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Article *in* Boletin de la Sociedad Espanola de Ceramica y Vidrio · May 2022

DOI: 10.1016/j.bsecv.2022.04.004

BOLETÍN DE LA SOCIEDAD ESPAÑOLA DE CERÁMICA Y VIDRIO XXX (2022) XXX–XXX

ELSEVIER

BOLETIN DE LA SOCIEDAD ESPAÑOLA DE
Cerámica y Vidrio
www.elsevier.es/bsecv

Original article

Historical restorations of the *Maqṣūrah* glass mosaics from the Great Mosque of Córdoba

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ARTICLE INFO

Article history:
Received 8 September 2021
Accepted 25 April 2022
Available online xxx

Keywords:
Mosaic
Glass *tesserae*
Great Mosque of Córdoba
Historical restorations

ABSTRACT

The Great Mosque of Córdoba is the only mediaeval Islamic monument in al-Andalus that still contains some of its original 10th-century glass mosaic decoration, even though they were significantly altered and restored several times in the 18th, 19th and 20th centuries. By examining analytical, textual, and graphic evidence, this study attempts to reconstruct the different transformations of the *Maqṣūrah*, focusing on the glass mosaics in order to assess possible implications for their state of preservation. The results show that high-alkaline glass, which can be associated with modern *tesserae*, was used to restore the *Miḥrāb* and *Sābāṭ* mosaics. Modern pigments were also detected in the paints that were applied *in situ* to the surface of the colourless glasses. Textual and analytical evidences prove that *Bāb Bayt al-Māl* mosaic was completely removed in the 20th century and a replica with high-lead *tesserae* was installed in the same place.

Las restauraciones históricas de los mosaicos de vidrio de la *Maqṣūrah* de la Gran Mezquita de Córdoba

Palabras clave:
Mosaico
Tesela de vidrio
Gran Mezquita de Córdoba
Restauraciones históricas

RESUMEN

La Gran Mezquita de Córdoba es el único monumento islámico en al-Andalus que aún contiene restos de su decoración original del s. X en mosaico de vidrio, a pesar de haber sido significativamente alterada y restaurada en varias ocasiones en los ss. XVIII, XIX y XX. Mediante el estudio analítico y las evidencias gráficas y textuales, este estudio pretende reconstruir las diferentes transformaciones de la *Maqṣūrah*, especialmente en los mosaicos

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https://doi.org/10.1016/j.bsecv.2022.04.004

de vidrio para evaluar posibles implicaciones para su estado de conservación. Los resultados muestran que vidrios de alta alcalinidad, relacionados con teselas modernas, fueron utilizados para restaurar los mosaicos del *Miḥrāb* y el *Sābāṭ*. También se detectaron pigmentos modernos en las pinturas aplicadas *in situ* a la superficie de los vidrios incoloros. Las fuentes textuales y los estudios analíticos prueban que el mosaico del *Bāb Bayt al-Māl* fue retirado en el s. XX y una réplica con teselas ricas en plomo fue instalada en el mismo lugar.

Introduction

Córdoba became the capital of the Roman province of Hispania Ulterior and was also an important administrative centre during the Visigoth period. The city prospered particularly after the Muslim conquest of the Iberian Peninsula, first as the capital of the Umayyad Emirate (756–929 AD), and later the Caliphate of Córdoba (929–1031 AD). ʻAbd al-Raḥmān I (Reign: 756–788 AD), the founder of the Umayyad dynasty of al-Andalus and the Emirate of Córdoba, commissioned substantial urban developments, including the construction of the Alcazar on the ruins of the Visigothic palace, and above all the foundation of the Great Umayyad Mosque (786–787 AD) [1–3]. The original Umayyad Mosque, finished by his son Hisham I, had eleven naves and twelve corridors from East to West (Fig. 1). This building was repeatedly modified and extended in the following centuries by ʻAbd al-Raḥmān II (~840 AD), Al-Ḥ akam II (~960 AD), and Almanzor (988 AD) [4] (Fig. 1). In the process, the original *qiblah* was destroyed and a new *Maqṣūrah*, with three chambers, was built in the mid of 10th century (Fig. 1) [4–6]. The *Miḥrāb* in the centre is flanked by two lateral chambers, the *Bāb Bayt al-Māl* (treasury) on the left and the *Sābāṭ* chamber on the right connected with a corridor to the caliphal palace [7–9]. The façades of the three chambers (*Bāb Bayt al-Māl*, *Miḥrāb,* and *Sābāṭ*) and the dome of the entrance hall of the *Miḥrāb* were decorated with multicoloured glass mosaics mainly composed of gold leaf *tesserae* and different shades of red, green and blue (Fig. 2).

The entrance hall of the *Miḥrāb* is crowned by a *qubba* almost 15 m above floor level. It is divided by eight ribs into segments thus forming an octagon decorated with verses from the Quran [22:76; 22:77 & 22:78] along its eight sides [11]. The central cupola is divided into eight petals separated again by eight ribs (Fig. 2a). The façade of the *Miḥrāb* is decorated with a broad horseshoe arch formed of nineteen voussoirs with symmetric floral decorations on alternating red, gold, and blue backgrounds (Fig. 2b). Around the arch, a verse from the Quran [59:23] appears in a horizontal line with blue letters on a golden background. Around this verse and the arch appear two more verses [32:5 & 40:67] as well as an inscription that commemorates al-Ḥ akam al-Mustanṣir as the patron of the mosaics. The inscription furthermore specifies that the work was carried out by the freeman and *ḥāŷib* (chamberlain) Ŷa'far ibn ʻAbd al-Raḥmān under the supervision of the *ṣāḥib al-shurṭa* (labour inspectors and police) Muḥammad ibn Tamlīj, Aḥmad ibn Naṣr, Jald ibn Hāšhim and Muṭarrif ibn ʻAbd al-Raḥmān from the *kātib* (secretary/scribe) [11,12]. These texts are written in vertical and horizontal lines, surrounding the arch. Seven niches on top of the arch are decorated with mosaics of flowers, symmetrically arranged.

The *Sābāṭ* and *Bāb Bayt al-Māl* façades, which are formed by an arch with 15 symmetric voussoirs, show the same mosaic consisting of vegetal motifs on red and gold backgrounds [4]. Around them, the alfiz was decorated with three texts alternating with geometric motives (Fig. 2c, d). The two inner inscriptions are commemorative texts about the work and the people involved in its execution, similar to the one from the *Miḥrāb*. However, the external inscription contains verses [2:236 & 3:6] from the Quran. The frames of the small windows above the mosaic are likewise decorated with Quranic verses [6:101 & 6:102] surrounded by the same geometric pattern. Under the horseshoe arch, verses [41:30, 41:31 & 41:32] are written in gold lettering on a blue background (Fig. 2c, d). Some inscriptions are partially lost. For example, the mosaic inscription on the façade of the *Sābāṭ* chamber was restored without following the original inscription.

The mosaics have undergone considerable changes over the centuries, especially in the aftermath of the building's conversion into a Christian cathedral in 1236 AD [4,8,13–16]. The original mosaics were thoroughly characterized in previous works [17,18] and, therefore, the main objective of the present study is to identify the historical changes and restorations of the *Maqṣūrah* mosaics based on a combination of textual and graphic sources as well as the material and compositional evidence of the mosaics. The close examination of the architectural and decorative modifications of the *Maqṣūrah* over time reveals the impact these had on the preservation of the mosaics. The characteristics of the different restoration campaigns in turn shed light on different traditions of conservation, which at different times were contingent on intrinsic cultural and aesthetic values and principles.

Methodology

For the historical review, different digital archives and libraries were consulted to obtain the historical documentation. This includes the Biblioteca Nacional de España, the Biblioteca Virtual de Prensa Histórica, the institutional repository of the Universitat Politècnica de Catalunya, and the Repositorio Real Academia de Córdoba, among others.

