MINISTERO DEI BENI E DELLE ATTIVITÀ CULTURALI E DEL TURISMO

# BOLLETTINO ICR

2016

ISTITUTO SUPERIORE PER LA CONSERVAZIONE ED IL RESTAURO

## CONTRIBUTI

Scientific Investigation of Glass Mosaic Tesserae from the 8th Century AD Archaeological Site of Qusayr' Amra (Jordan)

La Galleria delle Grottesche di Villa Farnesina-Chigi.
- Architettura, artefici, significati.
- Le trasformazioni e i cambiamenti d'uso attraverso i documenti

Il restauro dell'icona di Santa Maria Nova

Comparative mechanical study of two lining systems and three stretchers

Jheronimus Bosch (1450 ca.-1516) a 500 anni dalla morte, studi e ricerche

## RECENSIONI

Michelangelo. Il marmo e la mente.
La tomba di Giulio II e le sue statue

The wall paintings of the great Mosque of Işfahan

## NOTIZIE BREVI

Istituto Superiore per la Conservazione
ed il Restauro
Via di San Michele, 23
00153 Roma - Tel. 06.67236293
e-mail: is-cr@beniculturali.it

Spedizione in abbonamento
postale, 45%, art. 2
comma 20/b, legge 662/96
Autoriz. Direz. Filiale di Firenze
tassa riscossa/taxe perçue

NARDINI EDITORE

32

GENNAIO/GIUGNO 2016

# Bollettino ICR

*Nuova serie · n. 32 · 2016*

MINISTERO DEI BENI E DELLE ATTIVITÀ CULTURALI E DEL TURISMO
ISTITUTO SUPERIORE PER LA CONSERVAZIONE ED IL RESTAURO

**Istituto Superiore per la**
**Conservazione ed il Restauro**
Via di San Michele, 23
00153 Roma
Tel. 06.67236293
Fax 06.67236409
www.iscr.beniculturali.it
E-mail: is-cr@beniculturali.it

Iscrizione Tribunale di Firenze
n. 5319 del 19.01.2004

La pubblicità non supera il 45%

Spedizione
in abbonamento postale

ISSN 1594-2562

Periodico semestrale
ISBN 978-88-404-5084-1

Una copia Euro 32,00
Digitale PDF Euro 15,00

*Abbonamento (2 numeri)*
Cartaceo Euro 60,00
(Europa: Euro 80,00)

***Stampa***
Marzo 2017,
Tipografia Baroni & Gori,
Pescia (PT)

NARDINI EDITORE®
*Nardini Press srl*
Via delle Vecchie Carceri, snc
50122 Firenze
www.nardinieditore.it
www.nardinirestauro.it
info@nardinieditore.it

***Servizio Abbonamenti***
Tel. 055.2476080
E-mail: info@nardinieditore.it

***Design***
Ennio Bazzoni

***Coordinamento editoriale***
Andrea Galeazzi
Ennio Bazzoni

Le immagini in copertina (dall'alto):
- Giordania, sito di Qusayr' Amra, tessere vitree;
- Roma, Villa Farnesina, Galleria delle Grottesche, particolare prima del restauro;
- Roma, Santa Maria Nova, l'icona a fine restauro;
- Perugia, Galleria Nazonale dell'Umbria: Pietro da Cortona, *Madonna col Bambino e santa Martina*;
-Terni, Gaspar Van Wittel, *Veduta del Campo Vaccino dalla scala laterale dell'Aracoeli*, prima del restauro;
- Spagna, Cartagena, frammento di zanna d'avorio di età fenicia;
- Roma, giardini del Quirinale, biodeterioramento a carico di una statua.

Dove non diversamente
indicato, le foto pubblicate sono degli autori.

# Indice

*Bollettino ICR*
*Nuova serie • n. 32 • 2016*

## CONTRIBUTI

## RECENSIONI

BOLLETTINO ICR • NUOVA SERIE • N. 32 • 2016

Marco Verità
Paola Santopadre
Giovanna De Palma

# Scientific Investigation of Glass Mosaic Tesserae from the 8$^{th}$ Century AD Archaeological Site of Qusayr' Amra (Jordan)

## INTRODUCTION

Since 2011 the Istituto Superiore per la Conservazione e il Restauro (ISCR) in Rome in cooperation with the Department of Antiquities for the Kingdom of Jordan (DOA) and the World Monuments Fund (WMF), has been involved in the restoration and conservation of Qusayr'Amra complex in Jordany. The monumental complex date back to the Umayyad times (8$^{th}$ century AD) and was included in the UNESCO World Heritage list in 1985.

The ISCR team has been working in particular on the well known wall paintings that had almost completely lost their readability. First results were presented at an international conference held in Rome, October 22-23, 2014[1].

During the work thousands of mosaic glass tesserae were uncovered in two areas of the complex: the *calidarium* and the so called "workshop". In the *calidarium* most of the tesserae show traces of mortar adhering, which suggest they belonged to the now lost wall and floor mosaics of the building. In an adjacent area, the so called "workshop", tesserae without any mortar traces were found.

This work illustrates the results obtained from the analytical investigation of tesserae from the two areas indicated hereafter as: C (*calidarium*) and W (workshop).

Before discussing the results of the analyses of these materials, a short summary of present knowledge on the ancient glass technology used for the production of mosaic tesserae is given.

### GLASS MOSAIC TESSERAE

Glass mosaic tesserae can be divided into two main groups, i.e., coloured glass[2] tesserae and metal leaf tesserae.

Coloured glass mosaic tesserae are made of coloured transparent glass in which opacifying particles (crystals or bubbles) are dispersed in order to reduce their transparency and colour intensity. White tesserae are obtained from colourless glass by adding opacifier crystals, while increasing additions of these crystals to coloured glass allow progressively lighter tones to be obtained. Tesserae can be also coloured with pigment particles (yellow, red and orange) dispersed in a coloured or colourless glass[3].

Metal leaf tesserae are composite materials made of a thin gold or silver leaf hot sandwiched between two glass layers. These tesserae were obtained by cutting cakes consisting of a layer of poured glass (the support, less than 10 mm thick), a thin beaten gold leaf (less than 1 µm thick) and a thin layer of blown glass (less than 1 mm thick), the *cartellina*, protecting the gold leaf and increasing its brilliance[4].

After forming in a glass workshop the slabs were transported to the place where the mosaic had to be set and there they were cut by the mosaicists with a small hammer or some other sharp metal tool. The fracture surface of the coloured tesserae was placed facing outwards in the mosaic.

Glass tesserae were extensively used to decorate the walls and ceilings since the first centuries of the Christian era. Coloured tesserae cut from a glass cake were used since the beginning of the 1st century AD[5]. The earliest examples of metal leaf tesserae date back to the 1st century AD in Rome[6], and their use spread widely in the 3rd-4th century.

## GLASS PRODUCTION

The dominant glass type from the Roman time until the 8th-9th century AD was composed mainly of the oxides of sodium, calcium and silicon (soda-lime-silica glass), with the oxides of potassium and magnesium each below about 1.5% and phosphorous below 0.2%. A sodium carbonate mineral (associated to lower amounts of other salts such as chlorides and sulphates) from Egypt called natron[7] was mixed and fused together with silica-lime sand in which quartz and calcium carbonate were present in suitable ratios to make glass[8]. This sand was quarried in a few sites, such as the mouth of the rivers Belus (presently Na'aman, between Haifa and Acre in northern Israel) and Volturno (north of Neaples, Italy), as mentioned by Pliny in his *Naturalis Historia*[9]. Glasses of this type are termed natron glasses.

This composition did not change substantially until the 8th-9th centuries, when a new type of soda-lime-silica glass with higher potassium, magnesium and phosphorous contents produced using soda-lime plant ash as a flux[10], was introduced beside natron glass. It replaced natron glass completely only a few centuries later[11].

Recent archaeological evidence suggests that the practice of making natron type glass from its raw materials was carried out in a limited number of places located near the sources of the raw materials[12], in tank furnaces where several tons of glass could be melted[13]. Once the melting was completed, the furnace was left to cool and then demolished. The large block of transparent glass slightly coloured in natural hues from green, yellow to light blue was broken up into chunks (raw glass) that were traded throughout the Mediterranean and Europe and distributed to secondary workshops where they were remelted in smaller furnaces, coloured, opacified and made into artefacts. To the authors' knowledge, no secondary centres for the production of glass cakes for mosaic tesserae have been identified until now.

## AIM OF THE ANALYTICAL INVESTIGATIONS

The aim of this study was to determine the chemical composition of the glass tesserae from Qusayr'Amra and identify colourants and opacifiers. These data were then compared with the database of analyses of glass tesserae from other mosaics of the same period in order to ascertain similarities and differences. It is known that the mosaics used in this early Islamic building are close in their form, colours and techniques to the late Christian buildings[14]. It was interesting to investigate the possibility of ascertaining their origin by comparing present results with the analyses of similar materials published in the literature.

Some critical issues must be considered in this kind of approach. The distinction between glassmelting and glassworking in the production process has important implications for the interpretation of the analytical data. For instance, in our case, the chemical composition of the base glass of the tesserae reflects the location of the primary workshop, while the colourants and opacifiers and the metal leaves reflect the location of the secondary workshop where the glass cakes were made. This fact implies that the glass chemical composition is not specific to the production workshop of the glass cakes, but rather to the primary workshop producing the raw glass. The differentiation of some compositional groups was proposed, but the time range is rather wide and the characteristics cannot always be distinguished[15].

