Madīnat al-Zahrā' or Madīnat Qurtuba? First evidences of the Caliphate tin-glaze production of 'verde y manganeso' ware

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Abstract

The first workshop evidence of the Caliphate polychrome tin-glaze production known as 'verde y manganeso' in *al-Andalus* has been found in the Cordoban workshops area. This study reports on the analysis of recovered firing debris and workshop items and the tin-glaze production chaîne opératoire using SEM-EDS and μ -XRD analysis. The findings reveal the use of a tin and lead *calx* mixed with plant ashes both in the Emirate and later Caliphate tin glaze productions and demonstrate a direct relationship between the Umayyad Córdoba-Madīnat al-Zahrā' and the Abbasid regions. Moreover, ceramics from both domestic and palatial well dated archaeological contexts from Córdoba and Madīnat al-Zahrā' have been analysed to determine the differences among the domestic and palace wares and to shed light on the long running dispute among scholars regarding the location of the tin glaze workshops. Our data demonstrate so far that the workshop area of Córdoba manufactured 'verde y manganeso' tin glazed ceramics during the Caliphate period and that it could have been supplying both high quality wares for the palaces and cheaper products for the domestic contexts.

Keywords: Tin glazes, tin technology, polychrome decorations, 'verde y manganeso', Islamic, Umayyad Caliphate, Spain, Madīnat al-Zahrā', Córdoba, decorated ceramic.

1. INTRODUCTION: HISTORIC BACKGROUND

The beginnings of the tin-glaze technology in *al-Andalus* (Muslim medieval Spain and Portugal) are linked to the last emir rulers. During the Late Emirate period, seemingly under the rule of the Umayyad amir 'Abd Allah (888-912 CE), the first evidence (though no workshops) of a local polychrome tin-glaze production has been found in Córdoba, with simple geometrical green and brown patterns painted over an opaque white glaze and new ceramic shapes (Salinas & Pradell, 2018: 1-11). The tin glazes were produced using the recipe found in the Abbasid region: a *calx* made roasting lead and tin mixed with quartz and plant ashes.

In 929 CE, 'Abd Allah grandson 'Abdarrāḥmān III proclaimed himself as the Umayyad caliph of Córdoba. This new political period, known as the Caliphate of Córdoba (929-1031 CE), brought changes to *al-Andalus*, such as the creation of an ideological and iconographic program that would sustain his political and religious legitimacy, and the foundation of the new palace city of Madīnat al-Zahrā' (939 CE). This city was directly linked to the Umayyad power and was razed when the dynasty collapsed (1009/1010 CE). The large number of polychrome tin glazed ceramics, known as 'verde y manganeso' ware, found in the palace complex led many researchers to link its production with the establishment of the city, and even to raise the possibility that this ware was produced there (Ocaña 1970: 35). At the same time a relative dating of 945-1009 CE is reported for this tin-glaze ware, both in Madīnat al-Zahrā' and in the western suburbs of Madīnat Qurtuba (the Islamic name for Córdoba). The houses located at this area were also abandoned once the Caliphate of Córdoba collapsed and the civil war, the *fitna* (1009-1031 CE), began, and they were no longer re-occupied (see Figure 1 for the location of

the different archaeological sites mentioned in the text). This is why the 'verde y manganeso' ware recovered in the archaeological excavations of these areas are dated in the 10th-early 11th centuries.

<Figure 1>

With the end of the Umayyad Caliphate another political period began: the Taifa kingdoms (1031-1085 CE) and the production centres of the 'verde y manganeso' ware spread incorporating aesthetic changes associated with the new rulers. Little is known about these ceramics which have not yet been studied in depth, particularly from a technological point of view. The same applies to the later Almohad 'verde y manganeso' ware (c. 1147-1248 CE) which show very distinctive designs and ceramic shapes compared to the earlier products.

In regards to the Caliphate 'verde y manganeso' production centre of the 10th century, the location of the workshop/s where this tin-opaque ware was manufactured is unknown. Consequently, the scientific community has been divided for years between those who support the hypothesis that this ware was manufactured in *Madīnat al-Zahrā'* (i.e. Barceló 1993: 296) and those who argue that it was produced in the workshop area at Córdoba (*Madīnat Qurtuba*) (i.e. Rosselló 2002: 80). Aside from the large quality of tin glazed sherds recovered at *Madīnat al-Zahrā'*, support of a *Madīnat al-Zahrā'* manufacture is based on two historical facts: on the one hand, the move of the *dār al-ṣinā'a* (the official craft centre of the Umayyads) from *Qurtuba* to *al-Zahra* in 946 CE (*Al-Maqqarī*, 1855: 346, 371) and the identification of signatures on some 'verde y manganeso' wares related to the official control of the Caliphate productions. These facts reinforce the idea that the location of the Caliphate ceramic workshops in *Madīnat al-Zahrā'* (Barceló 1993: 296).

However, apart from historical texts referring to a pottery quarter located in the northern part of Córdoba (Torres, 1970: 191; Aziz, 1984-85: 227), the recently recovered archaeological evidence of glazed ceramic production in Córdoba support the notion that 'verde y manganeso' ware was not produced in *Madīnat al-Zahrā'* but in the Cordoban workshops. Although the workshop and kilns have not yet been found, recently, the examination of a dumping area found in the pottery quarter of Córdoba has provided the first evidences of a "verde y manganeso" Caliphate production, including firing wasters and workshop items such as vessels containing material related to the tin glaze production, tripod stands and kiln bars.

This finding has provided a unique opportunity to analyse these ceramics and determine the tin-glaze *chaîne opératoire*. Moreover, as part of this study, ceramics from well dated archaeological contexts from Córdoba and *Madīnat al-Zahrā'* have also been analysed to determine the differences among the domestic and palace wares and to shed light on the long-time dispute among scholars regarding the location of the tin glaze workshops. Finally, the Caliphate tin glaze wares are also compared to the earliest emirate production and changes in the tin-glaze *chaîne opératoire* determined.

2. ARCHAEOLOGICAL BACKGROUND

2.1. The pottery quarter of *Madīnat Qurtuba*

The main pottery production area of Córdoba was located in the northeast of the city. According to the Arabic written sources, it was called *al-Fajjarīn* (Aziz, 1984-85: 227). Its activity has been documented since at least the 9th century (Emirate period) with the production of both unglazed pottery and transparent glaze ware. The pottery quarter is known to have continued to be active until the end of the Caliphate period (1031 CE) as evidenced by structures and glazed wasters of

'cuerda seca' ware from this period, and continued through the 11th and 12th centuries until the end of the Almohad period, the end of the Islamic period in Córdoba (1236 CE) (Salinas 2012: 635-675).

More than 100 double chamber- and grill-type kilns have been recovered in the eastern sector of the production area, now known as *Zumbacón* (37°53'44"N 4°46'18"W)¹ (Fig. 1.1) and more workshops have been excavated in the surroundings and dated later. The bulk of the kilns found in *Zumbacón* so far date to the Emirate period (9th-early 10th centuries) and only three kilns date to the Almohad period (mid-12th-early 13th centuries). The workshop area was reorganised and dedicated to other uses at the beginning of the 10th century: the northern part was converted into a cemetery, the southern part to housing and the western part was used as a dumping ground for debris from the new nearby pottery quarter (Larrea 2008).

The examination of the archaeological material recovered from the pottery dumping area, mainly formed after ceasing the activity of the Emirate kilns has given first evidence of a 10th century tin-glaze production. The material included wasters of ceramics with Caliphate decorations and some vessels containing material related to the workshop production, including tripod stands and kiln bars.

2.2. The consumption market of the 'verde y manganeso' ware: houses and palaces of the Córdoba hinterland

Four archaeological sites have been selected in order to, characterise the tin-glaze ware consumed in the Córdoba area during the 10th century and determine whether or not the Cordoban workshop supplied both the Córdoba and *Madīnat al-Zahrā'* markets.