For the analytical characterization, 91 *tesserae* from the *maqṣūrah* mosaics of the Mosque-Cathedral of Córdoba were removed for analysis by optical microscopy (OM), scanning electron microscopy – energy dispersive X-ray spectroscopy (SEM-EDX), laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), micro-particle-induced

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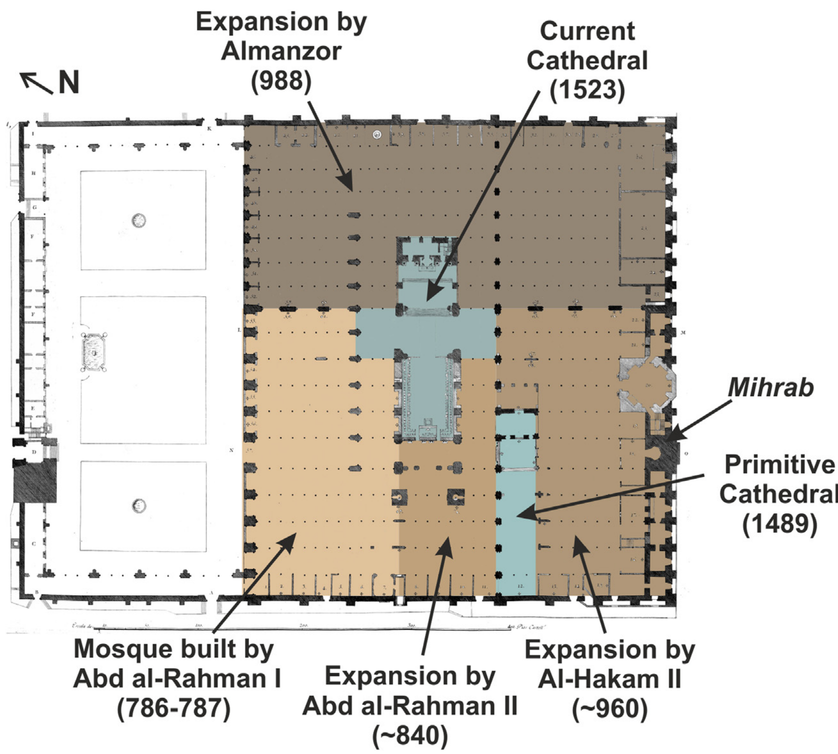

Fig. 1 – Plan of the Great Mosque of Córdoba indicating the different expansions and alterations. Adapted from Biblioteca Digital Hispánica, Biblioteca Nacional de España [10].

Fig. 2 – Mosaics *in situ*: (a) the dome of the entrance hall of the *Miḥrāb*; (b) the *Miḥrāb* chamber; (c) *Bāb Bayt al-Māl* chamber; (d) *Sābāṭ* chamber.
Source: Authors.

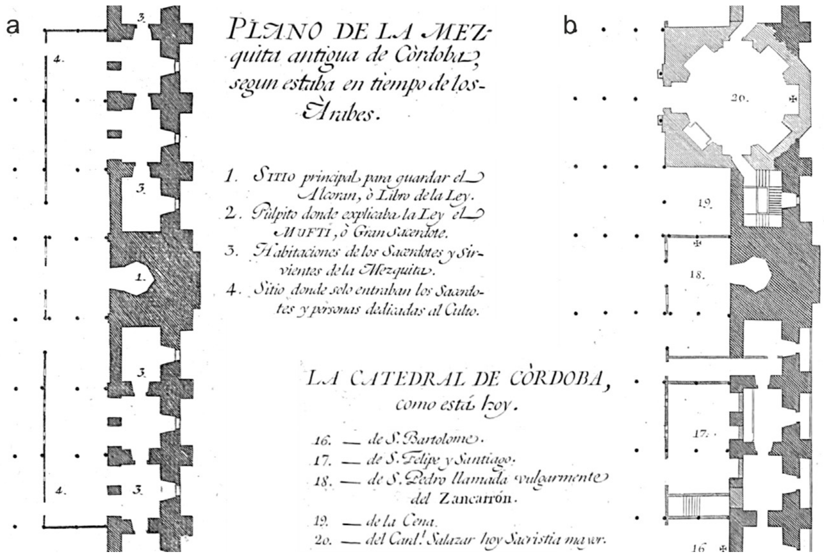

Fig. 3 – Plans of the Great Mosque of Córdoba (a) original, and (b) around 1804. Legend: 1. Main place to keep the Quran or Book of the Law; 2. Pulpit where the Mufti, or high Priest, explained the Law; 3. Rooms of the priests and servants of the Mosque; 4. Place accessed only by priests and people dedicated to worship. 16. Chapel of Saint Bartholomew; 17. Chapel of Saint Philip and Santiago; 18. Chapel of Saint Peter, commonly known as Zancarrón; 19. Chapel of the Last Supper; 20. Chapel of Cardinal Salazar, currently Main Sacristy.
Source: Biblioteca Digital Hispánica, Biblioteca Nacional de España [10].

X-ray emission (μ-PIXE), Fibre Optic Reflectance Spectroscopy (FORS), and μ-Raman spectroscopy (for detailed description of the analytical methods see [17]).

Additionally to these techniques, Gas Chromatography (GC) was applied to identify the organic compounds of the paints. For the determination of lipophilic substances, such as drying oils, resins and waxes; and of hydrophilic substances, such as proteins and gums – polysaccharide (gum Arabic and related products), samples are treated with the Meth-prep II methylation reagent. For carbohydrates and proteins, a hydrolysis is carried out with microwave-assisted 6 M HCl and a derivatization with MTBSTFA in pyridine of the resulting fatty acids, amino acids and monosaccharides.

Finally, Fourier transform infrared spectrometry (FTIR) was used to characterize the surface layers. The instrumental set-up was a PerkinElmer Spectrum 3 FT-IR/NIR Spectrometer coupled to an Attenuated Total Reflection (FTIR-ATR) accessory, microscopy spotlight 200 and detector MIR TGS. The analyses in cross-section were done with a spectral range from 4000 to 400 cm^{-1} with a spectral resolution of 4 cm^{-1}.

Results and discussion

Mosaics' creation and their modifications over the centuries

Muhammad al-Idrīsī, in the 12th century, and Ibn ʻIḏari, in the 14th century, wrote that the *qiblah* of the Great Mosque was decorated with *al-fusayfisa al-muḏ hab wa-l-mulwwan* (golden and coloured mosaics) and *muzŷŷaŷa* (with glaze) tiles, which were sent by the emperor of Constantinople to ʻAbd al-Raḥmān III, father of Al-Ḥakam II [8,13,19]. The mosaics of the *Miḥrāb* and the dome, were the first to be finished, followed by the decoration of both lateral chambers [4]. An inscription on the *Bāb Bayt al-Māl* façade specifies that the decoration here was finished in 354 H (965 AD). This date also appears in a marble inscription inside the *Miḥrāb* and in the cymatium of the *Miḥrāb*' arch [11,20]. Ocaña Jiménez argues that since the date appears in a restored part of the mosaic it may have been incorrectly attributed, and that a date in late 360 H (971 AD) is more likely for the completion of the mosaics [11]. The mosaics of the *Sābāṭ* door appear to have been finished between 970 AD and 973 AD [21]. The left border of the mosaic of the *Sābāṭ* door was mutilated around the year 366 H (976 AD) in connection with the opening of a narrow door to the left, where the *Minbar* (wooden pulpit) was typically stored [4].

On 29 June 1236, King Ferdinand III of Castile conquered Córdoba and the Bishop of Osma (Soria) consecrated the Great Mosque of Córdoba as a Christian church, dedicated to the Assumption of the Virgin. It eventually became the Cathedral of Córdoba and in 1368–1371, King Henry II of Castile ordered substantial architectural modifications to turn the mosque into a proper Christian ecclesiastical structure (Fig. 1) [1,22–25]. In this process, the *Miḥrāb* was converted to the sacristy of the chapel of Saint Peter known as the Chapel of Zancarrón (Fig. 3).