Another problem is the fact that the glass tesserae could have been recovered from the dismantling of older mosaics. The re-use of glass tesserae has always been (and so it is today) a common practice, owing to their high cost, shortage of specific raw materials (colorants, for instance) or decline periods of the glassmaking technology.

The metal leaves of the tesserae were also analysed for compositional identification. The use of circulating coins to obtain gold leaves during the Roman and Late Antique periods cannot be excluded. Gold coins were common currency in those days, representing an easily accessible source of gold. Coins are amenable to close dating because they are usually inscribed with the name of a known ruler. It is known that the composition of circulating gold coins varied in time and sometimes also according to the mint of coinage. The control over the purity of minted gold was exerted in Byzantine age, although complex dynamics occurred, as well as debasement phenomena in the provincial mints, especially from the end of the 7th century onwards[16].

### Sampling and analytical methods

Among the thousands of tesserae excavated at Qusayr' Amra 120 tesserae (20 from the *calidarium*, 100 from the workshop) were made available by the archaeologists as considered representative of the different types present in the site[17]. The tesserae were divided per type (coloured and metal foil tesserae) and according to their aspect (colour, opacity-transparency, etc.).

The weight of the tesserae ranged between 0.4 and 1.5 g; all of them show four fracture surfaces (cold cut) and two surfaces hot-formed on a flat surface, which confirms that they were obtained by cutting glass cakes according to conventional mosaic techniques. The tesserae were generally in a good state of preservation and adhesion of the *cartellina* in the metal leaf tesserae appeared good, without corrosion of glass along the edges of metal leaf[18].

From the 120 samples, 18 tesserae from the workshop (10 coloured, 8 metal leaf tesserae) and 8 tesserae from the *calidarium* (5 coloured, 3 metal leaf tesserae) were selected for analysis. Small fragments were taken from each tessera[19] and embedded in an acrylic resin; cross-sections were ground and polished with diamond pastes. After examination under the optical microscope the samples were carbon coated under vacuum.

The polished cross sections were analysed by scanning electron microscope (SEM) in backscattered mode to identify heterogeneities[20]. Quantitative chemical composition of glass[21] and metal leaves[22] were obtained by energy dispersive X ray microanalysis.

## Results

The chemical compositions of the *cartellina* and the support of the metal leaf tesserae analysed separately, are reported in Table 1 expressed in wt% of the oxides. The average chemical compositions (glassy phase + crystals) of the analysed coloured tesserae are reported in Table 2 expressed in wt% oxides. Hereafter the results are discussed separately for the base glass[23], opacifiers and colourants.

### Base glass

The base glass of the analysed tesserae from the Qusayr' Amra site is composed mainly of silica ($SiO_2$), sodium ($Na_2O$) and calcium (CaO) oxides (soda-lime-silica glass). Low concentrations of potassium and magnesium are also present ($K_2O$ and MgO less than 1.5% each), together with chlorine (Cl 0.7-1.3%), while phosphorous is not detected (lower limit of detection: $P_2O_5$ 0.2%)[24]. These characteristics point to

## TABLE 1

### CHEMICAL COMPOSITION IN WT% OF THE OXIDES OF THE SUPPORT (S) AND CARTELLINA (C) OF THE METAL LEAF TESSERAE

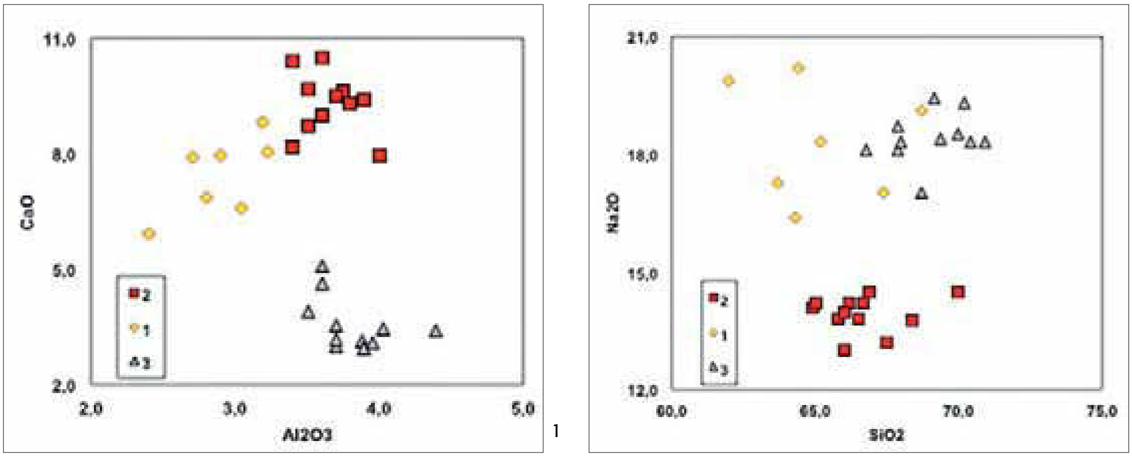
| Tessera | Support | Cartellina | Glass Type | Metal leaf Ag% | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $SO_3$ | Cl | $TiO_2$ | $Fe_2O_3$ | MnO | $Sb_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **wAu1(sc)** | dark yellow | dark yellow | 1 | 8 | 62.0 | 3.05 | 19.8 | 0.80 | 6.60 | 1.10 | 0.45 | 1.05 | 0.20 | 3.10 | 1.80 | |
| **wAu3(sc)** | yellow | yellow | 1 | 8 | 64.3 | 2.80 | 20.2 | 0.60 | 6.90 | 0.90 | 0.50 | 1.20 | 0.15 | 1.00 | 1.40 | |
| **wAu4(s)** | colourless | | 1 | 8 | 68.7 | 2.40 | 19.1 | 0.47 | 5.90 | 0.60 | 0.45 | 1.30 | 0.14 | 0.45 | | 0.48 |
| **wAg2(sc)** | yellow | yellow | 1 | 100 | 65.2 | 2.90 | 18.2 | 0.65 | 8.00 | 1.00 | 0.45 | 1.00 | 0.20 | 1.05 | 1.30 | |
| **wAg1(sc)** | green | green | 2 | 100 | 66.5 | 3.90 | 13.8 | 0.85 | 9.40 | 1.40 | 0.20 | 0.90 | 0.10 | 0.90 | 2.00 | |
| **wAu2(c)** | | dark yellow | 2 | | 66.0 | 3.50 | 13.0 | 0.85 | 9.70 | 1.25 | 0.14 | 0.90 | 0.20 | 0.73 | 3.70 | |
| **wAu2(s)** | green | | 2 | 4 | 68.3 | 3.60 | 13.8 | 0.65 | 10.5 | 0.90 | 0.16 | 1.05 | 0.17 | 0.70 | 0.15 | |
| **wAu5(c)** | | dark brown | 2 | | 67.5 | 4.00 | 13.2 | 0.70 | 8.00 | 1.10 | 0.33 | 1.15 | 0.08 | 0.54 | 3.40 | |
| **wAu5(s)** | yellow | | 2 | 12 | 66.0 | 3.50 | 14.0 | 1.00 | 8.70 | 1.40 | 0.29 | 0.75 | 0.11 | 0.75 | 3.50 | |
| **wAu6(c)** | | dark yellow | 2 | | 64.9 | 3.75 | 14.1 | 0.85 | 9.60 | 1.20 | 0.16 | 0.72 | 0.10 | 0.80 | 3.80 | |
| **wAu6(s)** | dark brown | | 2 | 20 | 65.0 | 3.60 | 14.2 | 0.90 | 9.00 | 1.30 | 0.20 | 0.75 | 0.15 | 0.90 | 4.00 | |
| **cAu7(sc)** | green | green | 2 | 8 | 70.0 | 3.40 | 14.5 | 0.90 | 8.20 | 1.10 | 0.20 | 0.90 | 0.10 | 0.60 | 0.05 | |
| **cAu8(c)** | | yellow | 2 | | 66.2 | 3.60 | 14.2 | 0.90 | 9.00 | 1.20 | 0.20 | 0.70 | 0.10 | 0.85 | 3.00 | |
| **cAu8(s)** | dark brown | | 2 | 8 | 66.0 | 3.60 | 14.0 | 0.90 | 9.00 | 1.20 | 0.20 | 0.70 | 0.10 | 0.90 | 3.40 | |
| **cAu9(c)** | | dark brown | 2 | | 65.8 | 3.80 | 13.8 | 1.00 | 9.30 | 1.35 | 0.10 | 0.60 | 0.20 | 1.00 | 3.00 | |
| **cAu9(s)** | yellow | | 2 | 15 | 66.7 | 3.70 | 14.2 | 0.95 | 9.00 | 1.20 | 0.10 | 0.70 | 0.15 | 0.78 | 2.00 | |

*The tesserae in which the two glasses are equal are marked (sc). The transparent glass colour is indicated (dark indicates intensely coloured glass). Other oxides analysed but not detected (general limit of detection: 0.1-0.3%): P, Pb, Sn, Cu, Co, As, Zn, Ba, Ni. The base glass type and the amount of silver detected in the metal leaf (expressed in wt% of the element) are also reported.*

**Figg. 1-2**
Diagrams of the base glass concentrations of calcium and aluminium oxides and sodium and silicon oxides; the three compositional groups are indicated with different symbols.

natron type glass. Some compositional differences observed in the samples can be attributed to the use of silica-lime sands of different provenance. A comparison of the concentrations of a number of meaningful elements is given in Figg. 1-2 where three natron type groups are indicated with different symbols.