Two of the archaeological sites sampled correspond to the main power centres of *al-Andalus*: the Umayyad *Alcázar* of Córdoba (37°52'38.44"N 4°46'47.73"W) (Ortiz & León 2018) and the *Madīnat al-Zahrā'* palace (37°52'52"N 4°52'26"W). The *Alcázar* of Córdoba, the *al-Qaṣr* (Fig. 1.2), was the main political centre of the Umayyad dynasty and is placed in the *madīna*, close to the river. After the collapse of the Caliphate, part of the *Alcázar* was looted and some walls were dismantled. The ceramic sherds sampled were recovered in recent excavations and belong to this context (Ortiz & León 2018). The city of *Madīnat al-Zahrā'* was built in 940 CE and razed in 1009-1010 CE (Fig. 1.5) and the sherds sampled were taken from old findings from the palace area.

The other two archaeological sites sampled belong to domestic contexts from two suburbs located in the west area of Córdoba/*Qurtuba*, known as *yanib al-Garbi*, halfway between *Madīnat Qurtuba* and *Madīnat al-Zahrā'* (González 2012; Cánovas & Moreno 2015). These two quarters were built in the 10th century, when the city experienced an important increase of the population. The excavated areas of the two suburbs are located respectively in the *Ibn Zaydun* square (37°53'08"N 4°47'40"W) (number 3 in Fig. 1) and in the *Piscinas Municipales de Poniente* (37°52'47"N 4°47'56"W) (number 4 in Fig. 1). The houses were abandoned due to the instability caused by the civil war (1009-1031 CE) giving an approximate dating c. 940-1009 CE for the pottery studied.

3. MATERIALS AND METHODS

¹ All the DMS geographical coordinates included in the manuscript refer to the archaeological sites. All are reporting coordinates, taken by the survey teams, that have been included in the archaeological reports for the four Córdoba archaeological sites and from VALLEJO (2010) for *Madīnat al-Zahrā'*.

The selection includes samples from five contexts: the pottery production area, two domestic contexts from two western suburbs and two palace contexts from the two official residences of the Umayyad caliph. A total of twenty-nine sherds were selected from the archaeological sites: 8 found in the workshop area of *Zumbacón* (Z), 6 found in the *Palacio Episcopal* where the Umayyad citadel and palace of Córdoba was located (PAL), 5 found in the *Madinat al-Zahra* palace (MZ), 8 for those in the houses of *Ibn Zaydun* (IZ) and 2 found in the houses of *Piscinas Municipales Poniente* (PM).

Tin-glazed ware sherds exhibit a remarkable homogeneity regarding shapes and decorations; serving dishes decorated with brown and green decorations on a white opaque background on one side and a plain white-yellowish transparent glaze on the other side. The decorations show a wide range of motifs: epigraphic, geometric and vegetal. Eight of the ceramics show semi-oval decoration in the inner rim. This motif, that evokes the Abbasid lustre ware (Watson 2004: 191-193), is very characteristic of the Caliphate decorations and is present in all the assemblages studied, including two of the glazed wasters.

<Table 1 >

The material has been divided into two groups: the first from the workshop and the second from the domestic and palace areas of Córdoba.

The sampling was performed on those sherds showing Caliphate decoration and which appeared better preserved. We have to mention that, due to the high acidity of the soil in the Córdoba region, the buried ceramics usually show a very poor preservation. In fact, for a long time, the powdery appearance of the ceramic surfaces suggested even the possibility of being slipped instead of tin glazed.

Samples have been examined and analysed in cross-section using an optical microscope and scanning electron microscopy (SEM) equipped with energy-dispersive spectrometry (EDS). These analyses were supplemented by X-ray diffraction (XRD) measurements on two pieces from the workshop. The primary aims of these analyses were first, to chemically characterise the local production of these ceramics in the Córdoba workshops studying the debris found so far; second, to determine the nature of the glazes, and colourants used for the decoration; third, to establish the *chaîne opératoire* and the connections with other contemporary tin glaze productions; and fourth, shed new light on the debate regarding the location of the tin glaze workshops by comparing the ceramics found in different consumption areas in Córdoba and *Madīnat al-Zahrā*.

3.1. Tin-glaze production materials and tin-glaze debris

Eight samples related to the tin-glaze production have been analysed: two vessels containing material related to the production, one kiln rod and five ceramic wasters showing Caliphate decorations, Figure 2.

<Figure 2 >

3.2. Glazed ceramic samples

Eighteen glazed samples, all from tableware, have been analysed. They include fifteen serving-dishes (IZ2, IZ3, IZ5, IZ9, IZ11, IZ13, IZ14, PM15, PM19, PAL7, PAL13, PAL14, PAL15, PAL27, I453), one closed form (IZ4) and one of undetermined shape (PAL31). All show the distinctive Caliphate

decorative patterns, such as plants and geometrical designs and the hemispheric decoration at the rim. A representation of the main shapes and decorations are shown in Figure 3.

<Figure 3>

3.3 Analytical procedures

Polished cross-sections of the sherds were prepared. The polished sections were examined both in reflected light with an optical microscope, and in a SEM with attached EDS. A crossbeam workstation (Zeiss Neon 40) equipped with SEM GEMINI (Shottky FE) column and EDS (INCAPentaFETx3 detector, 30mm², ATW2 window), operating at 20 KV with 120s measuring times, were employed. The glaze and body microstructures were studied and recorded in backscatter mode (BSE) in which the different phases present could be distinguished on the basis of their atomic number contrast.

Chemical compositions of the bodies were determined by analysing a minimum of one area, about 3 mm x 2 mm. Because of the porosity of the bodies, the analyses were normalised to 100 wt%, and then averaged. For the glazes, the areas analysed were somewhat smaller, and as far as possible, were chosen to avoid areas of weathered glaze and areas near to the glaze-body interface, although this was not always possible in view of the heavily weathered glazes on some of the samples; the results were again averaged. A selection of the non-plastic inclusions within the bodies, and opacifier and other particles in the glazes were also analysed. The EDS system was calibrated using oxide and mineral standards and a high lead (K229) standard, and a secondary alkali (SRM612) glass standard to validate the data. Typical absolute detection limits are 0.1% for Na, Mg, Al, P, K, Ca, Ti, Mn and Fe, 0.2% for Si and Cu, 0.3% for Sn and 0.4% for Pb. Considering that the ceramics found in the different sites around Córdoba (palaces, workshop) are very close and contemporary, we do not expect important differences among the chemical composition of the ceramic bodies. Consequently, the data have been analysed using bivariate plot for comparison.

μ -XRD has been performed at XALOC beamline at the Alba synchrotron (Cerdanyola del Vallès, Barcelona); high brilliance <10 keV energy focused beam 30 × 7 μ m² (width x height FWHM) together with the eventually noise-free large-area photon counting detector (Pilatus 6M) provides the necessary requirements for the determination of the crystalline compounds and their distribution in the thin layers.

4. RESULTS

4.1 Workshop materials

Several ceramics related to the production were recovered in the dump area. Among the debris, two vessels -Z57 and Z22- and one kiln rod -Z21- have been analysed. One of the vessels, -Z57- (Figure 4A) is filled with a white substance over a white-yellowish inner layer covering a red ceramic body (Figure 4B and 4C), and the other -Z22- shows only the inner white-yellowish layer over the red ceramic body. The kiln rod -Z21- shows white drops on the surface (Figure 5A). The chemical compositions of the materials related to the workshop area are given in Table 2.

<Table 2>

The optical microscope image of the cross section of the vessel (Z57) is shown in Figure 4C and the corresponding SEM-BSE images in Figure 4C and 4E. The chemical analysis data (Table 2) and the SEM-EDS spectra (Figure 4F) demonstrate that the white material filling the vessel contains a silica glassy material containing tin oxide (SnO_2 , cassiterite) particles and lead carbonate precipitates. The glassy material was formed by the reaction of the lead oxide contained in the vessel with the silica of the ceramic; the lead oxide contained in the vessel, unlike to tin oxide, is not very stable and during burial transforms into lead carbonate (cerussite, PbCO_3). Consequently, the material filling the vessel is likely related to lead-tin *calx*; that is, metallic lead and tin melted and oxidised (at a temperature of about 600°C) to obtain a fine mixture of lead and tin oxides which was afterwards used to make the tin glazes (Matin et al. 2018: 46-48). The white-yellowish layer covering the inner part of the vessels (Figure 4G) is calcareous rich (Table 2) and contains quartz, calcium rich feldspar, (anorthite, $\text{CaAl}_2\text{Si}_2\text{O}_8$), calcium magnesium silicate, (diopside, $\text{CaMgSi}_2\text{O}_6$) and calcium iron oxide (Figure 4H). This layer was applied on the interior of the vessel before firing, as a protecting layer, to avoid the lead of the *calx* from reacting with the non-calcareous body of the vessel (Table 2). Thus, the material found inside the vessel indicates that it was used as a crucible to make the *calx*.