From documentary and pictorial evidence we know that in 1390, the mosaics of the *Miḥrāb* were partially covered up with an altarpiece depicting Saint Catherine of Alexandria, Saint Francis of Assisi, Saint Peter, Saint Paul, and the Nursing Madonna [26–28]. The chapel progressively fell into total disrepair and was all but forgotten. In 1892, a newspaper notice in the Diario de Córdoba pointed out the existence of a partition wall in front of the *Miḥrāb* [27]. This agrees with the existence of a wall in front of the door and a corridor on the right side of the *Sābāṭ* chamber that appears in the historical plans of

Fig. 4 – Lithograph of the *Maqṣūrah* in 1879 with the altarpiece in front of the *Bāb Bayt al-Māl*.
Source: UPCommons [28].

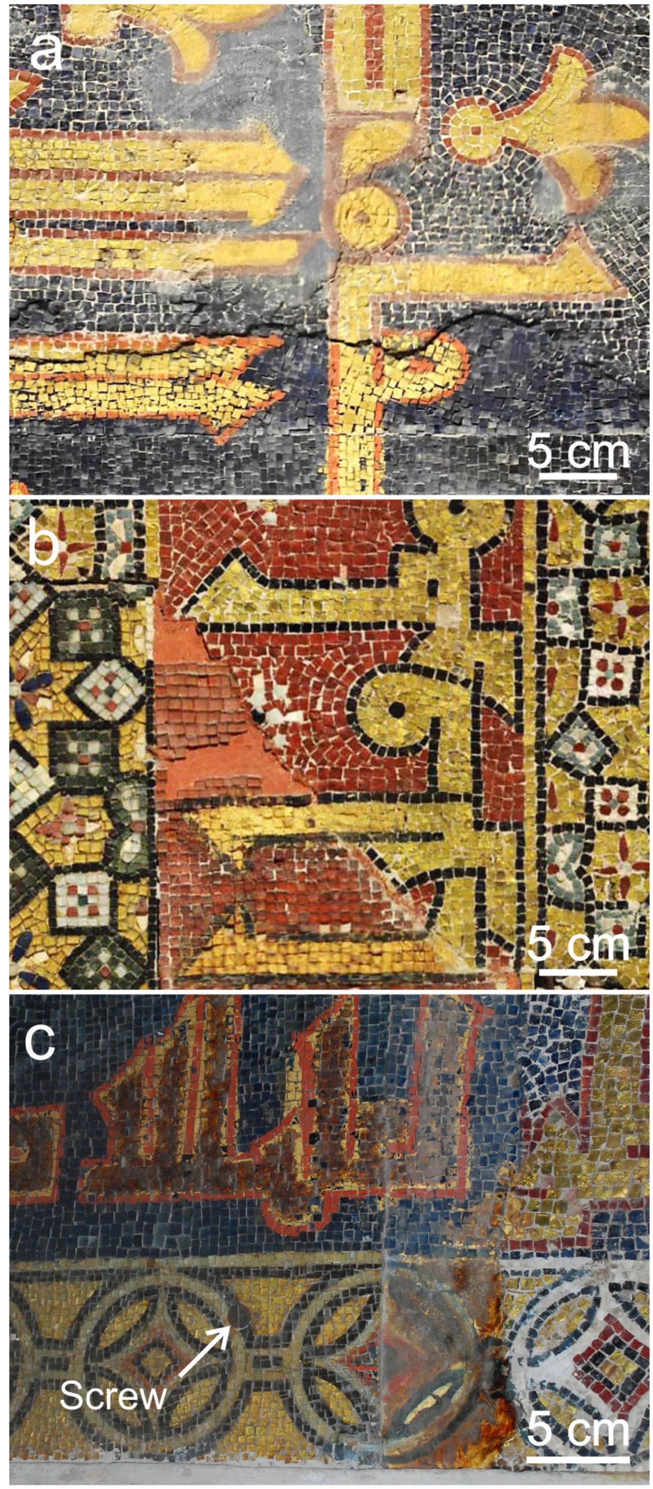

Fig. 5 – Different interventions in the mosaics: (a) painted mortar, (b) painted mortar with restoration *tesserae*, (c) painted mortar and modern *tesserae* on a plaque fixed with screws. The exact location of these interventions is shown in Fig. 6.
Source: Authors.

the Mosque made in the 18th century by the architects Juan de Villanueva and Juan Pedro Arnal (Fig. 3b) [10,29–31] and in an engraving from 1812 [32,33]. This wall was also hinted at in the description of the chapel of Saint Peter by Ambrosio de Morales in 1572 [34]. The historian described the chapel as consisting of two rooms (one inside the other) decorated with mosaics and another small room (inside the inner one), the *Miḥrāb* [34]. He described the decoration as a delicate mosaic work with small patterns of floral motifs and pointed out that the designs were less perceptible in the mosaic of the lateral chamber than in the *Miḥrāb* façade, probably due to low contrast, reduced lighting or poor conditions of the mosaic.

Until 1586, the *Bāb Bayt al-Māl* chamber to the left of the *Miḥrāb* housed the sanctuary of the cathedral [35]. In 1595, the canons Antonio and Hernando Mohedano de Saavedra founded the Chapel of the Last Supper in the *Bāb Bayt al-Māl* and covered the mosaics with the canvas of the "La Última Cena" ("Last Supper") by Pablo de Céspedes [35–37]. The canvas, which is still in the building, completely covered the façade of the chamber, as a result of which the mosaics fell into oblivion. Ancient plans of the mosque show a wall behind the canvas both in the theoretical mosque as well as in drawings of the cathedral (Fig. 2) [10]. Some engravings and photographs from the 19th century show the canvas in its original location in front of the mosaic [28,38–40] (Fig. 4). Even newspaper reports and books denied the possibility of the existence of two lateral chapels to either side of the *Miḥrāb* [23,41,42]. It was believed that they had disappeared entirely during the 15th-century modifications initiated by the bishop Iñigo Manrique [43].

For more than two centuries, the mosaics were covered with altarpieces. As a consequence of the Lisbon earthquake in 1755, several parts of the Mosque-Cathedral were severely damaged, such as the tower, causing serious structural damages [14,44]. The *Miḥrāb* dome was probably also affected because in 1767, the cathedral chapter ordered its repair as water filtered through several leaks into the chapel that

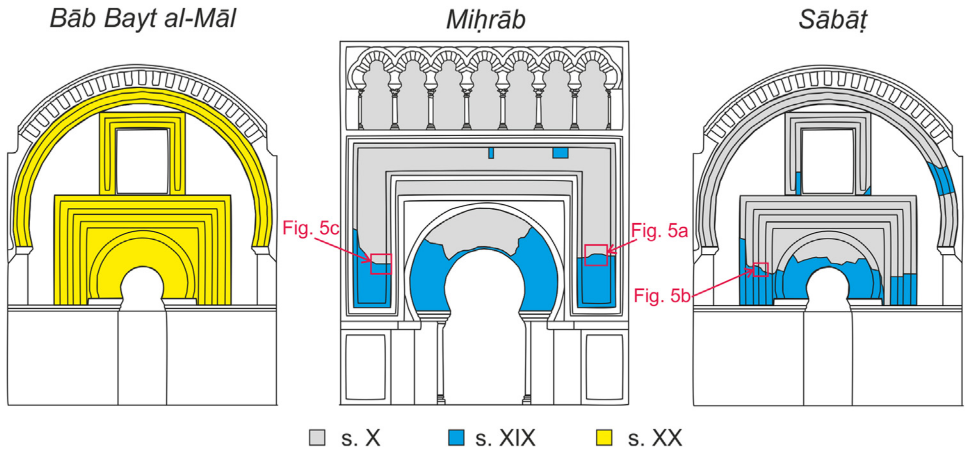

Fig. 6 – Schematic representation of the different interventions on the basis of textual and graphic material, highlighting the areas from where the photos were taken for Fig. 5.
Images adapted from G. Ruiz Cabrero, G. Rebollo, and S. Herrero's planimetry.