*Group 1* – This group (yellow diamonds in the plots) includes four metal leaf tesserae from the workshop (three gold leaf: wAu1,3,4, and one silver leaf wAg2), two red tesserae (wR1 and cR2) and a blue one wB2. As regards the glass composition the concentrations of alumina ($Al_2O_3$ 2.4-3.2%), potassium ($K_2O$ 0.5-1.2%),



1

2

**TABLE 2**

**CHEMICAL COMPOSITION IN WT% OF THE OXIDES OF THE COLOURED GLASS TESSERAE**

| Tessera | Colour | Glass Type | Opacifier | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $SO_3$ | $P_2O_5$ | Cl | $TiO_2$ | $Fe_2O_3$ | MnO | CuO | PbO | $SnO_2$ | CoO | ZnO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **wB1** | blue | 2 | CaP | 66.5 | 3.35 | 14.4 | 0.80 | 10.3 | 1.00 | 0.15 | 1.00 | 0.80 | 0.13 | 0.90 | 0.18 | 0.10 | 0.30 |  | 0.10 |  |
| **wB2** | dark blue | 1 | tr | 66.8 | 2.70 | 16.8 | 0.62 | 7.80 | 0.94 | 0.10 |  | 0.85 | 0.20 | 1.15 | 1.20 | 0.10 | 0.70 |  | 0.10 |  |
| **wR1** | red | 1 | Cu | 55.3 | 2.80 | 15.0 | 1.10 | 7.00 | 1.20 |  |  | 0.80 | 0.25 | 2.30 | 1.10 | 1.85 | 7.80 | 2.30 |  | 1.20 |
| **cR2** | red | 1 | Cu | 60.5 | 3.00 | 15.4 | 1.00 | 8.30 | 1.00 |  |  | 0.80 | 0.10 | 3.70 | 0.30 | 0.85 | 4.50 | 0.50 |  |  |
| **wN1** | black | 3 | tr* | 67.3 | 3.70 | 18.0 | 0.60 | 3.60 | 0.70 | 0.30 | 0.30 | 1.20 | 0.30 | 3.45 | 0.15 | 0.10 |  | 0.10 | 0.10 | 0.10 |
| **cN2** | black | 3 | tr | 67.8 | 3.50 | 18.3 | 0.60 | 3.90 | 0.70 | 0.20 |  | 1.20 | 0.20 | 3.60 |  |  |  |  |  |  |
| **wV1** | dark turquoise | 3 | PbSn* | 62.8 | 3.30 | 16.3 | 0.50 | 2.70 | 0.55 |  | 0.35 | 1.20 | 0.25 | 1.10 | 0.10 | 1.70 | 8.50 | 0.65 |  |  |
| **cV4** | dark turquoise | 3 | PbSn | 60.0 | 3.30 | 15.5 | 0.55 | 2.50 | 0.55 |  |  | 1.00 | 0.20 | 1.10 |  | 2.30 | 12.0 | 1.00 |  |  |
| **wV2** | turquoise | 3 | CaP | 68.0 | 3.60 | 16.8 | 0.45 | 4.60 | 0.75 | 0.20 | 2.40 | 0.80 | 0.35 | 1.15 | 0.15 | 0.20 | 0.30 | 0.20 |  |  |
| **wV3** | olive green | 3 | CaP | 66.0 | 3.60 | 17.9 | 0.70 | 5.00 | 0.75 | 0.20 | 2.20 | 1.20 | 0.30 | 1.08 | 0.15 | 0.20 | 0.50 | 0.20 |  |  |
| **wGV1** | green-yellow | 3 | PbSn | 53.0 | 2.80 | 14.5 | 0.45 | 2.40 | 0.50 |  |  | 0.60 | 0.20 | 1.00 |  | 0.50 | 22.0 | 2.00 |  |  |
| **cGV3** | green-yellow | 3 | PbSn | 57.0 | 3.20 | 16.0 | 0.50 | 2.60 | 0.80 |  |  | 1.00 | 0.25 | 1.05 |  | 1.10 | 15.0 | 1.50 |  |  |
| **wGV2** | green-yellow | 3 | PbSn | 58.8 | 3.30 | 15.4 | 0.53 | 2.50 | 0.60 |  |  | 1.10 | 0.25 | 1.15 | 0.15 | 1.20 | 13.8 | 1.20 |  |  |
| **cG2** | yellow | 3 | PbSn | 46.2 | 3.00 | 12.8 | 0.35 | 2.30 | 0.90 |  |  | 0.80 | 0.20 | 1.00 | 0.75 |  | 28.0 | 3.70 |  |  |
| **wG1** | yellow | 3 | PbSn | 46.6 | 2.70 | 12.3 | 0.20 | 2.30 | 0.60 |  |  | 0.55 | 0.15 | 1.05 | 0.55 |  | 29.0 | 4.00 |  |  |
| **wG1** | transp streak | 3 | tr | 65.0 | 3.80 | 17.5 | 0.50 | 3.20 | 0.80 |  |  | 1.20 | 0.25 | 1.40 | 0.65 |  | 5.00 | 0.70 |  |  |

*Other oxides analysed but not detected (general limit of detection: 0.1-0.3%): Sb, As, Ba, Ni. The sulphur concentration could not be determined for high lead glass. The base glass type and opacifier used (tr: transparent; Cu: metallic copper and cuprite; PbSn: lead stannate; CaP: bone ash) are also reported. The (*) indicates samples where few particles of bone ash were detected.*

magnesium (MgO 0.6-1.3%) and sodium ($Na_2O$ 16.5-20%) vary within the typical ranges of most natron type glasses. The tessera wAu4 is the only one in which antimony was found; it could be a reused tessera belonging to a more ancient dismantled mosaic.

*Group 2* – This group (red squares in Figg. 1-2) includes metal leaf tesserae (three gold leaf and one silver leaf from the workshop and three gold leaf from the *calidarium*), as well as the blue tessera wB1. The glass shows low concentrations of sodium oxide[25] ($Na_2O$ 13-14.5%) and high levels of aluminium ($Al_2O_3$ 3.4-4%) and calcium (CaO 8-10.5%). A certain similarity in composition with this group was found in Byzantine glasses from Asia Minor, for which a similar silica-lime sand might have been used[26].

*Group 3* – This group consists exclusively of opaque tesserae coloured turquoise to green and to yellow (11 tesserae: grey triangles in Figg. 1-2) in which the glass shows low calcium (CaO 3-4.6%)[27] and high alumina ($Al_2O_3$ 3.6-4.4%), iron ($Fe_2O_3$ 1.0-1.5%)[28] and titanium ($TiO_2$ 0.22-0.35%) concentrations. Quite similar compositions were found on glass money weights and others glass artworks from the Omayyade period (second half of 7th-middle of 8th century AD) for which an Egyptian provenance has been hypothesized[29].

## COLOURED TESSERAE

The colour of the tesserae is the result of the colour of the glass and of the possible presence of coloured (pigments) and/or white (opacifying) particles.

*Blue* – Blue tesserae are present only among those sampled in the workshop. The base glass is different in the two tesserae, type 2 in wB1 and type 1 in wB2. The blue colour is given by cobalt dissolved in the glass in equal amounts (CoO 0.10%) in the two tesserae. In the cross-section of tessera wB2 a deep blue coloured streak was identified containing high levels of cobalt (CoO 1.2%) together with iron ($Fe_2O_3$ 4.7%), lead (PbO 1.5%), alumina ($Al_2O_3$ 3.1% against 2.7% of the glass) and traces of copper (CuO 0.2%) and zinc (ZnO 0.1%). These elements were present together with cobalt in the ore used to colour the glass. It is known that before the industrial age cobalt was not used as the pure oxide but as an ore where it was associated with other elements. The cobalt associated mainly with iron and lead identified in the two tesserae was being used for several centuries, from the Roman age up to around the 12th century[30].

The light tone of tessera wB1 was obtained by adding to the glass melt a considerable amount of bone ash (calcium phosphate), whose white particles act also as a colour clarifier. SEM observation revealed residual bone ash particles and also euhedral crystals composed of silica and calcium oxide. These are wollastonite (*calcium silicate*) crystals that separate from the melt (which therefore is termed 'devitrified') when it dwells at around 900-1000 °C for relatively long times.

*Black* – The base glass composition of wN1 and cN2 black tesserae is of type 3. This transparent glass shows its intense yellow-green colour observing the thinner areas of the fragments. It is imparted mainly by the large additions of iron ($Fe_2O_3$ 3.5%) to the glass melt, as demonstrated by the iron-rich dark brown steaks present in both tesserae. The colour was obtained by maintaining a reducing (low oxygen) atmosphere in the furnace so as to develop the intensely amber coloured iron-sulphur complex. The composition of the two tesserae is almost identical, except for traces of cobalt, tin, copper and zinc (elements indicating recycling of coloured glass cullet) and few calcium phosphate particles found only in tessera wN1.

*Turquoise, green, yellow tesserae* – The colouring techniques of these tesserae are particularly varied, obtaining a range of colours from turquoise to green-yellow, to yellow-green and yellow (Fig. 3). A type 3 composition of the base glass was verified in all these tesserae.