<Figure 4 >

Figure 5 shows a kiln rod (Z21) with a white glassy substance adhered to the surface, probably corresponding to glaze drops from the ceramics fired in the kiln. SEM-EDS analysis of the substance, see Table 2, indicate that it corresponds to a high lead glaze with about 5% SnO_2 . SEM-BSE images show the presence of small cassiterite particles in the glaze, Figure 5D. Around large quartz grains some devitrification and alteration of the glaze is observed and the corresponding μ -XRD pattern show the presence of cerussite resulting from the alteration during burial of the lead glaze as well as cassiterite, Figure 5E.

<Figure 5>

These results demonstrate that the vessels were used as a crucible for the production of lead-tin *calx*, a precursor of the tin glazes, and in conjunction with drops of tin glaze on the kiln rod indicate tin glaze ware production.

The five glazed ceramic wasters with Caliphate decorative designs and found in the same dumping area (from the Zumbacón archaeological excavation) were also analysed and the data obtained will be discussed together with those corresponding to the other ceramics studied.

4.2 Ceramic Bodies

The major and minor chemical composition of the bodies of all the ceramics studied are included in Table 3. SEM-EDS was selected to obtain the chemical composition of the fabrics due to the limited size of the fragments available and state of preservation of the samples, nevertheless, it would be also desirable to obtain the trace elements and see what they could provide to this study. The ceramic bodies are of calcareous type clay with a relatively large variation of the CaO contents (10.0 - 19.5% CaO, with the exception of that of one overfired ceramic found in the workshop (7.5% CaO). The bodies have reddish colours because the firing was performed with an oxidising atmosphere (Figure 6A-6D). The microstructure of the fabrics is common to all the archaeological sites sampled, with a predominance of small quartz grains (25-50 μm), (Figure 6B), large white lime (Figure 6A, 6C) and red ferruginous nodules (made of a red clay mixed with

quartz grains) (Figure 6D, 7A), but also a few large biotite micas, potassium feldspars and elongated porosity. All the particles are visible under the optical microscope. The large lime nodules are the most distinctive feature of the Córdoba bodies and distinguish them from the other *al-Andalus* production centres. A μ -XRD pattern corresponding to one of these nodules was obtained showing the presence of anorthite, diopside and quartz similarly to the white-yellowish protective layer applied to cover the surface of the crucible vessels used to produce the *calx* (Figure 4H), suggesting that this lime clay was particularly selected to make the protecting layer for the crucibles. The white nodules are also found in other Córdoba glazed wares from the 9th to the 13th centuries (Salinas & Pradell 2018: 4). The presence of these lime inclusions is also seen in the lime rich clay deposits and especially in the carbonate rock quarries (Figure 6E) located in the main potter craft area in the northeast of Córdoba.

<Figure 6 >

Finally, semi-circular holes and micro-foraminifera globigerina fossils are also detected in the fabrics (Figures 7B-D) of workshop, palatial and domestic wares indicating that all the tin glazed production shares the same clay found in the workshop area.

<Figure 7 >

<Table 3 >

μ -XRD of the ceramic body shows the presence of quartz, anorthite and diopside and in small amounts gehlenite $-\text{CaAl}(\text{AlSiO}_7)-$ and magnesian calcite $-(\text{Ca,Mg})\text{CO}_3-$. Anorthite forms in fine calcareous ceramic bodies fired at temperature above 950°C. Although the presence of gehlenite and calcite might suggest a lower firing temperature, in lime rich clays the complete decomposition of the large lime/fossil inclusions leaves pores which are easily filled with secondary calcite. Moreover, the decomposition of calcite involves a strong endothermic reaction which consumes a lot of energy and which, consequently, might be delayed inside the ceramic bodies. Finally, the presence of biotite $-\text{K}(\text{Mg,Fe})\text{AlSi}_3\text{O}_{10}-$ can be associated to occasional large mica inclusions.

Generally speaking, the fabrics of the workshop, palace and domestic ceramics analysed are similar. However, they show a relatively large variation of the calcium content due to the presence of large lime rich clay nodules and quartz particles, as can be seen in Figures 8A and 8B.

<Figure 8 >

4.3 Tin-glazes and decorations

The chemical analyses of the glazes and decorated areas are given in Table 4 for the five glazed ceramic wasters found in the craft quarter, in Table 5 for the ceramics found in the palaces, and in Table 6 for the ceramics found in the houses.

Only one side of the ceramics is decorated on sherds in this study, the other side being an undecorated glaze. The glazes of the decorated side are of a lead-alkali type and contain 31-51% PbO, 1.0-2.9% Na₂O, 0.1-1.0% MgO and 1.1-4.6% CaO and are opacified with variable contents of tin oxide, 1-10 % SnO₂. In contrast, the glazes of the undecorated side are high lead, 50-60% PbO, with little sodium and magnesium, below 1% Na₂O and MgO, slightly higher amounts of potassium and calcium, 1-3% K₂O and 2-5% CaO and lower contents of tin oxide, 0-2 wt% SnO₂. The decorated glazes are opaque and show a white-creamy colour, while the glazes of the

undecorated side are mainly transparent with a honey colour, due to the presence of higher amounts of iron oxide ($\approx 2\% \text{FeO}$).

The main characteristics of the analysed glazes are the presence of homogeneously distributed very small cassiterite crystallites (most below $1 \mu\text{m}$, but with a few $2 \mu\text{m}$ long) (Figure 9B) in the decorated glazes (Figure 9A-8F) but with some also present in most of the undecorated glazes (Figure 9G and 9H); large quartz particles and bubbles are also seen.

The presence of small crystallites of tin oxide which scatter light very efficiently gives a white opaque smooth appearance to the glazes, similar to the early Chinese porcelains, accomplishing two main objectives: the reddish colour of the ceramic fabric is hidden and the colour decorations appear better defined. The opacity and whiteness of the glaze are greater the more, the smaller (a few micrometres size) and more homogeneously distributed the tin oxide crystallites are.

The colourants used are copper for the green ($0.4\text{-}0.9\% \text{CuO}$), manganese for the brown ($1.8\text{-}4.4\% \text{MnO}$) and iron for the honey plain glaze ($1.4\text{-}2.8\% \text{FeO}$). All three colorants appear completely dissolved in the glazes.

Typical glaze thicknesses for the undecorated surface vary between $125 \mu\text{m}$ and $200 \mu\text{m}$, while those of the decorated side are thicker varying between $200 \mu\text{m}$ and $500 \mu\text{m}$. The thicker areas are the coloured areas as the decoration was applied overglaze (Figure 9C and 9E). All the glazes show minimal glaze-ceramic interface, as a result of the use of a double firing.

Generally speaking, the tin-opaque glazes appear heavily weathered showing the characteristic layered microstructure formed by a sequence of micrometric silica rich sheets with lead carbonate precipitates (Figure 9F). The corrosion is so heavy that most of the surface is often lost and the bubbles appear full of secondary lead carbonate and/or phosphate precipitates (Figure 9D and 9F). This weathering results often in a yellowish colour, a dull surface and a powder-like appearance.

<Figure 9 >

<Table 4 >

The most remarkable difference among the ceramics analysed is the higher content of tin in the white background of the decorated sides of the tin glazes from Palace contexts compared to those of the Domestic contexts as shown in Figure 10. This can be related to a more expensive production destined for the court. We also see that among the sherds found in the workshop dump, although those that could be analysed are not many, both types are found indicating that those high-quality wares were also produced, probably *on demand*, in the Córdoba workshop. Furthermore, the earliest tin-glazes of Córdoba, from the Late Emirate period (Salinas & Pradell, 2018: 1-11), are compared to those of the Caliphate period in Figure 10 showing a tin/lead contents matching those of the Palace wares.