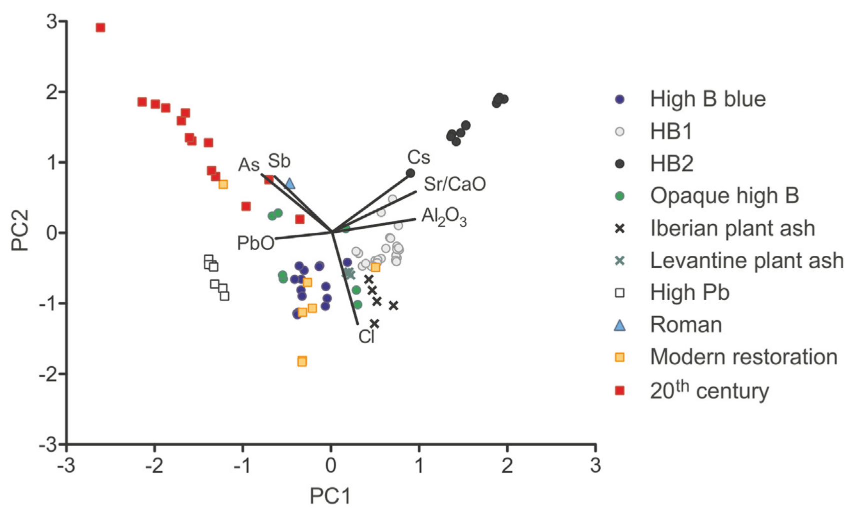

Fig. 7 – Principal Component Analysis (PCA) of the 91 analyzed *tesserae* divided according to the different groups of compositions [17]. Please note that the coefficient vectors are given on an enlarged scale (2×).

increasingly sank into total ruin [45,46]. The repairs were carried out in 1771 under the direction of the French architect Baltasar Dreveton and cost 24,000 reals [45,47]. According to the orders of the dean, the restorations were made "without altering or changing anything of the architecture" [14,15,45,46] following the principles of the San Fernando Royal Academy of Fine Arts [48,49]. There is no information about the restoration materials, but Romero de Torres pointed out that the horseshoe arches from the latticework, which act as skylights, were painted [13,14].

In 1815, Pedro Antonio de Trevilla, bishop of Córdoba, ordered the dismounting of the altarpiece of the Nursing Madonna and other furniture that was kept in the Chapel of Saint Peter. This led to the re-discovery of the mosaics of the *Miḥrāb* and the *Sābāṭ*, which were heavily damaged, especially in the lower part of the mosaics as a consequence of the installation and removal of the altarpieces [50]. Patricio Furriel was hired by Tiburcio María de la Torre, acting Governor of Córdoba, to restore the mosaics in 1817–1818 [47]. According to the documentary evidence, work was carried out on the lower part of the voussoirs and the intrados of the *Miḥrāb* as well as the lower part, frame, and part of the inscriptions of the *Sābāṭ* mosaic. In areas where the *tesserae* were lost, the mortar was painted and colourless glasses were fixed with screws or glue, so the colour was visible [8,42,47]. These parts are easily identifiable to this day (Fig. 5). Some of the material we analyzed appears to confirm this remark (see Section 3.2). Stern suggested that Patricio Furriel also used *patê de verre tesserae* in some areas such as the pendentives, the ribs of the dome, some parts of the window frames and in the central voussoirs of the *Sābāṭ façade* [13]; however, he might have confused them with lead glass *tesserae,* which appear very homogenous [17]. In places where the motifs were completely destroyed, Furriel re-designed the decoration in a baroque style, introducing some modifications in the epigraphic texts [8,43,47]. As a result of this intervention, eleven of the nineteen voussoirs of the *Miḥrāb* arch were restored, leaving only the central eight voussoirs in their original state. Similar interventions were carried

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Table 1 – Description of non-mediaeval *tesserae* from the Great Mosque in Córdoba. Partially extracted from [17].

Location	Name	Colour	Core description	Chromophore	Crystalline inclusions	Surface painted
Bāb Bayt al-Māl door	MAQ E 001base	Yellowish	Transparent	Fe^{2+}		
	MAQ E 001cart	Yellowish	Transparent			
	MAQ E 002	Red	Opaque	Cu^0, Cu^{2+}		
	MAQ E 003	Blue	Small crystals (white and red)	Co^{2+}	$KAlSi_3O_8$, $Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
	MAQ E 004	Blue	Small crystals (white and red)	Co^{2+}	$KalSi_3O_8$, $Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
	MAQ E 005	White	Small white crystals	Fe^{3+}?	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
	MAQ E 006	Red	Opaque	Cu^0		
	MAQ E 007	Black	Small crystals (white and red)	Co^{2+}	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
	MAQ E 008	Dark grey	Small crystals (white and red)	Co^{2+}, Fe^{3+}	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$, SiO_2	
	MAQ E 009	Red	Opaque	Cu^0	$Pb_2Sb_2O_7$	
	MAQ E 012	Black	Small crystals (white and red)	Co^{2+}, Fe^{3+}, $Cu^{2+0,0}$ Mn^{3+}?	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$, SiO_2, Fe_2O_3	
	MAQ E 013	Light grey	Small white crystals	Cu^{2+}	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
	MAQ E 014	Light blue	Small crystals (white and red)	Co^{2+}, Cu^{2+}	$KalSi_3O_8$, $Pb_2Sb_2O_7$	
	MAQ E 015	Light grey	Small white crystals	Co^{2+}, Cu^{2+}	$Pb_2Sb_2O_7$, $Ca_2Sb_2O_7$	
Sābāṭ door	MAQ O 004	Burgundy	Transparent			X
	MAQ O 005	White	Homogeneous opaque matrix		$Ca_2Sb_2O_7$	X
	MAQ O 007	Burgundy	Transparent			X
	MAQ O 030	Light blue	Transparent, homogeneous	Cu^{2+}		X
Miḥrāb door	MAQ C 001	Colourless	Transparent			X
	MAQ C 014	Colourless	Transparent			X
Miḥrāb ceiling	MAQ C 037base	Burgundy	Transparent			
	MAQ C 037cart	Burgundy	Transparent			
	MAQ C 042	Dark blue	Isolated small crystals			

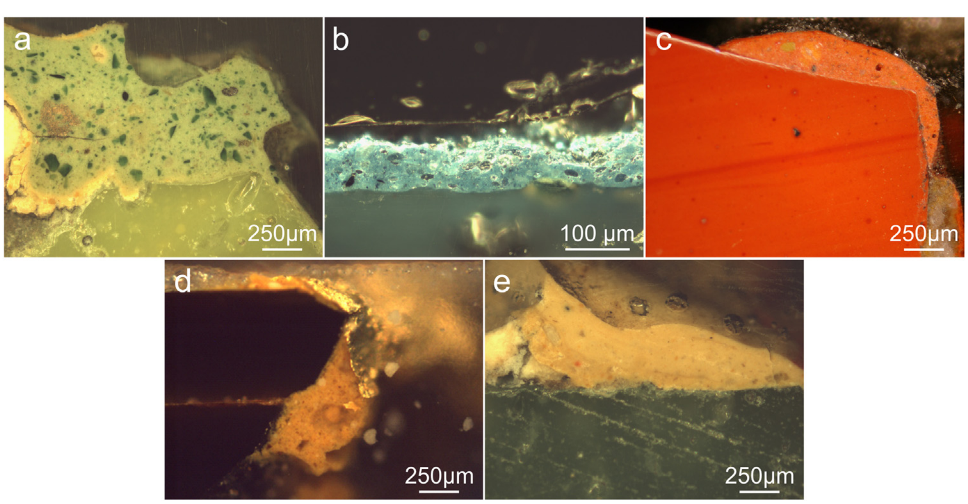

Fig. 8 – OM image (a–c) different paint layers on glass *tesserae*; (d) gold-plating on an original gold-leaf *tessera*, (e) tessera with adhesive.

Table 2 – Type of glass and LA-ICP-MS glass bulk composition (wt%), calculated as the average of three point analyses, in non-mediaeval *tesserae* from the Great Mosque in Córdoba. Partially extracted from [17].