3

**Fig. 3**
Tesserae of the turquoise to green to yellow range.

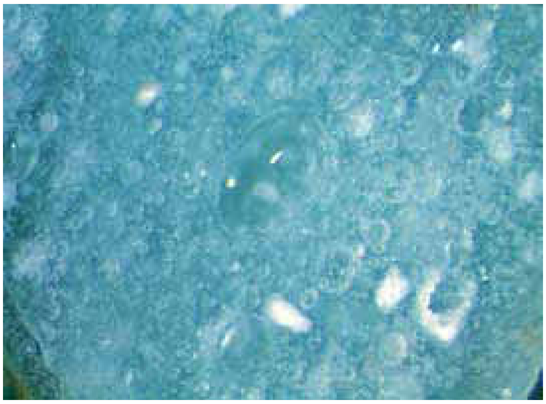
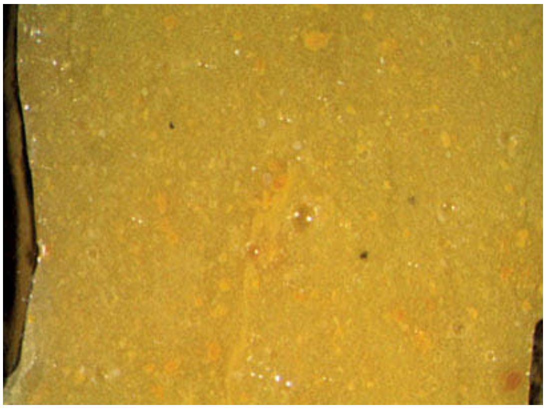
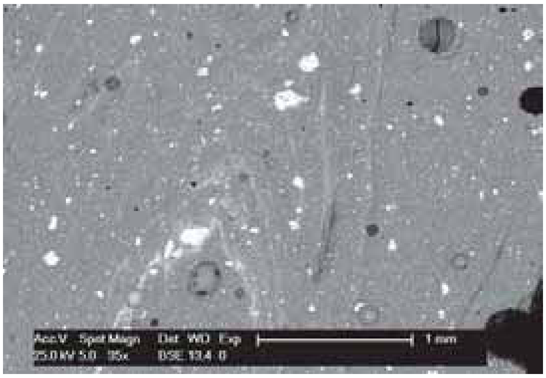

4

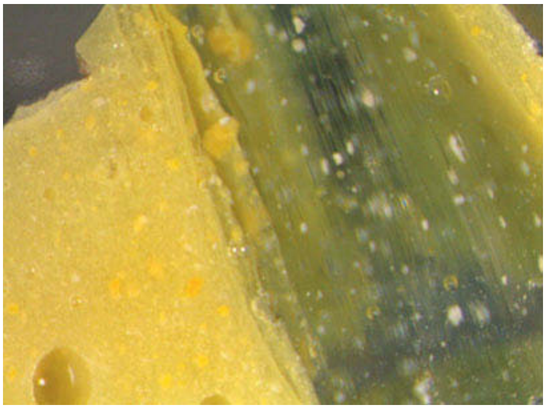
**Fig. 4**
Optical micrograph of the polished section of a fragment of the turquoise tessera wV2, opacified with bone ash particles and bubbles (long side of the micrograph: 2.5 mm).

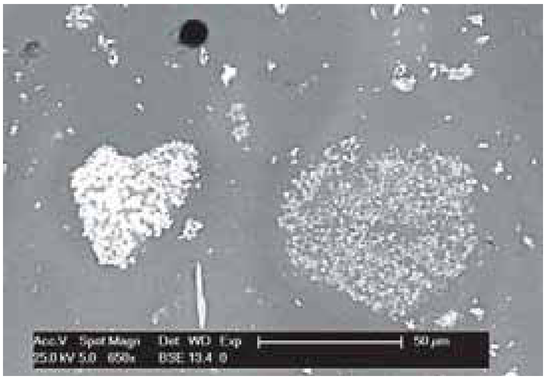

5

**Fig. 5**
Optical micrograph of the polished section of a fragment of the green-yellow tessera cGV3, opacified with yellow particles of lead stannate ((long side of the micrograph: 10 mm).

6


7


8


9


**Figg. 6-7**
Optical micrograph (Fig. 6; long side of the micrograph: 2.5 mm) and SEM micrograph (Fig. 7) of the polished section of a fragment of the yellow tessera cG2. The heterogenity of the tessera can be observed in the SEM micrograph where the lead stannate particles appear as white dots.

**Figg. 8-9**
Optical micrograph (Fig. 8; long side of the micrograph: 2.7 mm) of the polished section of a fragment of the yellow tessera wG1. In Fig. 9, the SEM micrograph shows a detail where an aggregate of yellow lead stannate crystals (white particle on the left) and a white aggregate of needle-like tin oxide crystals (gray aggregate on the right) can be observed.

The olive-green colour of the glass of tessera wV3 (bubbles and bone ash particles as an opacifier) is given by copper and the iron-sulphur complex developed in the reducing atmosphere of the furnace during melting, as mentioned above for black glass.

The turquoise glass colour of tesserae wV1 and wV2 was obtained with copper (CuO 1.7% and 0.2% respectively) and iron. In the wV2 tessera the colour was lightened with white particles of calcium phosphate (Fig. 4).

Instead, in the wV1 tessera the colour was lightened with white particles of calcium phosphate and yellow particles of lead stannate.

In the remaining tesserae of this group wGV1 and 2, cV4 and cGV3 the dark green transparent glass coloured by copper and iron is clarified by adding particles of lead stannate yellow pigment (Fig. 5). The same particles were identified in the yellow tesserae from both areas.

The composition of the yellow particles is similar regardless of the colour of the tesserae. They are made of lead (PbO 65-70%), tin ($SnO_2$ 22-25%) and silica ($SiO_2$ 7-10%) and consist of lead stannate crystals obtained by firing a batch of lead, tin and silica compounds[31].

The appearance of these tesserae is very heterogeneous (Figg. 6-7), a common feature of glass coloured with yellow pigments that dissolve easily in the molten glass and decompose at high temperatures. For this reason it is necessary to work and cool the glass as soon as possible after adding the pigment.

An example of this technique is shown by some yellow tesserae from the workshop in which large layers of opaque yellow and colourless transparent glass can be observed (Figg. 8-9).

SEM observation of the polished sections of the yellow and yellow-green tesserae reveals sometimes also the presence of white particles made of aggregates of needle-like crystals of tin oxide ($SnO_2$, cassiterite). The peculiar aspect of the aggregates and the euhedral appearance of the crystals demonstrate that these particles are not a voluntary added white opacifier (tin oxide or lead-tin calx) but they result from the process of decomposition of yellow pigment particles,

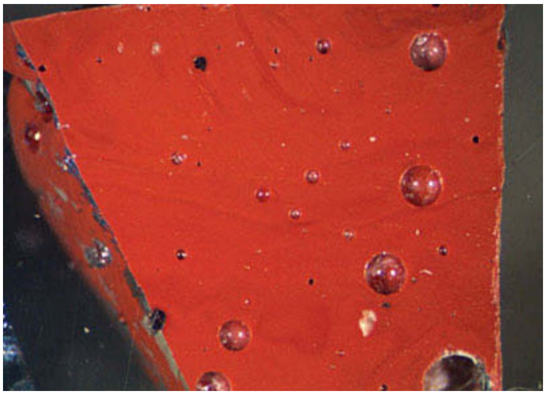
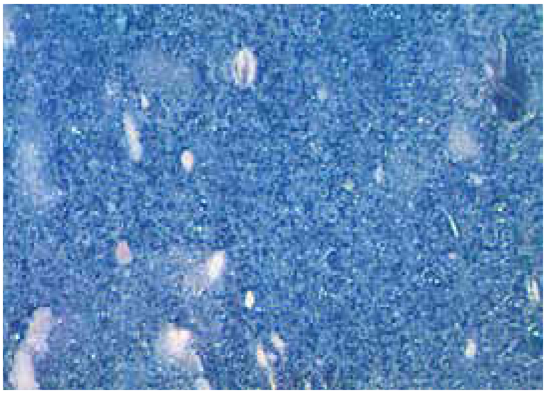


**Fig. 10**
Optical micrograph of the polished section of a fragment of the red tessera wR1. Long side of the micrograph: 2.7 mm.



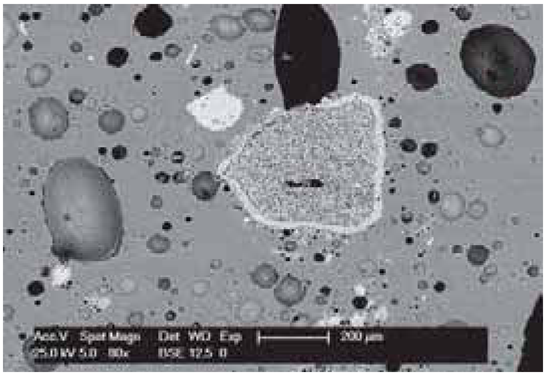


**Fig. 11-12**
Optical micrograph (Fig. 11; long side of the micrograph: 7 mm) of the polished section of a fragment of the blue tessera wB1 opacified with small bubbles and white particles of bone ash. In Fig. 12, SEM micrograph of a detail of the polished section of the same tessera: a large spongy particle of bone ash and many bubbles (black) can be observed.

dissolution of lead in the melt and crystallisation of tin oxide (a SEM example is given in Fig. 9).

*Red* – Red colour (Fig. 10) was obtained with copper in suitable melting conditions (reducing atmosphere with low oxygen) with the presence of specific elements (iron, tin, sometimes lead), so that copper separated from the melt during cooling and formed micrometric metallic copper particles (brown red colour) or cuprous oxide dendritic crystals (cuprite, sealing-wax red)[32].