<Figure 10 >

One of the problems with the analyses of the glazes in this study is the heavy alteration and losses shown by most of them. Consequently, in many cases, the analyses had to be made on areas of the glazes very close to the ceramic surface. As a consequence, the results show higher amounts of aluminium, potassium, calcium and magnesium dissolved from the ceramic into the glaze. This problem affects particularly the white background glazes as the colour decorations

were applied above. Nevertheless, and taking this into account, the original raw materials used for the production of the glazes could be estimated.

The glazes applied on the undecorated side of the ceramics show also tin oxide but in lower amounts; this suggests that they were also made using *calx* but with less tin added. Nevertheless, the variable presence of tin oxide might also be due to contamination rather than to a deliberate addition. Most undecorated glazes appear transparent, and honey coloured due to the higher iron content which was deliberately added.

In order to determine the other compounds added to the *calx* to produce the tin glazes of the decorated side, we recalculated the composition of the glazes subtracting the PbO, SnO₂ and colourants contents (copper and manganese). The corresponding Na₂O*, CaO* and K₂O+FeO* are plotted versus Al₂O₃* in Figures 11A, 11B and 11C respectively.

<Figure 11 >

The correlation of the higher aluminium oxide contents to those of the iron and potassium oxides, and also to the calcium contents in some of the glazes, is due to the fact that many analyses were obtained from areas very close to the glaze-ceramic interface. This is affecting less the coloured areas as they are painted on top of the white glazes. Nevertheless, the sodium oxide content of the Caliphate glazes is fairly constant (Figure 11A). The presence of relatively high Na₂O contents ($\approx 4\%$) independently of the low contents of the ceramic bodies ($< 1\%$) is expected if plant ashes were added to the glaze mixture. These data therefore indicate that a mixture of *calx*, a quartz sand and a soda rich compound (probably soda rich plant ashes, like barrilla) was used for the tin glazes. The Late Emirate tin glazes have also been added in the figure for comparison (Figure 11A), and we can see that they show a higher Na₂O contents ($\approx 6\%$) compared to the Caliphate tin glazes, which could be related to the addition of higher amounts of plant ashes.

5. DISCUSSION

The ceramics studied include mainly open forms, such as serving-dishes, and a small number of closed forms, including one jug. The forms show a continuity of the Late Emirate serving dishes shapes and are mainly hemispheric with round rims. Although the lower part of most of the ceramics analysed have been lost, those preserved are mainly foot-free or, on rare occasions, have a low ring-foot. In general, the features of those recovered from the archaeological sites of Córdoba and also from *Madīnat al-Zahrā'* are similar.

The decorative style is the most characteristic feature of this ceramics. Although the majority of the designs are drawn in brown and filled-in with green, some show brown and green lines, which may not be filled-in, and brown coloured areas. The decorative patterns studied are more complex than those of the previous Emirate period. The possible reason for this evolution is that as there was no earlier tradition of decorated polychrome ceramics in al-Andalus the first designs were very simple. Over time, the Caliphate 'verde y manganeso' ware developed a more complex decorative programme that included human and animal figures, as well as vegetal, geometrical, epigraphic and allegoric symbols related to the paradise. The decorations are applied overglaze, like in the previous Córdoba Emirate examples.

The tin-glaze wares of the Caliphate period are a continuation of those produced in the late Emirate period (early 10th C.), also found in the workshop quarter of Córdoba. Nevertheless, some differences are found: white opaque tin glazes were applied on both sides of the ceramic

in the Emirate production, and a honey coloured glaze was applied on the undecorated side of the ceramics in the Caliphate production.

Analysis of the workshop debris found in the dump area has demonstrated that the glazes were produced from a mixture of *calx* and sand, the *calx* used for those ceramics destined to Palace consumption containing higher tin oxide than for those destined to the urban market. The opaque glazes are also soda rich, due to the addition of plant ashes (most probably barrilla). The use of a mixture of *calx* is described in the Islamic treatise of Abu-l-Qasim Kashani dated in 1301 CE (Allan 1973: 111-120), and the addition of plant ashes to this medieval *calx* has recently proven to facilitate the crystallisation of cassiterite responsible for the white opacity of the glazes (Matin et al. 2018: 50). A mixture of a lead oxide richer *calx*, sand and iron rich clay was used for the glazes applied on the undecorated side of the wares.

The data obtained indicates that the methods of production used in the Caliphate 'verde y manganeso' tin wares are the same as those used in the earlier Emirate polychrome tin glaze production; the Emirate tin glazes contain a higher amount of soda indicative of a recipe containing a higher amount of plant ashes than the Caliphate ones. The tin oxide content of the Emirate tin glazes is similar to those of the Caliphate ceramics found in the Palaces, but higher than the Caliphate domestic ceramics. Moreover, the use of a tin-low or tin-free glazes for the undecorated amber side of the majority of the Caliphate ceramics (only one piece has an undecorated tin-opaque white side) in contrast with the Emirate ones shows either a desire to reduce the costs of production or something that signified the production from the previous one, such as a special symbolism for the honey colour.

The beginnings of the production and consumption of tin-glaze ware in *al-Andalus* appears to be directly related to two factors: the urban development of the Islamic society in medieval Spain, similarly to that in other territories of the *Dar al-Islam*, such as the big eastern cities of Basra, Samarra or Bagdad, and, second, the desire to emulate the sophistication of the Abbasid court, through the use of tin-glaze tableware. This first Andalousi high-quality polychrome tin-glaze ware was produced and consumed on a small-scale in the Umayyad capital of Córdoba during the Late Emirate period, according to the archaeological records. At first it was intended for the Cordoban elites. Moreover, the use of a tin and lead *calx* mixed with plant ashes both in the Late Emirate and Caliphate tin glaze productions demonstrate a direct relationship between the Umayyad Córdoba-*Madīnat al-Zahrā'*, located in the western Islamic lands, and the Abbasid regions of the Middle East. The dating circa 900 CE for the beginnings of the tin-glaze technology in *al-Andalus* suggests a technological transfer from the nowadays Iraq (Basra) or Syria (Raqqa). Córdoba continued to be the capital of the Umayyad Caliphate, from the 929 to the 1031 CE, and the most populated city of *al-Andalus*. This fact together with the location of the 'verde y manganeso' workshops in the city, resulted in Córdoba-*Madīnat al-Zahrā'* being by far the first market for this ware, and, consequently the site of *al-Andalus* from where the largest quantity of these decorated ceramics has been recovered. Thus, the production of 'verde y manganeso' ware increased and its use spread to the rest of the Córdoba urban population, unlike rural areas. Nevertheless, statistical analyses regarding the consumption of ceramics in domestic contexts of the western suburbs of Córdoba during the 10th C. have proven that the 'verde y manganeso' ware was not as common, since it represented only 6% of the total domestic ware (Camacho & Valera, in press). This indicates that tin glaze was a semi-luxury ware, 'the Friday tableware' for the Muslims. Regardless, it became popular, reaching the entire Córdoba population. However, the need to supply a wider market and the fact that tin was an expensive product due to the scarcity of nearby ores may be behind the use of less tin, which translates into a decrease in production costs for the domestic use, and thus, a lower quality ware, in contrast to the Palace that continued to use a high-quality tin-glaze ware.

Moreover, although a high-quality ware characterised by opaque glazes containing a higher amount of tin oxide is identified in the Palace contexts, this does not necessarily imply that they were produced in a different workshop but rather that both higher and lower quality wares were produced on demand. Supporting this hypothesis, of the five ceramic wasters analysed one has a high tin content similar to the Palace ceramics. Consequently, our data so far demonstrates that the workshop area in Córdoba produced 'verde y manganeso' tin glazed wares during the Caliphate period and that it could have been supplying both more expensive ceramics for the palaces and cheaper ceramics for the domestic contexts.

6. CONCLUSION

The identification of the recipe of tin and lead *calx* mixed with plant ashes used to manufacture polychrome tin-glazed ware in Córdoba during the 10th century has enabled us to link it to the Abbasid tradition. This local production and consumption of high-quality polychrome tin-glaze tableware has been interpreted as an emulation of the Abbasid court lifestyle by the Cordoban elite in the Umayyad capital of Córdoba-*Madīnat al-Zahrā'*.

The production of 'verde y manganeso' ware began on small-scale in the Late Emirate to increase during the Caliphate, when the market reached not only the palaces but also the Córdoba urban population. The need to supply a wider market and the fact that tin was an expensive product translated into a decrease in production costs of a second-class ware for the domestic use. The production of a high-quality ware for the Caliph and his court has been demonstrated, and this most probably affects also the range of the decorative themes and quality of execution, although an in-depth study of the subject has not yet been performed.