Location	Name	Composition	(wt%)														ppm		
			Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CuO	SnO_2	PbO	As	Sr	Sb
Bāb Bayt al-Māl door	MAQ E 001 base	Lead-silica glass	17.1	0.13	0.20	53.1	0.04	0.13	1.92	2.07	0.02	2.78	3.73	0.02	0.011	18.4	502	50	535
	MAQ E 001 cart	Lead-silica glass	15.8	0.11	0.24	59.6	0.04	0.13	4.36	2.19	0.03	2.53	0.75	0.04	0.037	13.7	510	35	1963
	MAQ E 002	Lead-silica glass	14.8	0.20	0.82	58.6	0.04	0.16	1.45	4.71	0.03	0.40	2.24	2.83	0.067	13.0	744	71	2493
	MAQ E 003	Lead-silica glass	17.8	0.19	0.44	59.9	0.02	0.18	0.64	5.59	0.02	0.40	0.65	0.51	0.036	12.0	475	70	10,401
	MAQ E 004	Lead-silica glass	15.2	0.20	0.57	56.2	0.02	0.26	0.80	4.88	0.03	0.21	0.38	1.12	0.022	17.6	511	41	19,786
	MAQ E 005	Lead-silica glass	15.6	0.14	0.56	57.7	0.01	0.18	0.73	6.04	0.02	0.08	0.21	0.16	0.005	15.6	138	96	22,717
	MAQ E 006	Lead-silica glass	16.3	0.76	1.17	61.1	0.21	0.66	1.94	5.97	0.06	0.29	3.33	1.86	0.112	5.85	330	428	1291
	MAQ E 007	Lead-silica glass	14.5	0.25	0.69	56.3	0.04	0.14	0.67	5.41	0.04	2.64	0.94	0.37	0.036	15.9	577	139	12,530
	MAQ E 008	Lead-silica glass	20.3	0.15	0.35	62.5	0.01	0.16	0.18	6.28	0.02	0.03	0.26	0.16	0.012	8.94	112	78	4021
	MAQ E 009	Lead-silica glass	16.3	0.62	1.21	59.3	0.15	0.37	1.48	5.99	0.06	0.39	3.21	1.82	0.148	8.37	486	304	1868
	MAQ E 012	Lead-silica glass	14.4	0.37	0.49	57.4	0.08	0.23	2.07	5.33	0.03	2.51	0.80	0.68	0.099	14.4	1006	118	5800
	MAQ E 013	Lead-silica glass	8.8	0.18	0.35	48.9	0.02	0.16	0.59	5.22	0.02	0.17	0.25	0.94	0.073	31.9	472	71	19,374
	MAQ E 014	Lead-silica glass	17.9	0.19	0.42	59.9	0.02	0.17	0.63	5.62	0.02	0.40	0.63	0.52	0.035	12.0	481	72	10,814
	MAQ E 015	Lead-silica glass	16.2	0.31	0.61	55.8	0.03	0.19	1.07	5.41	0.03	0.59	0.56	1.40	0.095	15.2	1238	69	17,920
Sābāṭ door	MAQ O 004	High-lime-low-alkali glass	8.6	0.78	0.85	70.1	0.19	0.75	4.25	14.0	0.12	0.021	0.30	0.002	2E-04	0.003	2	159	
	MAQ O 005	Mixed-alkali glass	7.7	2.92	1.09	61.3	0.19	0.61	9.45	8.55	0.15	0.025	0.48	0.010	7E-04	1.241	6533	491	44,026
	MAQ O 007	Soda-rich glass	10.4	0.76	0.62	72.3	0.39	1.03	1.20	12.9	0.15	0.009	0.23	0.001	2E-04	0.001	6	150	3
	MAQ O 030	Soda-rich glass	10.2	0.80	0.88	71.7	0.22	1.01	0.93	13.7	0.17	0.010	0.31	0.000	1E-04	0.003	1	207	
Miḥrāb door	MAQ C 001	Calco-potassic glass	2.6	0.27	0.27	68.9	0.19	0.23	18.7	8.61	0.03	0.008	0.11	0.003	4E-05	0.000	558	42	
	MAQ C 014	High-lime-low-alkali glass	9.6	0.52	2.92	68.3	0.35	0.74	4.15	12.8	0.06	0.021	0.40	0.001	2E-04	0.001	3	207	
Miḥrāb ceiling	MAQ C 037 base	Soda-rich glass	19.9	0.19	0.48	74.4	0.08	1.59	0.15	2.77	0.03	0.004	0.19	0.000	3E-05	0.000	54	17	
	MAQ C 037 cart	Soda-rich glass	19.7	0.20	0.46	74.5	0.08	1.60	0.15	2.82	0.03	0.004	0.18	0.000	3E-05	0.000	52	17	
	MAQ C 042	Soda-lime silicate glass	16.8	1.00	1.99	68.0	0.08	0.87	0.52	6.55	0.07	0.21	0.93	0.25	0.004	0.34	112	392	18,348

Please cite this article in press as: T. Palomar, et al., Historical restorations of the *Maqṣūrah* glass mosaics from the Great Mosque of Córdoba, Bol. Soc. Esp. Cerám. Vidr. (2022), https://doi.org/10.1016/j.bsecv.2022.04.004

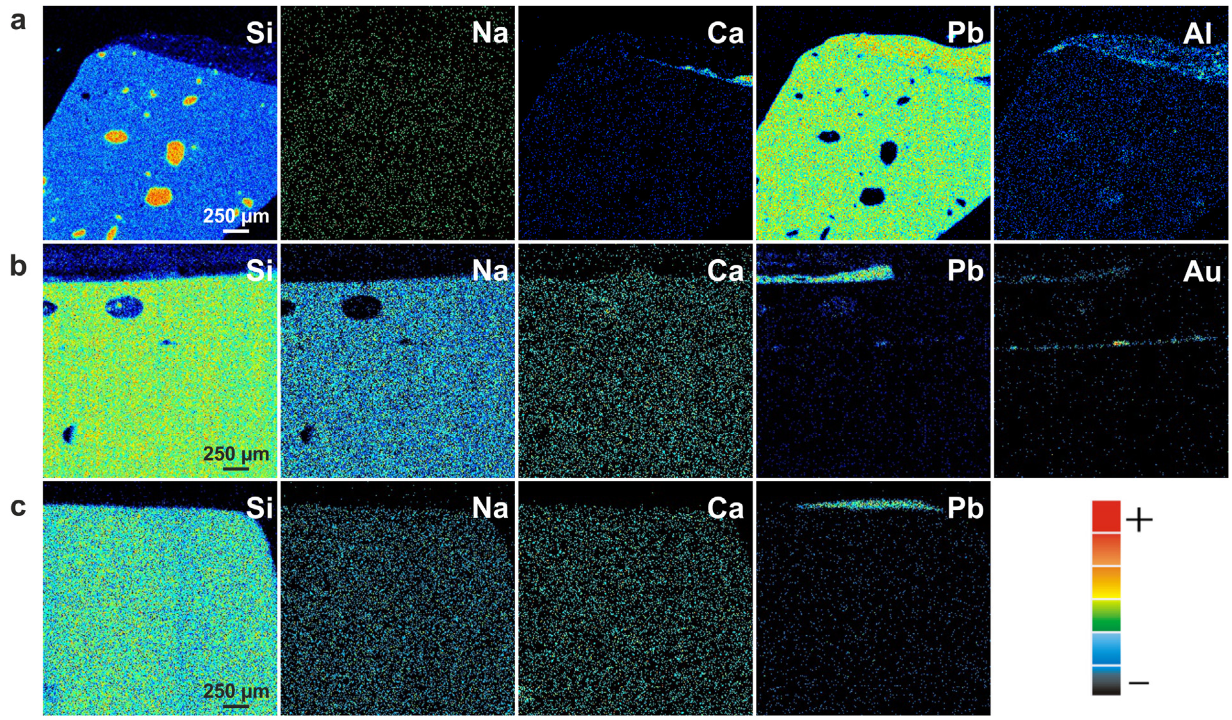

Fig. 9 – PIXE maps (a) original *tessera* painted with white lead and green aluminosilicates (MAQ O 03), (b) original gold-leaf *tessera* with a preparation layer and a second gold leaf (MAQ C 34), (c) modern painted *tessera* (MAQ O 05).

out on the façade of the *Sābāṭ* chamber, where only the 5th to the 11th voussoirs still have their original decoration (Fig. 6).