In the wR1 and cR2 tesserae significant amounts of lead (PbO 7.8% and 4.5% respectively), copper (CuO 0.85%; 1.85%), iron ($Fe_2O_3$ 2.3%; 3.7%) and tin ($SnO_2$ 2.3%; 0.5%) are present. Zinc is present only in tessera wR1 (ZnO 1.2%). These results indicate that copper was introduced as scrap copper (probably of bronze in tessera cR2, copper-tin-lead-zinc alloy in tessera wR1).

Beside micrometric round particles of metal copper and cuprite crystals up to about ten micrometers, SEM observation revealed the presence of needle-like crystals of $SnO_2$ (cassiterite) resulting probably from the oxidation of tin present in the copper alloy. The base glass of the two tesserae is of type 1. These contrasting data (same type 1 base glass and different copper scraps) would require further investigation to ascertain their technological meaning (the tesserae were made in different workshops or two different copper slags were used to obtain various hues of red glass).

## OPACIFIERS

The conventional white opacifiers such as calcium antimonate and tin oxide crystals[33] used in contemporary glass were not detected in the tesserae excavated at Qusayr' Amra.

The blue (wB1 and 2) tesserae and part of the turquoise and green tesserae (wV1, 2 and 3) are quite heterogeneous due to a great amount of small bubbles and white particles most varying in size (from 5 micrometers to 0.2 millimeters) roughly dispersed in the glass (Fig. 11)[34].

The scanning electron micrographs provide evidence of the round, often coarse shape of these particles, sometimes spongy in aspect (Fig. 12).

Chemical analysis revealed that coarser particles consist mainly of calcium and phosphorous oxides (CaO 55%; $P_2O_5$ 43%, calcium phosphate), whereas in smaller particles sodium is also present (average composition: CaO 40%; $Na_2O$ 18%; $P_2O_5$ 38%)[35]. The analytical data show that they are bone ash particles. The presence of sodium in the smaller particles results from the dissolution process of the particles in the glass melt involving formation of intermediate compounds[36], resulting also in gas release and bubbles formation.

A similar opacification technique (bubble glass and particles of calcium phosphate and calcium-sodium phosphate) was identified by the analysis of a number of tesserae and mosaic cakes remains excavated in a Byzantine basilica at Petra (Jordan), which had been active between middle 5th-early 8th centuries[37], and in tesserae of the 5th century mosaics in the Neonian baptistery in Ravenna[38]. In both cases the composition of the glass is of natron type. Unlike the Qusayr' Amra tesserae, the glass of the Neonian baptistery tesserae shows a low alumina ($Al_2O_3$ 1.3-1.7%) and a high sodium ($Na_2O$ 20.6-22%) levels[39]. The presence of these tesserae in the Neonian baptistery has been interpreted as a demonstration of their production in the Byzantine area. Indeed, this is one of the few examples of tesserae opacified with calcium phosphate discovered in the Western area, where calcium antimonate and later tin oxide were being used instead[40].

## METAL LEAF TESSERAE

*Glass* – The observation by optical microscopy revealed that the *cartelline* (thickness in the range 0.3 to 0.8 mm, an average value of 0.5 mm was measured for the investigated tesserae) were made with homogeneous, bubble free glass obtained from pieces of blown glass. Instead, the glass heterogeneity resulting from cords, bubbles and coloured streaks indicates that the supports were made by pouring molten glass.

The quantitative chemical composition of the support (s) and *cartellina* (c) are reported in wt% of the oxides in Table 1 together with the gold leaf composition (wt% of the silver content). The *cartellina* resulted to be similar in composition to the support in the tesserae where the colour of the *cartellina* and support is the same (tesserae indicated with (sc) in Table 1).

The aspect of the metal leaf tesserae is the result of the colours of the metal sheet, and the *cartellina* and support glass. The thin metal leaves are discontinuous because of tears caused by pressing during the forming of the slab and become semi-transparent, so that the aspect of the tessera is influenced also by the colour of the support glass (Fig. 13).

Dark and light gold leaf tesserae can be distinguished according to their aspect (Fig. 14), depending on the glass colour of the support and *cartellina*.

The difference in colour between *cartellina* and support is more evident by examination of the polished sections of the metal leaf tesserae from Qusayr' Amra (Fig. 15 and Fig. 16).

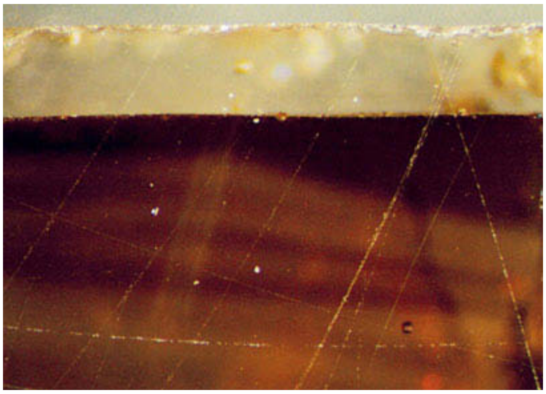
The glass was perfectly decolourized (i.e. without any hue) only in tessera wAu4 where antimony was used as a decolourant to neutralise the natural colour due to the iron (a contaminant of the silica-lime sand)[41]. In the tesserae wAu3, wAg2,3 the glass is slightly coloured in natural hues from green to yellow as the result of the iron content ($Fe_2O_3$ 0.5%-1.0%) and of the deliberate addition of manganese. No manganese was added to the glass of cAu7 tessera to obtain the natural green hue[42].

The glass of the wAu1 tessera was intensely yellow coloured with voluntary addition of iron ($Fe_2O_3$ 3.1%) and manganese (MnO 1.8%). Instead, the *cartellina* of the wAu2 tessera was intensely coloured in yellow with large addition of manganese (MnO 3.7%), while the support without significant addition of this element

13

15

14



16

**Fig. 13**
Metal leaf tesserae showing different colours of the glass support and cartellina.

**Fig. 14**
Examples of a light gold leaf tessera (cAu8, left) and a dark gold leaf tessera (cAu9, right).

**Figg. 15-16**
Optical micrographs of the polished sections of the gold leaf tesserae wAu2 (Fig. 15) and cAu8 (Fig. 16) showing different colours of the cartellina (top) and support glass (long side of the micrographs: 2.7 mm).

(MnO 0.15%) is slightly coloured in green.

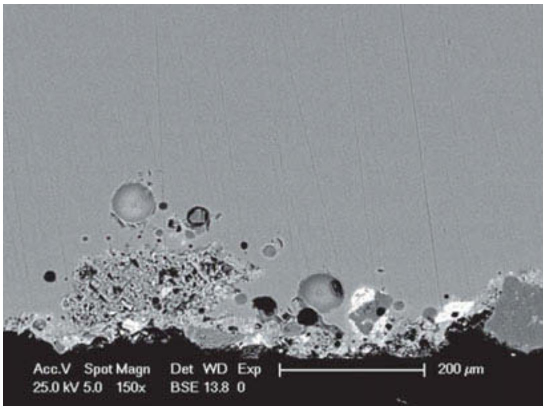
The other gold tesserae show an intensely coloured *cartellina* and a slightly coloured support, or vice versa. Despite the differences in colour of the support and *cartellina* of the wAu5,6 and cAu8,9 tesserae, only minor differences in the iron and manganese contents were detected (see Table 1). The manganese colour in glass depends on the amount of this element and on its oxidation state ($Mn^{2+}$ is a colourless ion in glass, while $Mn^{3+}$ is a strong colouring ion). Therefore, it is no surprise to observe in some tesserae marked colour differences between the *cartellina* and the support, even if the two glasses have similar concentrations of iron and manganese[43]. In the intensely coloured glass manganese is present mainly in the oxidised form $Mn^{3+}$, while in almost colourless glass it the reduced form $Mn^{2+}$ prevails.

The tesserae in which the *cartellina* and support glasses are different, one being intensely brown coloured, are a novelty in the scenario of gold leaf tesserae analysed up to now. In the Western area a voluntary colouring of glass has been ascertained only for a few silver leaf tesserae from the 5th century mosaic of Santa Sabina, Rome[44]. Up to the 12th century both the support and *cartellina* of gold leaf tesserae are of transparent colourless or weakly coloured glass in natural hues. Only later (mosaics in San Clemente, Rome, and Monreale, Palermo) opaque coloured (red) supports began to be used[45]. To the authors'knowledge, published analytical data for Byzantine and Islamic mosaics do not report any tesserae with voluntary intense colours of the support and/or *cartellina*.

*Metal leaf* – The thickness of the metal leaves

17

18



**Figg. 17-18**
Optical micrograph (Fig. 17) of the bottom of the support of the gold leaf tessera wAu1 (long side of the micrograph: 10 mm). In Fig. 18, SEM micrograph of the polished cross section of a fragment of the bottom of the support of the same tessera, where terracotta particles (dark gray) and iron-rich particles (white) firmly fixed in the glass can be observed.

was determined by SEM observation of the polished cross-sections. Due to the irregular beating of the leaves, differences were found in the thickness. Most of the measurements are in the range 0.4 ± 0.2 µm, and maximum thickness never exceeds 1 µm. The analyses detected the use of gold-silver alloys for the gold tesserae[46] and of pure silver for the two silver tesserae. The silver content detected by the analyses is reported in Table 1. In the three tesserae of Qusayr' Amra made with type 1 glass, the gold leaf has the same composition (Au 92%; Ag 8%). Unlikely, the composition of the gold leaf varies within a wide range (Au 80-96%; Ag 20-4%) in the tesserae made with type 2 glass, which is quite unusual for tesserae excavated in a same site. A voluntary addition of silver to gold to modify colour hues cannot be excluded for Qusayr' Amra tesserae[47]. Yet, another hypothesis is the use of beating circulating coins to make the leaves. This hypothesis was verified by comparing the gold leaves composition of Italian mosaic tesserae with the composition of the gold coins circulating between the 1st and 9th centuries in Italy: marked similarities were found[48]. Nevertheless the use of other gold sources such as native gold, jewels, etc. cannot be excluded at this stage for the Qusayr' Amra tesserae. Further research and analogous studies on gold tesserae of Levantine origin[49] are required for an exhaustive clarification on this issue.

