of distant areas.

Slight differences in the chemical concentrations of minor elements are due to the exploitation of different sources available to the glassworker which further supports the primary-secondary production model[35].

Other characteristics

One of the samples analyzed has an accretion consisting mainly of alumina and silica (80 %). Other main components are calcium (2 %), iron (7 %), soda (5 %), magnesium (4 %) and potassium (1 %). This material

29. van der Werf *et al.* 2009, 2630.
30. Mass *et al.* 1998.
31. Lahlil 2009, 575.
32. Barber *et al.* 2009.
33. Ricciardi *et al.* 2009; 2556, van der Werf *et al.* 2009, 2632.
34. Santagostino Barbone *et al.* 2008.
35. Foy *et al.* 2000.

is assumed to be part either of the substratum that supported the *tesserae* or of the ceramic crucible (Fig.3).

Scattered calcium phosphate inclusions were found in this area and it is interesting that compositionally similar particles were detected within two opaque samples – a yellow and a purple. Calcium phosphate (bone ash) has been found probably as opacifier in glass cakes from Jordan[36]. However, its presence in the samples from ancient Messene is more haphazard rather than constant. It is believed that the existence of these inclusions in the glass matrix is accidental. It has been previously mentioned that high temperatures were utilized to manufacture these glasses. Thus, one possible explanation for the presence of these particles would be the absorption of impurities from the ceramic vessel. The absorption of the parting layer into glass as temperature increases has been already discussed[37].

V. Conclusions

It has been demonstrated that the production of the vitreous *tesserae* from ancient Messene follows Roman techniques and recipes consistent with current analytical studies. Thus, it is confirmed that Roman craftsmen had developed an international *koine* regarding the manufacture of glass *tesserae*.

Moreover, the colouring and opacifying agents identified and discussed were found either to cluster in tight groups or to be evenly distributed throughout the glass matrix. The colourants and opacifiers should have been prepared to be added into the melt at a second stage. The occurrence of different recipes for the production of colouring and opaque shades confirms the advanced level of technology, knowledge and technical skill involved in the production of these Roman artifacts.

Hence, SEM-EDS analysis is a useful tool for the identification of both base glass compositions and additives. However, the information obtained does not lead to concrete results regarding the mineralogical origin of several aggregates. Furthermore, it cannot provide evidence for the provenance of the glass due to compositional homogeneity. Therefore, complementary investigative techniques should be employed in order to better understand the nature of the raw materials used as well as the production technologies of the Roman *tesserae*.

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36. Marii and Rehren 2009, 298
37. Rehren 2008, 1348.

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