In 1912, the canvas of "La Última Cena" was removed, revealing the mosaics of the *Bāb Bayt al-Māl* façade. The construction of the adjacent chapel of Cardinal Salazar (Fig. 3) together with the mounting and dismounting of the altarpiece resulted in the destruction of the mosaic [16]. For this reason, the Cathedral Chapter of Córdoba ordered their complete restoration. In keeping with the principles of Eugène Viollet-le-Duc, the architect responsible for the restoration campaign, R. Velázquez Bosco, commissioned a replica of the mosaic from the atelier *J. & H. Maumejean Fréres* in Madrid. A. Gilbert, the artistic director of the atelier, hired the Venetian mosaic artist F. Morolin to make the facsimile that was installed in 1916 [4,13,16,51,52] (Fig. 6).

Finally, in 1997 and 1999, the dome was consolidated by the Andalusian Historical Heritage Institute (IAPH) due to the poor condition of the mortars that contributed to the dislodging of the *tesserae*. This pathology was directly related to water infiltration. The fallen *tesserae* were reintegrated in the mosaics [53].

Characterization of the restoration's tesserae

The analyses of 91 *tesserae* revealed highly variable compositions (Fig. 7). Of the ten compositional groups, eight groups can be attributed to the original tenth-century decoration, including three types of Byzantine high boron glasses (number of *tesserae*, $n = 46$), two different types of soda-rich plant ash glasses ($n = 9$), and two types of high lead glasses ($n = 14$) as well as a single sample that represents the re-use of a Roman *tessera* (MAQ C 042) [17,54]. The remaining 21 *tesserae* can be attributed to non-mediaeval material from later restorations due to the morphological characteristics and chemical composition of the glasses (Table 1). A principal component analysis (PCA) was performed on a selected subset of LA-ICP-MS data (Cs, Sr/CaO, Al_2O_3, Cl, PbO, As, Sb) using the openly accessible RESET database (https://c14.arch.ox.ac.uk). These elements were chosen as they represent the mineral impurities in the silica source (*e.g.* Al_2O_3), the alkali and alkaline earths (Cs, Sr/CaO), chlorine that can separate ancient from modern raw materials [55,56], the type of glassy matrix (PbO) as well as additives (As, Sb) that have a clear chronological range. The first two principal components (PC) cover 68% of the variance of the dataset and single out the 20th-century *tesserae* as having elevated As, Sb, and very low alumina, chlorine and strontium to lime ratios (Fig. 7; Table 2). These features indicate the use of modern raw materials, and the elevated arsenic and antimony levels clearly point to a date after the 17th-century date [57]. Seven painted *tesserae* (MAQ O 004, MAQ O 005, MAQ O 007, MAQ O 030, MAQ C 001, MAQ C 014, MAQ C 037) (Table 1) were also identified as material originating from restoration campaigns but with very different compositional characteristics [17].

Painted samples

Most of the seven painted restoration *tesserae* were transparent, colourless or weakly coloured glasses (Table 1). It was not possible to characterize the chromophore by FORS because its pale hue reduced the light reflected from the surface. Their analysis showed a great variety of compositions (Table 2) such as soda-rich glasses (MAQ C 037, MAQ O 007, and MAQ O 030),

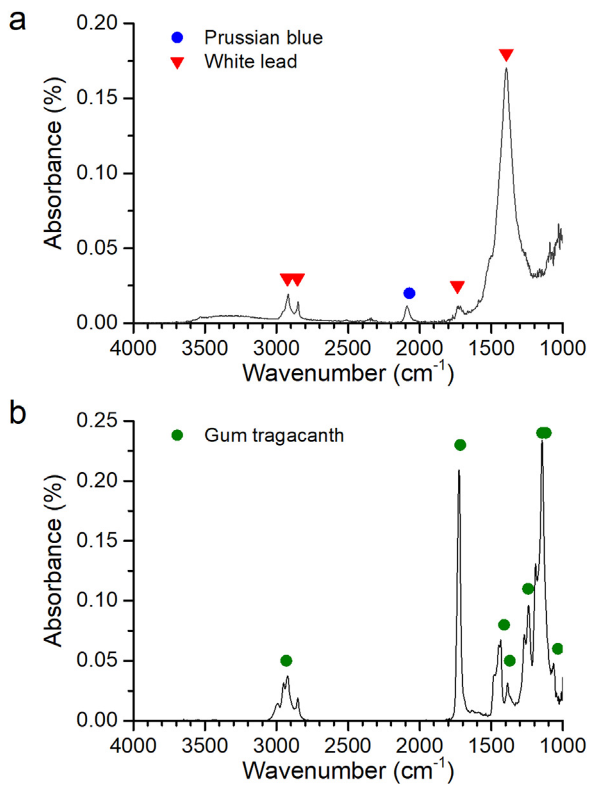

Fig. 10 – FTIR-ATR spectra of (a) the blue paint on the *tessera* MAQ O 30, (b) the adhesive on the *tessera* MAQ O 13. Peaks attributions made using [64,65].

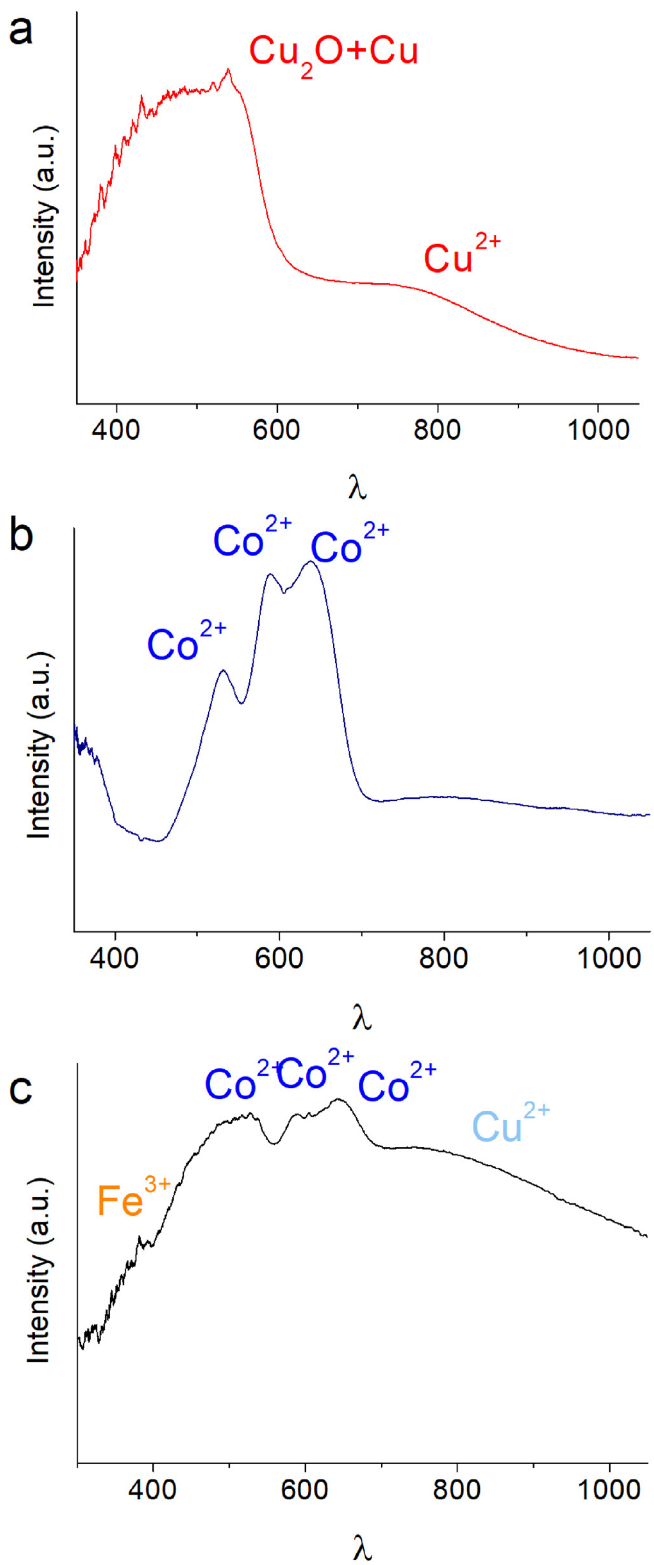

Fig. 11 – FORS spectra of the *tesserae* (a) MAQ E 002, (b) MAQ E 004 and (c) MAQ E 012. Bands attributions made using [73].

a calco-potassic glass (MAQ C 001), a mixed-alkali glass (MAQ O 005), and high-lime-low-alkali glasses (MAQ C 014 and MAQ O 004).