*Metal leaf cakes technology* – The investigated metal leaf tesserae show a rough, opaque reddish or grey layer firmly adhering to the bottom of the support (Figg. 17-18).

The analysis shows that the adhering powder consists of particles of various origins that came in contact with the molten glass (Fig. 17); these are mainly terracotta (an alumina-silica material containing also calcium, magnesium and iron oxides), iron oxide (probably hematite, white dots in Fig. 18) and other particles including an uncommon iron-manganese-chrome compound.

These characteristics demonstrate that the tesserae were produced with a technique previously observed in other tesserae of this kind[50]. Glass was first blown in thin cylinders or similar shapes from which fragments (the *cartelline*) were cut, and a metal leaf obtained by beating was laid upon. Molten glass was then poured on the leaf to create the support. The obtained sandwich was then turned rapidly upside down placing the still plastic layer of poured glass on a flat surface covered with refractory powder (anti-adhesion purpose). A flat tool was used to press the sandwich in order to ensure adhesion between the layers and obtain elongated slabs (called 'tongues') from which the tesserae were

19

**Fig. 19**
A 12th century silver leaf cake (approximate size: 7x13 cm) from St. Mark's Basilica in Venice.

cut. Fragments of tongues dating to the 12th-13th century have been discovered in St. Mark's Basilica in Venice (Fig. 19) and in Monreale Cathedral in Palermo[51].

## CONCLUSIONS

The analyses of the mosaic tesserae excavated in two areas (workshop and *calidarium*) of the early Islamic archaeological site of Qusayr' Amra, Jordan (8th century AD) helped identifying the types of glass used, as well as colouring and opacifying techniques. The composition of the tesserae corresponds to the natron type glass, which was produced for a long time period by melting mixtures of silica-lime sand and a natural source of soda (natron).

The analytical data reveal also interesting details on working techniques that establish a few issues to help understanding the nature and technology of glass mosaic tesserae used in the still scarcely explored Byzantine-Islamic area.

The glass of seven tesserae (three gold leaf, one silver leaf, two red and one blue) shows no peculiarity as compared to commonly produced natron glass (type 1). Likely, these tesserae have different provenances, including possible reuse of tesserae belonging to more ancient dismantled mosaics (tessera wAu4, containing antimony).

The second type of glass (type 2) with high alumina and low sodium levels corresponds to a number of Byzantine glasses from the Pergamon area (Anatolia)[52]. It was used to prepare golden leaf tesserae in a wide range of hues obtained by modifying the colour of the support and *cartellina* glass. This kind of tesserae from Qusayr' Amra made with deliberately coloured transparent glass used in varying combinations with colourless or lightly coloured glass for the *cartellina* and support had never been identified previously among mosaic glass tesserae manufactured prior to the 12th century[53].

A low-calcium, high-alumina glass (type 3) similar to that identified in Islamic artefacts dating to the Omayyade period (second half of the 7th-middle 8th century AD) discovered in the Egyptian area was used to manufacture mosaic tesserae in a wide range of colours from turquoise to green and yellow through a series of intermediate hues. A feature peculiar to these tesserae is the use of a yellow artificial pigment prepared by firing a mixture of lead, tin and silica compounds (lead stannate, the so-called *anime*) added to a colourless glass (yellow tesserae) or to green glass coloured with copper and iron. This pigment was being used in Rome since the second century AD[54] and was going to be used extensively in medieval glassmaking in the Levantine area.

The analyses have shown that bone ash was added to coloured glass to opacify blue and some green tesserae. These particles tend to dissolve in contact with the molten glass and a large amount of bubbles develops. This technique was being adopted since the fifth century AD and in following centuries in Byzantine mosaics in Italy and in several Levantine places. This kind of tesserae was produced with type 2 and type 3 glass.

It is important to point out that no white and flesh coloured glass tesserae have been found in this site. This absence is typical of Byzantine mosaics[55].

The metal leaf tesserae were prepared with thin sheets of pure silver or gold- silver alloys. It was found that the composition of the gold leaf is unvarying (Au 92%; Ag 8%) in the tesserae made with type 1 glass, while in the tesserae made with type 2 glass the silver content varies over a wide range (Ag 4-20%).

By comparing the coloured tesserae excavated in the *calidarium* and in the workshop as to types and nature the analytical results indicate that tessere quite similar in composition and optical characteristics were present in both areas, yet a greater variety was found in the workshop[56].

A conclusive interpretation of these results is not possible at this stage. The use of tesserae coloured with lead stannate pigments and of gold leaf tesserae made with coloured glass has not been ascertained in the large number of analyses of glass tesserae from Western mosaics.

The analytical data seem to suggest that the Qusayr' Amra tesserae might come from two main workshops, one specialised in the synthesis of the lead stannate pigment and in the production of green-yellow tesserae, while a second one produced the metal leaf tesserae. This production model might be supported by the location of these secondary workshops in Egypt and in Anatolia respectively, in the proximity of primary glassmaking centres where different silica-lime sands were used. This is a plausible (the production techniques of both types of tesserae are different and require specific skills) yet hypothetic model. It should be recalled that the production at that time took place in primary sites where the glass batch was melted: then the raw glass was transported to different and even far sites where it was remelted, coloured and finally worked. Therefore, a different production model cannot be excluded, in which the same secondary centre worked with raw glass coming from various primary sites (hence with different compositions). This model was confirmed for a manufacture of blown items of the fifth century at Ostia Antica[57]. In this case remelting of raw glass of differing compositions was justified by the need to have transparent glass available with different natural hues from yellow to green-blue. In the case of mosaic tesserae this possibility seems to have no technological reason for raw glass was coloured during remelting. Extended investigation on a higher amount of tesserae also from other Byzantine and Islamic sites[58] is required to further verify this hypothesis.

Acknowledgements: Mirella Pellegrini for English translation of the text and Alberto Conventi for SEM-EDS analyses are kindly acknowledged.

## AUTORS

Giovanna De Palma, *Archaeologist*, ISCR.;
Paola Santopadre, *Chemist*, ISCR.;
Marco Verità, *Chemist*, Laboratorio Analisi Materiali Antichi LAMA, Sistema dei Laboratori, IUAV University, Venice, Italy.

## NOTES

[1] The proceedings of the Conference are in press.

[2] Dissolving in the melt ions of transition elements such as manganese, iron, cobalt and copper (these are the colouring ions of ancient glass), the glass looks coloured. Colour depends on type of ion (or ions), oxidation or reduction of the ion, its coordination number, concentration and glass composition. The colouring efficiency of the ion is defined at a certain wavelength by optical density, measured for a 1% concentration and a glass thickness of 10 mm.

[3] M. Verità, *Technology and deterioration of vitreous mosaic tesserae*, "Reviews in Conservation", 2000, 1, pp. 65-76.

[4] M. Verità, *Technology and deterioration...*, cit.; E. Neri, M. Verità, *Glass and metal analyses of gold leaf tesserae from 1st to 9th century mosaics. A contribution to technological and chronological knowledge*, "Journal of Archaeological Science", 2013, 40, pp. 4596-4606.

[5] C. Boschetti, *Vitreous Materials in Early Mosaics in Italy: Faience, Egyptian Blue, and Glass*, "Journal of glass studies", 2011, 53, pp. 59-91.

[6] M. Bartoli et al., *Il mosaico parietale del ninfeo sotto il Palazzo Nuovo della Bibliotheca Hertziana a Roma: le nuove acquisizioni*, "Bollettino ICR - Nuova serie", 2013, 26, pp. 5-29.

[7] According to Pliny also Macedonia Media and Thrace were rich in natron: Gaio Secondo Plinio, *Storia naturale*, I. Garofalo trans., Torino 1986, IV, XXXI, 107.

[8] Calcium oxide, an essential component for the chemical resistance of glass, was introduced involuntarily with sand, see M. Vallotto, M. Verità, *Glasses from Pompeii and Herculaneum and the sands of the rivers Belus and Volturno*, in J. Renn, G. Castagnetti (eds.), *Homo Faber: Studies on nature, technology and science of the time of Pompei*, Roma 2002, pp. 63-73.

[9] Gaio Secondo Plinio, *Storia naturale*, R. Mugellesi trans, Torino 1988, V, XXXVI, 190-199.

[10] Ash of halophyte plants growing on the costal and desert areas of the Middle East, such as salsola kali and salicornia was used. The plant ash containing comparable amounts of sodium carbonate and calcium carbonate was mixed with a silica source to make glass. The change from natron glass to plant ash glass probably occurred because of a shortage of natron from Egypt.

[11] In some places the use of natron glass continued up to the 12th-13th century see M. Verità, *Studio delle tessere vitree di mosaici medievali romani. Tecnologia e degrado*, in M. Andaloro, C. D'Angelo (eds.), *Mosaici medievali a Roma attraverso il restauro. Storie di otto cantieri*, Rome in press).

[12] Remains of tank furnaces have been identified on the Syro-Palestinian coast and in Egypt.