This study has demonstrated that Caliphate 'verde y manganeso' workshop/s were inserted in the main pottery quarter, contrary to what has been thought for a long time, and placed in the northeast sector of Córdoba. Our data shows two unknown facts: firstly, that two qualities of tableware were produced and consumed in the *al-Zahrā'-Qurtuba* palaces and in the *Madīnat Qurtuba* houses. Secondly, that both could have been manufactured in the same workshop, although the 'verde y manganeso' ware for palatial consumption was subjected to quality control, such as the signing of the products.

Finally, our data suggests that tin-glaze technology came from the East to the West, that is, from the Abbasid world to *al-Andalus* and was assimilated first by the Córdoba pottery tradition, where the seat of the Umayyad centralised state was, and from there spread to other Andalusian production centres.

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Table 1. Classification of the archaeological sites sampled.

Sites	Archaeological Context	Samples	Shards
Zumbacón Pottery quarter	Dump/Production vessels	2	Z22, Z57
	Dump/Rod	1	Z21
	Dump/Tin-glaze debris	5	Z13, Z20, Z46, Z61, Z28
Palacio Episcopal	Córdoba Caliphal Palace	6	P7, P13, P14, P15, P27, P31
Ibn Zaydun	House of west suburb	8	IZ2, IZ3, IZ4, IZ5, IZ9, IZ11, IZ13, IZ14
Piscinas Municipales	House of west suburb	2	PM15, PM19
Madinat al-Zahra	Palace	5	I453, CS7, CS14, CS15, CS43

Table 2. Chemical compositions of the ceramic bodies and protective layers from Córdoba workshop crucible vessels and the glaze drops found on the kiln rod determined by SEM-EDS (wt% normalised to 100 wt%).

Type	Samples	Layer	NaO ₂	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	FeO	SnO ₂	PbO	Cl
Vessel	Z57	body	5.3	0.7	14.9	67.3	1.7	1.0	0.8	5.3	-	1.9	1.0
		protective layer	3.5	1.9	13.1	61.0	0.1	10.8	0.7	5.2	-	2.3	0.6
Vessel	Z22	body	0.9	1.4	16.3	60.1	4.2	6.7	0.9	6.1	-	3.2	-
		protective layer	1.1	2.4	17.2	53.0	1.2	15.1	0.8	6.6	-	1.4	0.6
Rod	Z21	Glaze drop	2.5	0.5	0.4	26.9	0.2	1.5	-	0.3	5.6	61.1	1.3

Table 3. Chemical compositions of the workshop and housing areas from Córdoba and Madinat al-Zahra ceramic bodies determined by SEM-EDS (wt% normalised to 100 wt%). The data are the average over at least two analyses taken in different areas of the ceramic bodies. *white lime rich clay nodule.

Context	Samples	n		Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	FeO	PbO
Workshop	Z13	2	avg	1.1	2.1	15.5	56.3	2.2	15.0	0.9	6.0	0.9
			std	(0.1)	(0.1)	(0.2)	(1.0)	(0.1)	(0.0)	(0.0)	(0.1)	(0.6)
	Z20	2	avg	0.8	2.1	14.6	57.5	2.4	15.1	0.8	5.9	0.5
			std	(0.3)	(0.3)	(0.4)	(0.2)	(0.5)	(0.3)	(0.0)	(0.5)	(0.5)
	Z46	2	avg	0.7	1.6	14.3	61.2	2.8	11.6	0.8	5.7	1.0
			std	(0.1)	(0.0)	(0.1)	(0.4)	(0.0)	(0.0)	(0.2)	(0.0)	(0.5)
	Z61	2	avg	0.6	1.5	14.1	65.2	3.5	7.5	0.9	5.8	0.7
			std	(0.0)	(0.0)	(0.1)	(0.1)	(0.0)	(0.1)	(0.0)	(0.1)	(0.1)
	Z28	2	avg	0.5	2.1	14.6	52.7	2.6	19.0	0.9	5.6	0.9
			std	(0.1)	(0.0)	(0.8)	(3.6)	(0.1)	(4.4)	(0.0)	(0.2)	(0.1)
Palace MQ	PAL7	2	avg	0.6	2.0	13.4	59.3	3.1	14.5	0.8	5.6	0.5
			std	(0.1)	(0.0)	(0.4)	(0.0)	(0.2)	(1.1)	(0.0)	(0.1)	(0.0)
	PAL13	2	avg	0.5	1.8	13.5	57.1	2.9	16.6	0.8	5.4	1.3
			std	(0.1)	(0.1)	(0.2)	(0.4)	(0.1)	(0.2)	(0.1)	(0.1)	(0.3)
	PAL14	2	avg	0.7	1.9	13.7	59.8	2.9	13.5	0.8	5.9	0.5
			std	(0.3)	(0.0)	(0.0)	(1.4)	(0.1)	(1.1)	(0.0)	(0.2)	(0.1)
	PAL15	2	avg	0.5	1.7	16.2	59.6	3.8	10.0	1.0	6.7	0.1
Palace MZ			std	(0.0)	(0.0)	(0.4)	(1.0)	(0.1)	(0.1)	(0.1)	(0.6)	(0.2)
	PAL27	2	avg	0.6	1.8	14.2	60.2	2.9	13.0	0.9	5.7	0.7
			std	(0.2)	(0.0)	(0.2)	(0.5)	(0.1)	(0.4)	(0.1)	(0.0)	(0.2)
	PAL31	3	avg	0.4	1.8	15.4	58.7	3.6	11.8	0.9	6.6	0.1
			std	(0.2)	(0.0)	(1.0)	(1.1)	(0.1)	(2.7)	(0.0)	(0.9)	(0.1)
	I453	2	avg	0.6	1.9	14.4	60.7	2.9	12.2	0.8	5.7	0.8
			std	(0.1)	(0.0)	(0.1)	(0.2)	(0.0)	(0.2)	(0.0)	(0.1)	(0.1)
	CS7	2	avg	1.0	2.1	15.1	55.9	2.9	15.1	0.9	5.4	1.4
			std	(0.1)	(0.1)	(0.5)	(0.3)	(0.0)	(0.2)	(0.2)	(0.1)	(0.2)
	CS14	2	avg	1.0	2.3	14.2	55.4	2.3	17.9	0.8	5.1	0.9
Houses			std	(0.0)	(0.1)	(0.0)	(0.3)	(0.1)	(0.4)	(0.1)	(0.0)	(0.1)
	CS15	2	avg	0.9	1.9	14.0	57.6	2.8	16.1	0.7	5.1	0.8
			std	(0.2)	(0.5)	(0.2)	(3.4)	(0.8)	(3.0)	(0.0)	(0.0)	(0.0)
	CS43	2	avg	0.6	1.8	15.5	62.1	3.5	9.3	0.9	5.7	0.7
			std	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.3)	(0.2)	(0.2)
	IZ4	2	avg	0.6	1.5	14.9	58.9	3.3	12.9	0.9	6.2	0.7
			std	(0.0)	(0.1)	(0.6)	(0.3)	(0.0)	(0.8)	(0.2)	(0.1)	(0.1)
	IZ5	2	avg	0.5	1.9	15.3	56.3	3.3	15.3	1.0	6.2	0.3
			std	(0.0)	(0.1)	(0.0)	(0.1)	(0.0)	(0.1)	(0.0)	(0.1)	(0.1)
	IZ2	2	avg	0.5	2.0	14.7	53.4	3.0	19.1	0.7	5.6	0.5
			std	(0.0)	(0.1)	(0.2)	(1.3)	(0.0)	(1.9)	(0.0)	(0.1)	(0.3)