The soda-rich glasses have a chemical composition similar to some 17th-century glasses, specifically European *Façon de Venise*, Venetian common, or *Vitrum Blanchum* [58]. This composition has been maintained in commercial glasses from the second half of the 19th century and the first decades of the 20th century [59,60]. The potash glass was similar to that developed in Central Europe in the 17–19th century [59,61]. The white glass MAQ O 005, found in one voussoir of the *Sābāṭ* door, has similar amounts of Na_2O and K_2O (7% and 9.5%, respectively) and it was classified as mixed-alkali glass. Even though its content did not agree with 17th-century mixed-alkali glasses [58], the combination of a very homogeneous matrix opacified by $Ca_2Sb_2O_7$ crystals and high arsenic levels indicates a post-17th-century date [62,63].

Despite their different composition, the painted *tesserae* located in the *Sābāṭ* door (MAQ O 30, MAQ O 05, MAQ O 07, and MAQ O 04) have high levels of TiO_2 relative to Al_2O_3 as a common feature (Table 2). This provides solid evidence that these glasses are derived from different raw material sources and represent a distinct production from the other samples in the *Miḥrāb* mosaics, especially with respect to the silica source.

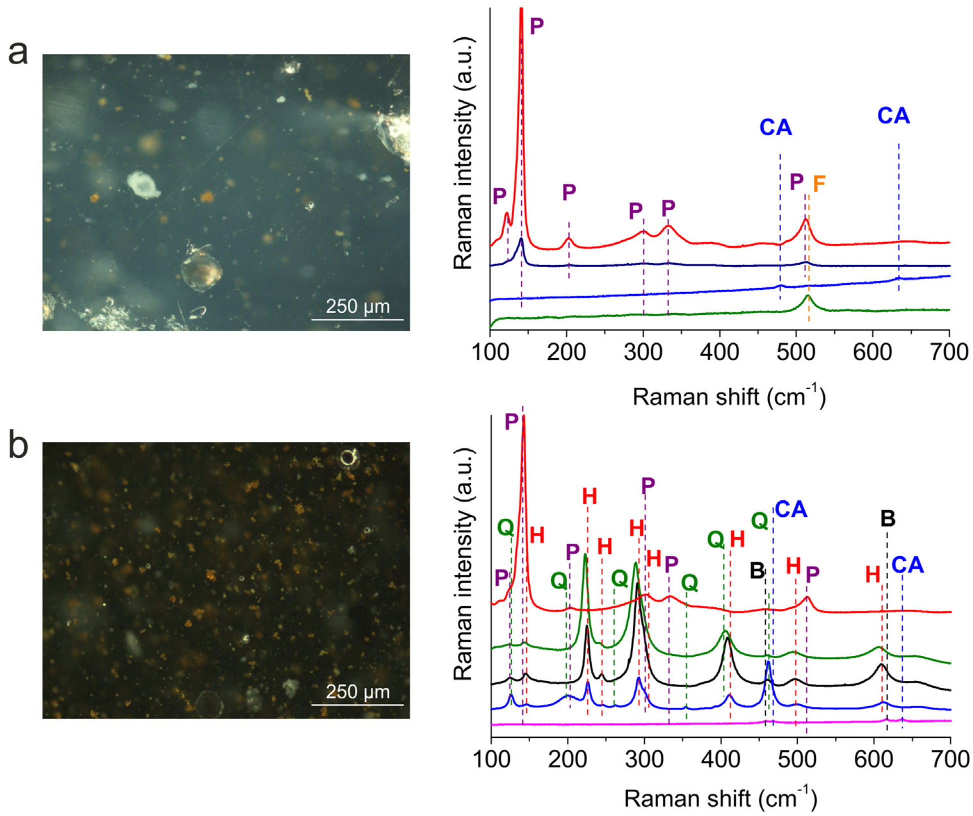

Fig. 12 – OM and μ-Raman spectra of inclusions in *tesserae* (a) MAQ E 003 and (b) MAQ E 012. Legend: CA: Calcium Antimonate, $Ca_2Sb_2O_7$; F: Feldspar, $KAlSi_3O_8$; P: Bindheimite, $Pb_2Sb_2O_7$; H: Hematite, Fe_2O_3; Q: Quartz, SiO_2; B: Alkaline sulphate. Attributions made using the RRUFF database on minerals and [74–76].

The surface of these *tesserae* together with 11 original *tesserae* [17] was coated with different colours (blue, red, green, and golden) (Fig. 8). The analyses made by SEM-EDX and PIXE detected high contents of lead in the surface paints (Fig. 9), and FTIR-ATR confirmed the use of white lead ($2PbCO_3{\cdot}Pb(OH)_2$) (Fig. 10a), as a base where pigments were dispersed. High contents of iron and alumina was detected in green crystals of the green paints (Figs. 8a and 9a) that could be related to the use of iron aluminosilicates. In the blue paints, FTIR-ATR spectra identified the Prussian blue – $Fe_4[Fe(CN)_6]_3$ – as pigment (Figs. 8b and 10a), while the high levels of mercury detected by SEM-EDS in the red paint agrees with the use of vermilion – HgS – (Fig. 8c) to produce the red paint. Grains of hematite – Fe_2O_3 – (45.6 – 216 μm) were also detected on the red paint, as well as calcite grains on the blue. To restore the golden areas, the surface was covered with a preparative layer to which the gold leaf was applied, occasionally even over an original gold-leaf *tessera* (Figs. 8d and 9b). A yellowish adhesive, identified by FTIR-ATR as gum tragacanth, was identified on some reposition *tesserae* (Fig. 8e).

Vermilion as red and lead white as white pigments were known since ancient times [66,67]; Prussian blue, however, was introduced only in the early 1700s, being widely used until 1970 when it was replaced by the phthalocyanine blue [68]. The glasses are similar to those of the 17th and 18th centuries. They may have either been imported to the Iberian Peninsula or produced by Italian or Bohemian glass makers in Spanish factories [69].

The analyses of the green painting layer on the Byzantine sample MAQ C 025 by GC showed the presence of linseed oil and traces of conifer resin as binders of the paint without residue of varnish, and FTIR-ATR identified gum tragacanth in sample MAQ O 13. The use of linseed oil together with white lead was already used in antiquity and described by Heraclius for the preparation layers on a wooden support [70]. It was particularly popular during the Renaissance until the middle of the 20th century when it was replaced by cobalt or zirconium-based driers due to toxicological and environmental concerns [71].

It is thus reasonable to conclude that all the painted *tesserae* are related to the intervention of 1817–1818. The fact that both original and new samples were painted suggests the paint was applied directly to the mosaic surface in some areas. The implicit goal of the 19th-century restoration was to restore the Islamic mosaics without altering their overall appearance. The original parts were not touched but the gaps were filled with painted glass and plaques of modern *tesserae*. This approach is similar to the modern tradition of conservation, which consists of preserving the original areas as much as possible and filling in the missing parts with materials that are easily recognizable, while preserving the overall appearance of the work from a distance [72].

Table 3 – Summary of the main interventions and type of *tesserae* used in the *Maqṣūrah* of the Mosque-Cathedral of Córdoba.