[13] I. Freestone, *The provenance of ancient glass through compositional analysis*, in P. Vandiver, J. Mass, A. Munray (eds.), *Materials Issues in Art and Archaeology VII*, (Materials Research Society Symposia, Proceedings, 852), Warrendale 2005, pp. 195-208.

[14] J. Warren, *Key Monuments of Islamic Architecture: Syria, Jordan, Israel, Lebanon*, in G. Michell (ed.), *Architecture of the Islamic World*, London 1978, pp. 230-235.

[15] I. Freestone, *The provenance of ancient glass...*, cit.

[16] 13th-14th century documents attest that gold coins were beaten for this purpose, see E. Neri, M. Verità, *Glass and metal analyses*, cit.

[17] It is interesting to observe that all colours were present, except white and flesh tones; stone tesserae were used for these colours.

[18] A presentation of the typologies of glass mosaic tesserae and of the forms of weathering is given in M. Verità, *Technology and deterioration...*, cit.

[19] A thin diamond wheel was used to cut fragments from the bottom of the coloured tesserae; from the metal leaf tesserae a thin cross section including the *cartellina* and the support was taken.

[20] SEM observation in backscattered mode allows areas with different chemical composition in the tesserae to be identified; darker gray indicates areas where lighter elements prevail.

[21] A scanning electron microscope Philips XL30 with an Edax energy dispersive X-ray microanalysis was used. Analyses were run under the following parameters. A 25 kV and 1.5 nA electron beam was scanned on surfaces of 400 x 400 µm or more and X-rays were collected for 200 s. In the coloured tesserae both the glassy phase and the dispersed particles were analysed. In the metal leaf tesserae the support (s), the *cartellina* (c) and the metal leaf were analysed separately. The obtained data were corrected for matrix effect by specific programs and verified further by analysing reference glasses of known composition in the same analytical conditions. The net X-ray intensities were quantified by means of a correction program supplied by Edax. The accuracy for $SiO_2$, $Na_2O$ and CaO is below 1% and for the remaining oxides is below 5%. Lower limits of detection in the range 0.1%-0.3% for most of the oxides were calculated. For further details of X-ray microanalysis applied to the glass analysis, see M. Verità et al., *X-ray microanalysis of ancient glassy materials: a comparative study of wavelength dispersive and energy dispersive techniques*, "Archaeometry", 1994, 36, pp. 241-251.

[22] The electron beam was scanned across an area 15 µm long and as wide as the gold leaf. The analysis was repeated in three areas for each sample and the average value was considered. During analysis SEM operated at 20 kV, with beam intensity adjusted to give an input rate of approximately 1500 count per second (cps) and counting live-time of 200 s. Of the resulting spectrum, only gold, silver and copper were quantified and calculated to 100 wt% of the elements, excluding other elements related to the surrounding glass composition. A standardless ZAF correction of the raw data was performed. An accuracy of the method within 2% was calculated. The analytical conditions allowed us to calculate a lower limit of detection of 0.10% for silver and 0.20% for copper. The method is discussed in A. Conventi, E. Neri, M. Verità, *SEM-EDS analysis of ancient gold leaf glass mosaic tesserae. A contribution to the dating of the materials*, "IOPScience, Materials Science and Engineering", 2012, 32, pp. 1-8.

[23] The base glass is the transparent glass to which colourants and opacifiers were added. The composition of the base glass of the coloured tesserae was calculated by subtracting colouring-opacifying oxides

and recalculating the composition at 100 wt%.

[24] Phosphorous is present in some coloured tesserae to be discussed later, where it was added as an opacifier in form of bone ash.

[25] In natron type glass the concentration of $Na_2O$ is usually higher than 16%.

[26] T. Rehren et al, *Glass supply and circulation in early Byzantine southern Jordan*, in J. Drauschke, D. Keller (eds.), *Glass in Byzantium. Production, usage, analyses*, Internatinal Workshop of Byzantine Archaeology, Mainz 17th-18th January 2008, (Römisch-Germanischen Zentralmuseums-RGZM Tagungen, 8), Mainz 2010, pp. 65-81.

[27] The calculation of the CaO concentration in the base glass of this group excluded tesserae wV2 and wV3, in which a considerable calcium amount was introduced with the bone ash added as an opacifier.

[28] The calculation of the $Fe_2O_3$ concentration in the base glass of this group excluded the two black tesserae wN1 and cN2 in which iron was added as a colourant.

[29] B. Gratuze, D. Foy, *La composition des verres islamiques d'Al-Hadir*, in Rousset (ed.), *Al-Hadir. Étude archéologique d'un hameau de Qinnasrin (Syrie du Nord, VIIe-XIIe siècles)*, (Travaux de la Maison de l'Orient, 59), 2012, pp. 139-149. B. Gratuze, J.-N. Barrandon, *Islamic glass weights and stamps: analysis using nuclear techniques*, "Archaeometry", 1990, 32, pp. 155-162.

[30] B. Gratuze et al., *De l'origine du cobalt: du verre à la céramique*, "Revue d'Archaeométrie", 1996, 20, pp. 77-94.

[31] The preparation technique of artificial yellow pigments used in glass production is described in C. Moretti, S. Hreglich, *Opacification and Colouring of Glass by the Use of 'Anime'*, "Glass Technology", 1984, 25, 6, pp. 277-282.

[32] A discussion of ancient opaque red glass colour can be found in I. Freestone, *The production of red glass and enamel in the Late Iron Age, Roman and Byzantine period*, in C. Entwistle (ed.), *Through a glass brightly. Studies in Byzantine and Medieval Art and Archaeology presented to David Buckton*, Oxford 2003, pp. 142-154.

[33] As previously explained the cassiterite crystals identified in some tesserae result from the dissolution of yellow lead stannate particles (metal slag in red tesserae).

[34] These tesserae are translucid in aspect, not really opaque.

[35] In both types small amounts of other elements such as magnesium and iron are present.

[36] The great mobility of sodium ions in molten glass favours its diffusion into the calcium phosphate particles, thus changing them into calcium-sodium double phosphate prior to dissolution.

[37] F. Marii, T. Rehren, *Archaeological coloured glass cakes and tesserae from Petra church*, in K. Janssens, P. Degryse, P. Cosyns (eds.), *Annales of the 17th Association for the History of Glass (AIHV) Conference*, Antwerp 4th-8th September 2006, Antwerp 2009, pp. 295-300.

[38] M. Verità, *Tessere vitree del battistero Neoniano: tecniche e provenienza*, in C. Muscolino et al. (eds), *Il Battistero Neoniano. Uno sguardo attraverso il restauro*, Ravenna 2011, pp. 73-87.

[39] To the authors' knowledge no quantitative analysis of the Petra tesserae has been published.

[40] E. Neri, M. Verità, *La produzione di tessere musive vitree a Milano tra IV e VI secolo? Un'indagine archeologico archeometrica*, in A. Coscarella (ed.), *Il vetro in Italia: testimonianze, produzioni e commerci in età bassomedievale. Atti XV Giornate Nazionali di Studio AIHV*, Cosenza 9th-11th June 2011, Cosenza 2012, pp. 13-30.

[41] M. Verità, *Mosaico vitreo e smalti: la tecnica, i materiali, il degrado, la conservazione*, in C. Moldi Ravenna (ed.), *I colori della luce. Angelo Orsoni e l'arte del mosaico*, Venezia 1996, pp. 41-97.

[42] Glasses contain iron generating a range of yellows, greens, bluish-green hues, the so-called 'natural' colours of glass, which depend on the iron concentration and its oxidation state. To remove colour and obtain colourless glass a chemical decolorizer such as $MnO_2$ is added which converts $Fe^{2+}$ (strong green-blue) to $Fe^{3+}$ (week yellow). In the analyses of decolourised glass, the MnO content is generally comparable or larger (up to 1.5 times) to the $Fe_2O_3$ content.

[43] Similarly, dark brown streaks in slightly coloured glass are observed in some supports without any difference in the chemical composition of the two glasses.

[44] Both *cartellina* and support were coloured with manganese.

[45] The analyses of glass tesserae from mosaics in Rome dated to 4th to 13th century can be found in M. Verità, *Studio delle tessere...*, cit.

[46] No copper, lead and platinum were detected in the analyses. The content of these elements found in Roman gold coins are under the lower limit of detection of the analytical method, see E. Neri, M. Verità, *Glass and metal analyses*, cit., pp. 4596-4606.

[47] Today leaves of gold-silver alloys in the range Ag 10%-70% are used for mosaic tesserae to obtain colour hues from worm yellow (pure gold) to silver gray.

[48] A. Conventi, E. Neri, M. Verità, *SEM-EDS analysis*, cit., pp. 1-8. E. Neri, M. Verità, *Glass and metal analyses*, cit., pp. 4596-4606.

[49] PIXE analytical data for a gold leaf tessera from Qusayr' Amra were published in P. Colomban et al., *Dorures des céramiques et tesselles anciennes: technologies et accrochage*, "Revue d'Archéométrie", 2005, 29, pp. 7-20. Compositional data for the gold leaf fall in the range reported in the present paper (Au 85%; Ag 15%), while the values for the support and *cartellina* glass are different and unusual, maybe due to surface deterioration of the tessera (PIXE is a non-invasive analytical technique).

[50] In 10th-14th century tesserae in mosaics of Italy (Venice, Torcello and St Mark's basilicas; Palermo, Monreale) and Greece (Daphni and Hosios Loukas).

[51] M. Verità, S. Rapisarda, *Studio analitico di materiali vitrei del XII-XIII secolo della Basilica di Monreale a Palermo*, "Rivista della Stazione Sperimentale del Vetro", 2008, 38, 2, pp. 15-28.