Houses	IZ3	2	avg	0.4	1.6	14.6	58.5	3.2	13.6	0.8	5.8	1.3
			std	(0.1)	(0.1)	(0.2)	(0.7)	(0.1)	(0.7)	(0.0)	(0.1)	(0.5)
	IZ9	2	avg	0.5	1.7	13.9	57.1	3.0	16.4	0.8	5.9	0.7
			std	(0.1)	(0.0)	(0.5)	(1.1)	(0.1)	(1.7)	(0.1)	(0.1)	(0.2)
	IZ11	2	avg	0.5	1.8	13.6	56.7	2.7	17.0	0.8	5.5	0.5
			std	(0.2)	(0.2)	(0.7)	(0.9)	(0.2)	(0.4)	(0.2)	(0.1)	(0.0)
	IZ13	2	avg	0.6	2.0	15.5	56.2	3.2	14.3	0.8	5.9	1.1
			std	(0.1)	(0.2)	(0.2)	(0.3)	(0.2)	(0.4)	(0.2)	(0.3)	(0.4)
	IZ14	2	avg	0.5	2.0	15.3	54.6	3.1	16.8	0.9	6.2	0.6
			std	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.2)	(0.0)	(0.0)	(0.1)
	PM15	2	avg	0.6	1.8	14.4	57.1	2.9	14.6	0.6	5.7	1.3
			std	(0.1)	(0.0)	(0.1)	(1.1)	(0.2)	(1.3)	(0.1)	(0.1)	(0.2)
	PM15*	1		0.4	2.9	16.3	50.3	2.0	19.5	0.7	4.9	1.9
	PM19	2	avg	0.6	1.6	14.4	58.0	3.1	14.2	0.7	5.6	0.8
			std	(0.1)	(0.0)	(0.4)	(0.7)	(0.2)	(0.8)	(0.1)	(0.4)	(0.1)

Table 4. Chemical composition of the Córdoba workshop glazes determined by SEM-EDS (wt% normalised to 100 wt%). The data are the average over at least two analyses taken in different areas of the glazes.

¹d-decorated, u-undecorated

²w- white, b- brown , g- green , h- honey , *- heavily altered

Samples	Side ¹	Colour ²	n		NaO ₂	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	MnO	FeO	CuO	SnO ₂	PbO
Z13	d	w	1		1.7	0.3	3.7	37.5	2.1	2.5	-	-	0.9	-	3.3	48.1
		b	2	avg	1.5	0.2	3.5	38.8	2.4	2.2	-	1.3	0.8	-	1.5	47.7
				std	(0.2)	(0.2)	(0.1)	(0.7)	(0.2)	(0.1)		(0.8)	(0.2)		(0.7)	(0.3)
	u	h	1		0.7	0.8	4.3	36	3.3	4.1	0.4	-	1.9	-	1.2	47.5
Z20	d	w	1		1.6	0.4	3.9	41.7	1.6	4.5	-	-	2.1	-	2.6	41.5
		b	1		1.2	0.4	2.7	35.4	1.3	2.9	-	2.8	1.3	-	3.5	48.3
		g	2	avg	1.0	0.4	2.0	36.9	0.8	2.8	0.9	1.1	-	5.1	4.8	43.7
				std	(0.1)	(0.1)	(0.7)	(2.7)	(0.9)	(0.3)	(0.3)	(0.2)		(2.8)	(0.1)	(1.2)
	u	h	2	avg	0.8	0.7	5.0	38.4	2.1	6.7	0.4	-	2.3	--	0.4	43.3
				std	(0.0)	(0.1)	(0.7)	(1.2)		(0.3)	(0.0)		(0.1)		(0.1)	(2.3)
Z46	d	w*	1		-	-	0.6	11.5	0.1	2.7	-	-	0.4		10	74.7
	u	h	2	avg	1.0	0.6	4.6	40.9	4.5	5.2	0.4	0.3	2.7		1.4	38.9
				std	(0.0)	(0.1)	(0.3)	(0.5)	(0.1)	(0.3)			(0.4)		(0.6)	(1.4)
Z61	d	w	2	avg	0.1	0.3	2.7	31.3	0.8	2.7	0.2	-	1.2	0.3	4.0	56.4
				std	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		(0.0)	(0.0)	(0.0)	(0.0)
	u	t	2	avg	0.8	1.3	6.1	41.1	4.1	7.9	0.6	-	2.8	-	0.3	35.1
				std	(0.0)	(0.2)	(0.0)	(1.1)	(0.2)	(0.3)	(0.1)		(0.3)		(0.0)	(1.8)
Z28	d	w	1		1.7	0.5	1.7	39.0	3.2	2.9	-	0.2	1.1	0.4	10.3	38.9
		b	1		1.4	0.6	2.3	42.0	3.8	2.4	-	4.4	0.9	-	3.3	39
	u	h	2	avg	0.8	0.4	3.4	34.5	2.2	3.5	-	-	1.6	-	1.0	52.6
				std	(0.3)	(0.0)	(0.2)	(0.3)	(0.1)	(0.2)			(0.3)		(0.5)	(0.5)

Table 5. Chemical composition of the Córdoba palaces glazes determined by SEM-EDS (wt% normalised to 100 wt%). The data are the average over at least two analyses taken in different areas of the glazes.

¹d-decorated, u-plain

²w- white, b- brown , g- green , h- honey

Context	Samples	Colour	Side	n		NaO ₂	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	MnO	FeO	CuO	SnO ₂	PbO
Palace MQ	PAL7	w	d	2	avg	2.7	1.1	4.2	43.3	2.6	4.3	-	-	1.5	-	2.6	37.7
					std	(0.3)	(0.1)	(1.3)	(1.1)	(0.4)	(0.1)			(0.4)		(1.0)	(2.2)
		b	d	2	avg	3.1	0.7	4.7	41.5	2.7	3.2	-	2.1	1.5	-	10.9	29.6
					std	(0.6)	(0.1)	(1.5)	(2.9)	(0.5)	(0.2)		(0.3)	(0.4)		(4.4)	(1.4)
		g	d	3	avg	2.3	0.6	1.1	40.0	1.5	4.0	-	-	2.9	3.9	3.5	39.6
					std	(0.3)	(0.1)	(0.4)	(0.8)	(0.1)	(0.1)			(1.7)	(0.4)	(3.2)	(2.5)
		a	u	2	avg	0.5	0.7	4.2	34.4	1.5	5.0	0.1	-	1.6	-	-	52.0
					std	(0.1)	(0.3)	(0.0)	(0.6)	(0.0)	(0.1)	(0.1)		(0.0)			(0.3)
	PAL13	a	u	2	avg	0.9	0.4	4.1	32.2	1.4	3.5	0.3	-	1.7	-	0.5	55.2
					std	(0.2)	(0.0)	(0.0)	(0.1)	(0.1)	(0.3)	(0.4)		(0.1)		(0.2)	(0.1)
	PAL14	b	d	3	avg	1.0	0.1	0.7	32.7	1.0	1.1	-	2.6	0.6	0.8	5.2	54.3
					std	(0.2)	(0.0)	(0.1)	(0.2)	(0.1)	(0.1)		(0.1)	(0.1)	(0.3)	(0.4)	(1.0)
		g	d	2	avg	0.8	0.2	0.9	32.2	0.8	1.3	-	-	0.6	3.6	8.2	51.4
					std	(0.2)	(0.1)	(0.1)	(0.3)	(0.2)	(0.3)			(0.1)	(0.1)	(1.8)	(1.1)
		a	u	2	avg	0.6	0.6	4.8	34.5	1.9	4.9	0.1	-	2.0	-	0.2	50.6
					std	(0.0)	(0.1)	(0.3)	(0.5)	(0.1)	(1.0)	(0.1)		(0.0)		(0.2)	(0.4)
	PAL15	w	d	3	avg	2.6	0.6	3.0	41.2	2.1	3.0	-	0.2	0.9	1.2	6.7	38.5
					std	(0.5)	(0.1)	(2.0)	(2.4)	(0.8)	(0.4)		(0.2)	(0.3)	(1.2)	(3.0)	(4.3)
		b	d	4	avg	2.0	0.5	1.5	43.4	1.6	3.4	-	4.1	0.7	-	2.4	40.5
					std	(0.3)	(0.0)	(0.6)	(2.3)	(0.1)	(0.2)		(0.6)	(0.1)		(2.0)	(3.1)
		g	d	2	avg	2.0	0.7	1.3	41.1	1.5	3.7	-	-	1.0	2.3	4.9	41.6
					std	(0.1)	(0.0)	(0.2)	(0.3)	(0.1)	(0.0)			(0.1)	(1.3)	(1.4)	(0.2)
		a	u	2	avg	0.5	0.6	3.7	33.1	1.1	4.1	0.3	-	1.6	-	-	55.1
					std	(0.0)	(0.0)	(0.4)	(0.0)	(0.0)	(0.2)	(0.0)		(0.0)			(0.6)
	PAL27	w	d	2	avg	1.2	0.1	0.8	36.3	1.5	1.5	-	-	0.6	0.5	6.2	51.4
					std	(0.1)	(0.2)	(0.1)	(0.6)	(0.2)	(0.1)			(0.1)	(0.2)	(1.5)	(1.3)
		b	d	4	avg	1.6	0.1	0.8	33.7	1.1	1.0	-	2.2	0.6	1.9	6.6	50.4
					std	(0.2)	(0.1)	(0.3)	(0.3)	(0.1)	(0.2)		(0.6)	(0.1)	(0.3)	(1.1)	(1.0)
		g	d	2	avg	1.6	0.3	1.4	33.9	1.3	1.4	1.2	-	0.6	2.0	6.5	49.8
					std	(0.0)	(0.1)	(0.2)	(1.1)	(0.2)	(0.2)	(1.1)		(0.3)	(0.3)	(1.4)	(1.3)
		a	u	2	avg	0.7	0.4	3.9	33.4	1.9	4.1	0.2	-	3.0	-	0.5	51.9
					std	(0.0)	(0.3)	(0.1)	(0.1)	(0.0)	(0.1)	(0.3)		(0.1)		(0.3)	(0.0)
	PAL31	w	d	2	avg	1.9	0.5	1.2	38.9	1.4	1.7	-	-	0.8	-	9.2	44.5
					std	(0.1)	(0.1)	(0.0)	(0.0)	(0.1)	(0.1)			(0.1)		(0.2)	(0.2)
		b	d	2	avg	1.4	0.4	3.4	40.4	2.1	3.5	0.2	1.7	2.1	-	2.1	42.7
					std	(0.5)	(0.2)	(0.1)	(1.1)	(0.3)	(1.6)	(0.3)	(1.0)	(0.3)		(1.2)	(0.3)
		g	d	2	avg	1.8	1.0	1.9	39.2	1.4	2.8	-	-	1.1	2.9	2.1	45.9