	Data	Principal	Fact	Type of *tesserae*
The Great Mosque of Córdoba	786–787	Abd al-Rahman I	Construction of the mosque	
	~840	Abd al-Rahman II	Expansion of the mosque	
	~960	Al-Hakam II	Expansion of the mosque and construction of the *Miḥrāb* and mosaics	Homogeneous coloured and gold-leaf soda-lime silicate and high-lead glasses
	988	Almanzor	Expansion of the mosque	
The Mosque-Cathedral of Córdoba	1236	King Ferdinand III of Castile	Consecration of the Great Mosque of Córdoba to the Assumption of Mary	
	1390	–	Installation of the altarpiece of the Nursing Madonna in front of the *Miḥrāb*	
	1595	Antonio and Hernando Mohedano de Saavedra	Installation of the altarpiece "Última Cena" in front of the *Bāb Bayt al-Māl* chamber	
Modern interventions	1771–1772	Baltasar Dreveton	Restoration of the *Miḥrāb* dome	
	1815	Bishop Pedro Antonio de Trevilla	Dismounting the altarpiece of the Nursing Madonna from the *Miḥrāb* chamber	
	1817–1818	Mr. Patricio Furriel	Restoration of the mosaics of the *Miḥrāb* and *Sābāṭ* façades	Very pale high-alkaline glasses painted with blue, red, green or golden colours
	1912	Ricardo Velázquez Bosco	Dismounting the altarpiece "Última Cena" from of the *Bāb Bayt al-Māl* chamber	
	1914–1916	J. & H. Maumejean Fréres	Reproduction and installation of the mosaic in the *Bāb Bayt al-Māl* chamber	Homogeneous coloured and gold-leaf high-lead glasses
	1997–1999	Instituto Andaluz del Patrimonio Histórico (IAPH)	Consolidation of the mortars and reintegration of the *tesserae*	

The 20th-century tesserae

The other group of non-mediaeval *tesserae* ($n = 15$) was formed by the samples from the *Bāb Bayt al-Māl* door, and includes one transparent gold-leaf *tessera*, red opaque samples, and coloured bulk glasses with a high density of crystals (Table 1). All of them were lead-silica glasses with high contents of Na_2O (17–20 wt%) (Table 2). In comparison with the historical *tesserae*, they have higher contents of arsenic, antimony, and low levels of aluminium oxide and chlorine (Fig. 7) [17].

The gold-leaf *tessera* was formed by a transparent glass support with a leaf of gold (~16 μm of thickness) on its surface that was protected by a thin layer of glass, the so-called *cartellina* (~500 μm). The composition of the *cartellina* was slightly different from the support [17].

The red *tesserae* were completely opaque due to the presence of small nanoparticles of copper (Fig. 11a), which agrees with the high content of copper and iron in these samples (Table 2). The red glasses do not contain additional inclusions; however, isolated crystals of $Pb_2Sb_2O_7$ were detected in one of the analyzed samples (MAQ E 009).

The transparent glasses with inclusions (Fig. 11) have a similar composition despite a great variety of colours due to the addition of chromophores. Co^{2+} and Cu^{2+} ions are the most common chromophores in the bluish and greyish *tesserae* (Fig. 11b) (Table 1). The black samples also contain manganese to darken the glass colour (Table 2), but the absorption bands were difficult to be distinguished due to the overlapping of the bands from the different chromophores (Fig. 11c).

Lead antimonate ($Pb_2Sb_2O_7$) and calcium antimonate ($Ca_2Sb_2O_7$) particles dispersed the light in most of the *tesserae*, independent of their colouration (Table 1). $Pb_2Sb_2O_7$ inclusions are small yellowish crystals (~20 μm), and $Ca_2Sb_2O_7$ accumulate into very small deposits forming large and irregular structures (150–250 μm). Some regular feldspars ($KAlSi_3O_8$) were additionally detected in the blue *tesserae* (Fig. 12a), but typically in smaller amounts than the antimonate crystals. An agglomeration of SiO_2 and Fe_2O_3 in varying proportions was found in the black samples (Fig. 12b) that may be residues of the sand raw material. Similarly, the dark grey sample displayed some big rounded quartz grains (~300 μm). In all cases, the addition of these big inclusions modified the material and optical properties and contribute in case of the mosaic *tesserae* to an increase in glass opacity.

Tesserae with similar features (high-lead silicate glasses with lead and calcium antimonate) were found in the 18th-century *tesserae* from the Capela de São João Baptista (Lisbon, Portugal) [77]; although each colour showed different compositions with concentrations of PbO from 2 wt% to ~50 wt%. These evidently modern *tesserae* appeared only in the mosaic from the *Bāb Bayt al-Māl* door and not in the other two façades. This means that the other mosaics in the Great Mosque were probably not touched during the early 20th-century restorations. This agrees with the news published at the beginning of the 20th century that talked about the installation of a mosaic facsimile due to the poor state of conservation of the original one following the principles of "stylistic restoration" by Eugène Viollet-le-Duc [78,79].

Conclusions

The mosaics of the Mosque-Cathedral of Córdoba offer a unique opportunity to study the evolution of the architectural and decorative traditions and the significance attributed to them over the centuries because the various restoration campaigns reflect changing attitudes towards the cultural and aesthetic value of Islamic art and architecture, as well as a paradigm shift in art conservation.

In the first centuries, the mosaics were part of the private *Maqṣūrah* of the caliph. Access was only allowed to people dedicated to worship and religious service. This testifies to the value and prestige associated with the art of glass mosaics. After the Christian conquest, the Islamic mosaics were covered with altarpieces, either because the mosaics were deemed inappropriate in the context of the ecclesiastical space of the cathedral or mosaics were no longer considered a desirable art form. The main degradation factor of the mosaics was the water leaks and dampness in the walls, which caused the mortar to disintegrate and the glass *tesserae* to detach. The lack of ventilation, especially during the period when the mosaics were hidden, together with the mounting and dismounting of the altarpieces accelerated this process, so that the lower parts of the *Miḥrāb* and *Sābāṭ* mosaics and the whole of the *Bāb Bayt al-Māl* mosaics were lost entirely.

The façades of the *Miḥrāb* and the *Sābāṭ* still preserved original mosaic *tesserae,* despite different interventions particularly in the 19th and 20th centuries. In the first quarter of the 19th century, colourless *tesserae* were inserted and painted to reproduce the colour of the original mosaics. The high-alkaline silicate composition of these glasses identifies these *tesserae* as modern glass. Similarly, some of the pigments that were applied, such as Prussian blue, and the binder correspond to technical developments in the 18th century, confirming once more their modern origin.

On the other hand, the *Bāb Bayt al-Māl* façade no longer contains any original mosaics as it has been completely restored in compliance with the Viollet-le-Duc's principle of "stylistic restoration". The *tesserae* used in this mosaic have a completely different composition (high-lead glasses) with lead antimonate and calcium antimonate as inclusions to opacify the glass. These types of *tesserae* have not been identified in any other part of the mosaics, suggesting that the restorations remained confined to the *Bāb Bayt al-Māl* mosaic in line with contemporary newspaper reports.

The main changes in the *Maqṣūrah* mosaics and the characteristics of the *tesserae* used in each intervention are summarized in Table 3.

Glossary

Hijri year (H): The era used in the Islamic lunar calendar.

Maqṣūrah: The 'closed-off space' near the centre of the Qiblah wall in the direction of prayer, usually reserved for the caliph

Miḥrāb: Prayer niche in the Qiblah wall

Minbar: Wooden pulpit for the imam's sermon.

Muzŷŷaŷa: tesserae with glaze.

Qiblah: Wall of the mosque where the Mihrab opens, which is normally the direction towards the Sacred Mosque in Mecca.

Qubba: Islamic domed shrine.

Conflict of interest

No potential conflict of interest was reported by the authors.

Acknowledgments

The authors acknowledge to Cabildo of Córdoba Cathedral, Instituto Andaluz del Patrimonio Histórico and the Research Unit VICARTE (FCT NOVA) for the facilities provided to accomplish this research, and to Biblioteca Nacional de España and Universitat Politècnica de Catalunya (UPCommons) for the permission of use of the images from their databases. This work was partially funded by the European Research Council under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 647315 to NS) and the Fundación General CSIC (ComFuturo Programme). The authors wish to acknowledge the professional support of the Interdisciplinary Thematic Platform from CSIC Open Heritage: Research and Society (PTI-PAIS).

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Please cite this article in press as: T. Palomar, et al., Historical restorations of the *Maqṣūrah* glass mosaics from the Great Mosque of Córdoba, Bol. Soc. Esp. Cerám. Vidr. (2022), https://doi.org/10.1016/j.bsecv.2022.04.004

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