[52] T. Rehren et al., *Changes in glass consumption in Pergamon (Turkey) from Hellenistic to late Byzantine and Islamic times*, "Journal of Archaeological Science", 2015, 55, pp. 266-279.

[53] The analyses of tesserae of this period from Middle-Eastern mosaics are still not many and glass is generally described there as transparent, without specifying any colour.

[54] The Romans had developed a wide set of yellow pigments made by firing mixtures of lead and tin, antimony and lead and antimony, tin and lead; see M. Verità et al., *Colors of Roman Glass: An Investigation of the Yellow Sectilia in the Gorga Collection*, "Journal of Glass Studies", 2013, 55, pp. 39-52.

[55] For a possible explanation on this issue see M. Verità, S. Zecchin, *Scientific investigation of the Byzantine glass tesserae from the mosaics of the south Chapel of Torcello's Basilica, Venice*, D. Ignatiadou, A. Antonaras (ed.), Proceedings of the 2009 18th AIHV Conference, Thessaloniki 2012, pp. 315-320.

[56] Tesserae opacified with calcium phosphate seem to be absent in the *calidarium*. The number of tesserae made available for analysis does not allow for any definitive conclusion and additional sampling and analyses are necessary.

[57] Unpublished authors' observations.

[58] Analytical investigations of glass mosaic tesserae from Qusayr'Amra are in progress at the University College London, Qatar. Some results were the object of the dissertation in conservation studies by F. Alshishani, supervisor professor T. Rehren 2014.

Scientific Investigation of Glass Mosaic Tesserae from the 8th Century AD Archaeological Site of Qusayr' Amra (Jordan)

## *Studio delle tessere musive vitree provenienti dal sito archeologico di Qusayr' Amra in Giordania (VIII sec. dC)*

*In questo lavoro si presentano i risultati ottenuti analizzando le tessere musive vitree rinvenute nel sito archeologico di Qusayr' Amra (Giordania), in due ambienti diversi. Le analisi sono state effettuate mediante microscopia elettronica a scansione (SEM) con microanalisi a raggi X a dispersione di energia.*
*Pur essendo il vetro di base di tipo natron (vetro silico-sodico-calcico), sono stati individuati tre gruppi composizionali di diversa provenienza. Come pigmento giallo è stato utilizzato lo stannato di piombo, materiale sintetico che veniva preparato per calcinazione di stagno, piombo e silice. Per il rosso sono state utilizzate scorie metalliche a base di rame, mentre il blu è ottenuto con un minerale di cobalto.*
*Le tessere sono state opacizzate aggiungendo al vetro fuso ossa calcinate polverizzate.*
*Nelle tessere a foglia metallica sono state usate lamine sottili di argento puro o di leghe oro-argento, racchiuse tra uno spesso vetro di supporto e una sottile cartellina. Allo scopo di ampliare la gamma cromatica di queste tessere sono state usate varie combinazioni di vetro intensamente colorato e vetro incolore.*

Glass mosaic tesserae found in two areas of the archaeological site of Qusayr' Amra (Jordan) were analysed by scanning electron microscopy (SEM) and energy dispersive X ray microanalysis.
The base glass is of the soda-lime-silica natron type; three different compositional groups and provenances were identified.
Lead stannate obtained by firing a batch of lead, tin and silica compounds was used as a yellow pigment. The red colour was obtained with copper introduced as a metallic scrap. The blue colour is given by a cobalt mineral. Bone ash was used as an opacifier.
The metal leaf tesserae were prepared with thin sheets of pure silver or gold-silver alloys. A particular technique has been identified that combines coloured and uncoloured glass in the support and cartellina in order to widen the range of colours.

***(Paper to page 5)***

La Galleria delle Grottesche di Villa Farnesina-Chigi: architettura, artefici, significati

## *"Galleria delle Grottesche" at Villa Farnesina-Chigi: architecture, artifices, meanings*

The ISCR restoration worksite for the "Galleria delle Grottesche" at Villa Farnesina-Chigi in Rome provided important information of a historical and artistic nature on an important and little-known aspect of Renaissance architecture and construction – that of vaulted wooden ceilings which have rarely been preserved due to their fragility. On the basis of the diagnostic surveys conducted by ISCR in its established multidisciplinary manner, the wooden ceiling of the Farnesina villa represented a very early example of work that would spread in the following centuries thanks to treatises by authors ranging from Sebastiano Serlio to Philibert De l'Orme), as a way to obtain impressive architectural results at lower cost and with fewer construction problems compared to masonry work.
Baldassare Peruzzi's personal connections and professional experience established his role in developing this method that was used to produce ephemeral constructions for celebrations and performances, earning him the praise of Giorgio Vasari. The use of this technique at the Farnesina villa responded to structural constraints within the building, requiring the corridor to run on the false ceiling of the underlying Loggia di Galatea. For this reason, it is probably the clue that confirms recent ideas about the presence of a pre-existing structure which Peruzzi enlarged and adapted substantially with the inclusion of two loggias to create a type of building that had considerable success in subsequent centuries.

***(Paper to page 21)***

# Guida per la pubblicazione di contributi sul Bollettino ICR

**Tel. 0039.06.67236293**
**Fax 0039.06.67236409**

**www.iscr.beniculturali.it**
**E-mail: is-cr.bollettino@beniculturali.it**

La rivista Bollettino ICR ha la finalità di rispondere alle esigenze operative e di aggiornamento di quanti operano nel settore della conservazione e del restauro dei beni culturali, e di proporre indirizzi metodologici nelle scelte tecniche.

Si propone come momento di incontro di competenze interdisciplinari per la conoscenza e analisi dei materiali costitutivi e delle tecniche di esecuzione; cause e processi di deterioramento; tecniche e materiali per interventi di conservazione e di restauro; fonti di tecnologia artistica e del restauro; storia e metodologia della conservazione e del restauro; metodologia della manutenzione; metodologia nella didattica; metodologia e pratica della documentazione di restauro. Pubblica inoltre restauri di particolare interesse metodologico o storico-artistico.

I destinatari del Bollettino sono gli organismi preposti alla tutela e alla salvaguardia del patrimonio culturale attivi in Italia; ricercatori e tecnici del settore che operano nelle Università ed in altri Istituti di ricerca; organismi internazionali o di paesi stranieri con compiti operativi e di ricerca nel settore della conservazione e del restauro; restauratori privati; studiosi italiani e stranieri interessati alla politica di salvaguardia e tutela del patrimonio culturale.

## Iter editoriale

I contributi proposti dagli autori devono pervenire a:
Redazione Bollettino ICR
Istituto Superiore per la Conservazione ed il Restauro
Via di san Michele, 23 - 00153 Roma
con la scadenza del 3 novembre per il numero di giugno, del 2 maggio per il numero di dicembre.

Il Bollettino è edito con contributi in lingua italiana o inglese. La redazione potrà accettare contributi in altre lingue.

Tutti i contributi sono soggetti a revisione da parte della redazione e, quando giudicato necessario, da *referees* che rimarranno anonimi.

Le prime bozze saranno inviate agli autori per la correzione e comunque saranno sottoposte ad editing finalizzato allo stile e alla chiarezza dell'informazione. Dopo la pubblicazione il materiale illustrativo sarà restituito.

Salvo diversi accordi con la redazione, i contributi devono essere inediti e non sottoposti ad altri editori. Gli autori si assumono tutta la responsabilità dell'originalità del lavoro e delle opinioni che vi sono espresse. Una volta che i contributi sono accettati per la pubblicazione gli autori dovranno sottoscrivere una dichiarazione di rinuncia ai diritti d'autore a favore dell'ISCR; nulla pertanto sarà dovuto agli autori per la pubblicazione. Gli autori dovranno inoltre ottenere i necessari permessi legati al copyright del materiale illustrativo; a tal fine dovrà pervenire alla redazione una dichiarazione liberatoria firmata dall'autore sotto la propria responsabilità.

## Struttura e stile

I contributi devono contenere la data; il/i nomi degli autori corredati di indirizzo, ente di appartenenza e professione; il titolo; il testo corredato di note e riferimenti bibliografici ed eventuale lista delle abbreviazioni e legende e un abstract in italiano di 1500 battute al massimo (articoli costituiti da più contributi dovranno avere un abstract unico).

I contributi devono pervenire in forma digitale, con specifica del programma di scrittura e dell'eventuale uso di particolari fonts (caratteri) con relativa stampa, su pagine numerate progressivamente, perfettamente coincidente con il contenuto del file. Nel testo devono essere evitati tabulazioni, rientri, sillabazioni e ogni forma di impaginazione. Titoli e sottotitoli devono essere brevi, nello stesso stile del testo e numerati gerarchicamente. È comunque richiesta una totale rispondenza alle norme redazionali: in caso contrario il contributo sarà restituito all'autore per le necessarie modifiche, e potrebbe esserne ritardata la pubblicazione.

Il materiale illustrativo, derivante possibilmente da originali (diapositive, stampe o file in formato .tif o .jpg ad alta risoluzione), deve essere di buona qualità, corredato di didascalie, numerato progressivamente e citato nel testo (es.: fig. 1, figg. 2 e 9, figg. 3-8).

Devono essere fornite informazioni sull'orientamento delle immagini e su eventuali tagli. Si raccomanda di tener conto del formato della rivista (cm 21x27) per la realizzazione del materiale grafico da sottoporre a riduzione.

Finito di stampare
nell'aprile 2017
da Tipografia Baroni & Gori
per Nardini Editore, Firenze