				std	(0.1)	(0.1)	(0.3)	(0.4)	(0.0)	(0.1)							(0.1)	(0.2)	(0.4)	(0.2)
Palace MZ	a	d	2	avg	1.0	0.5	4.3	35.2	1.7	4.2	0.2	-	2.1	-	1.9	49.0				
				std	(0.1)	(0.1)	(0.0)	(0.2)	(0.0)	(0.3)	(0.3)		(0.3)		(0.2)	(0.1)				
	a	u	4	avg	0.6	0.6	4.6	33.1	1.9	4.5	0.1	-	2.2	-	-	52.5				
				std	(0.1)	(0.1)	(0.1)	(0.4)	(0.1)	(0.6)	(0.3)		(0.2)			(1.0)				
	w	d	2	avg	1.4	0.0	0.4	33.8	0.5	0.8	-	-	0.3	-	8.4	54.4				
				std	(0.0)	(0.0)	(0.0)	(0.5)	(0.0)	(0.2)			(0.0)		(0.3)	(1.1)				
	b	d	2	avg	1.4	0.2	0.5	32.7	0.4	0.7	-	1.9	0.3	-	7.0	55.1				
				std	(0.3)	(0.0)	(0.0)	(0.6)	(0.2)	(0.0)		(0.1)	(0.1)		(1.4)	(0.2)				
	g	d	2	avg	1.3	0.2	0.8	33.9	0.4	0.6	-	0.6	0.4	3.7	5.7	52.2				
				std	(0.1)	(0.1)	(0.4)	(0.1)	(0.1)	(0.2)		(0.3)	(0.0)	(0.5)	(2.3)	(1.7)				
	a	u	2	avg	0.6	0.5	4.0	33.7	1.6	4.1	0.4	-	3.0	-	-	52.5				
				std	(0.1)	(0.1)	(0.3)	(0.2)	(0.1)	(0.2)	(0.1)		(1.9)			(1.8)				
	w	d	2	avg	1.7	0.5	4.6	38.7	2.4	3.2	-	-	1.1	-	3.3	44.6				
				std	(0.1)	(0.2)	(0.1)	(0.5)	(0.4)	(0.0)			(0.1)		(1.8)	(1.3)				
	b	d	3	avg	1.6	0.2	2.5	38.0	1.7	1.9	-	3.3	0.8	-	4.1	45.8				
				std	(0.2)	(0.1)	(1.5)	(1.3)	(0.5)	(0.8)		(1.5)	(0.5)		(1.3)	(2.6)				
	a	u	2	avg	0.6	0.3	3.8	34.4	1.9	4.0	-	-	1.5	-	0.5	52.9				
				std	(0.1)	(0.0)	(0.5)	(0.2)	(0.0)	(0.3)			(0.1)		(0.5)	(1.4)				
	w	d	2	avg	1.9	0.3	0.1	32.1	1.1	0.9	-	0.1	0.0	-	16.5	46.3				
				std	(0.0)	(0.2)	(0.0)	(0.2)	(0.1)	(0.4)		(0.2)	(0.0)		(0.7)	(0.7)				
	b	d	2	avg	2.0	0.1	0.2	31.9	0.9	1.0	-	2.1	0.3	-	12.4	48.5				
				std	(0.4)	(0.1)	(0.2)	(1.9)	(0.2)	(0.2)		(1.9)	(0.1)		(1.7)	(0.8)				
	w	u	2	avg	2.4	0.3	0.9	32.8	0.9	0.7	-	-	2.2	-	11.5	47.9				
				std	(0.1)	(0.4)	(1.1)	(3.0)	(0.1)	(0.2)			(2.1)		(2.2)	(0.0)				
	w	d?	2	avg	1.6	0.1	0.1	33.5	0.8	0.7	-	-	0.2	-	9.3	53.6				
				std	(0.2)	(0.1)	(0.1)	(0.2)	(0.1)	(0.5)			(0.2)		(1.8)	(0.5)				
	a	u	2	avg	0.6	0.5	3.9	34.8	1.6	4.1	-	-	1.8	-	0.7	51.9				
				std	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.4)			(0.3)		(0.3)	(0.4)				
	w	d	2	avg	1.5	0.2	0.4	35.4	0.7	0.6	-	-	0.4	-	7.7	52.8				
				std	(0.1)	(0.1)	(0.5)	(0.9)	(0.1)	(0.4)			(0.3)		(1.7)	(1.0)				
	b	d	2	avg	1.3	0.1	0.3	34.1	0.7	0.5	-	3.0	0.1	-	6.8	53.0				
				std	(0.2)	(0.1)	(0.0)	(0.4)	(0.1)	(0.1)		(0.1)	(0.0)		(0.1)	(0.2)				
	g	d	2	avg	2.0	0.1	0.7	35.2	0.8	0.7	-	0.8	0.6	2.6	5.7	50.4				
				std	(0.9)	(0.2)	(0.0)	(1.0)	(0.1)	(0.3)		(1.1)	(0.1)	(0.5)	(1.5)	(0.1)				
	a	u	2	avg	0.2	0.2	4.3	35.2	1.7	4.0	0.2	-	1.8	-	0.3	51.9				
				std	(0.0)	(0.2)	(0.2)	(0.0)	(0.2)	(0.1)	(0.3)		(0.1)		(0.4)	(1.0)				

Table 6. Chemical composition of the Córdoba houses glazes determined by SEM-EDS (wt% normalised to 100 wt%). The data are the average over at least two analyses taken in different areas of the glazes.

¹ d-decorated, p-plain

² w- white, b- brown, g- green, h- honey,

Context	Samples	Colour	Side	n		NaO ₂	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	MnO	FeO	CuO	SnO ₂	PbO
Houses 1	IZ4	g	d	1		1.2	0.2	2.4	40.0	2.0	1.5	-	-	1.0	1.3	2.2	48.1
		b	d	2	avg	1.3	0.2	0.7	30.6	0.9	1.2	-	2.5	0.6	0.3	4.7	57.0
					std	(0.1)	(0.0)	(0.0)	(0.8)	(0.1)	(0.1)		(0.2)	(0.2)	(0.4)	(1.5)	(1.1)
	IZ5	w		2	avg	2.3	0.4	4.1	39.7	1.8	2.2	-	-	1.1	-	2.7	45.8
					std	(0.1)	(0.0)	(0.5)	(1.1)	(0.0)	(0.2)			(0.4)		(0.3)	(0.1)
		b	d	2	avg	2.1	0.3	2.7	37.7	1.2	2.0	-	2.0	1.0	0.4	4.1	46.5
					std	(0.5)	(0.2)	(1.6)	(2.4)	(0.4)	(0.1)		(0.4)	(0.0)	(0.6)	(3.3)	(1.2)
		g	d	2	avg	1.4	0.3	2.3	41.1	1.1	2.6	-	-	0.9	3.8	2.8	43.6
					std	(0.3)	(0.0)	(0.8)	(1.1)	(0.3)	(1.2)			(0.3)	(0.4)	(0.9)	(0.4)
	IZ2	a	u	2	avg	0.4	0.4	4.2	35.6	1.4	4.0	-	-	1.7	-	0.4	52.0
					std	(0.1)	(0.1)	(1.1)	(3.0)	(0.2)	(1.0)			(0.1)		(0.6)	(4.8)
		w	d	1		1.3	0.4	3.7	40.0	2.3	2.3	-	-	1.0	0.4	3.6	45.1
		b	d	3	avg	1.3	0.4	1.8	38.8	1.4	1.7	0.6	2.5	1.1	1.2	3.9	45.4
					std	(0.1)	(0.2)	(0.9)	(3.3)	(0.6)	(0.5)	(0.5)	(0.4)	(0.5)	(1.4)	(0.7)	(2.8)
	IZ3	g	d	2	avg	1.4	0.3	2.6	37.6	1.7	2.1	-	0.3	1.2	0.9	6.4	45.6
					std	(0.1)	(0.1)	(0.3)	(0.5)	(0.1)	(0.2)		(0.4)	(0.4)	(0.4)	(1.6)	(1.6)
		a	u	2	avg	0.5	0.6	3.7	33.3	1.9	4.4	0.1	0.0	1.8	-	2.7	51.2
					std	(0.2)	(0.0)	(0.0)	(0.5)	(0.0)	(0.0)	(0.2)	(0.0)	(0.1)		(2.4)	(1.9)
		w	d	2	avg	1.4	0.4	2.5	35.9	1.2	2.2	-	1.4	0.9	1.6	2.7	49.8
	IZ9				std	(0.2)	(0.0)	(1.6)	(2.4)	(0.4)	(0.3)		(2.0)	(0.1)	(1.3)	(1.6)	(0.1)
		g	d	2	avg	1.0	0.1	0.8	34.3	0.6	2.1	-	0.9	0.8	8.3	3.8	47.2
					std	(0.1)	(0.0)	(0.1)	(0.3)	(0.1)	(0.0)		(0.2)	(0.1)	(0.2)	(0.8)	(0.9)
		a	u	2	avg	0.5	0.5	2.9	31.1	1.3	2.4	0.2	-	1.4	-	1.7	58.2
	IZ11				std	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.7)	(0.2)		(0.0)		(0.6)	(0.4)
		w	d	2	avg	2.4	0.2	3.5	39.1	1.9	0.8	-	-	0.7	-	0.8	49.8
					std	(0.0)	(0.2)	(0.1)	(0.1)	(0.1)	(0.0)			(0.1)		(1.1)	(0.2)
		g	d	2	avg	1.6	0.1	0.9	32.8	1.1	1.9	-	-	4.4	2.6	2.9	51.7
	IZ13				std	(0.2)	(0.1)	(0.1)	(0.5)	(0.1)	(0.0)			(0.2)	(0.2)	(0.0)	(0.6)
		a	u	2	avg	0.5	0.3	2.8	31.2	1.4	1.9	-	-	1.4	-	0.4	59.6
					std	(0.2)	(0.2)	(0.7)	(0.6)	(0.0)	(0.1)			(0.1)		(0.6)	(0.0)
		w		1		1.2	0.3	2.8	37.3	1.3	3.0	-	-	1.3	-	3.0	49.8
	IZ13	w2		2	avg	1.4	0.4	3.1	36.6	1.3	2.7	-	-	1.2	-	3.1	50.4
					std	(0.2)	(0.1)	(0.3)	(0.7)	(0.1)	(0.3)			(0.1)		(0.1)	(0.5)
		w	d	2	avg	2.2	0.4	3.7	37.7	2.0	2.1	-	-	0.9	-	5.4	45.6
	IZ13				std	(0.0)	(0.0)	(0.4)	(3.4)	(0.2)	(0.0)			(0.3)		(3.6)	(0.0)
		g	d	2	avg	1.7	0.4	2.4	36.8	1.2	2.4	-	0.7	1.0	2.3	3.3	47.8
					std	(0.3)	(0.3)	(1.5)	(1.6)	(0.4)	(0.5)		(0.2)	(0.4)	(0.3)	(1.5)	(2.9)

Houses 2	IZ14	a	u	2	avg	0.9	0.4	3.3	36.8	1.8	3.6	0.1	-	1.3	-	2.0	49.7
					std	(0.0)	(0.2)	(0.0)	(0.1)	(0.1)	(0.2)	(0.1)		(0.0)		(0.1)	(0.8)
		w	d	2	avg	2.3	0.3	3.6	39.9	2.0	2.7	-	-	1.1	-	4.1	44.2
					std	(0.2)	(0.0)	(1.2)	(0.1)	(0.2)	(0.2)			(0.6)		(1.3)	(3.8)
		b	d	2	avg	2.4	0.3	3.7	39.8	2.2	2.0	-	0.7	0.8	-	4.0	44.1
					std	(0.0)	(0.2)	(0.0)	(0.0)	(0.2)	(0.0)		(0.1)	(0.1)		(0.8)	(1.3)
		a	u	2	avg	0.9	0.2	4.5	29.5	1.2	4.1	-	-	1.9	-	0.4	57.3
					std	(0.1)	(0.3)	(0.6)	(0.7)	(0.1)	(0.1)			(0.1)		(0.5)	(0.8)
	PM15	w	d	1		1.4	0.4	2.5	42.4	3.3	2.6	-	-	0.5	1.6	2.1	43.3
		g	d	2	avg	1.1	0.4	2.4	39.1	2.7	3.1	-	-	1.5	2.5	3.1	44.3
					std	(0.5)	(0.1)	(1.4)	(0.4)	(0.0)	(0.3)			(0.2)	(0.1)	(3.5)	(2.1)
		a	u	2	avg	0.6	0.5	3.6	33.3	1.9	2.0	0.2	-	1.7	-	0.5	54.1
	PM19				std	(0.0)	(0.1)	(0.4)	(1.4)	(0.1)	(2.8)	(0.3)		(0.0)		(0.5)	(2.2)
		w	d	3	avg	1.6	0.3	3.0	38.7	1.2	2.0	-	0.1	1.1	-	5.3	46.8
					std	(0.1)	(0.0)	(0.2)	(0.6)	(0.1)	(0.2)		(0.1)	(0.1)		(1.0)	(0.6)
		g-b	d	2	avg	1.6	0.4	2.8	40.6	1.4	1.8	-	0.3	1.1	0.6	3.1	46.5
					std	(0.1)	(0.1)	(0.0)	(0.6)	(0.1)	(0.0)		(0.1)	(0.0)	(0.2)	(0.1)	(0.6)
		g	d	2	avg	1.7	0.3	2.6	40.3	1.3	1.8	-	-	0.9	0.4	2.8	47.9
					std	(0.1)	(0.1)	(0.8)	(1.5)	(0.3)	(0.3)			(0.1)	(0.2)	(2.6)	(0.1)
		a	u	2	avg	0.7	0.7	4.1	34.3	1.3	4.1	0.2	-	2.1	-	0.7	51.9
					std	(0.0)	(0.1)	(0.1)	(0.2)	(0.1)	(0.4)	(0.2)		(0.0)		(0.1)	(1.0)

Figure captions

Figure 1. Plan of Córdoba, showing *Zumbacón* (*al-Fajarīn* pottery quarter) (1), *Alcázar* (2), *Ibn Zaydun* (3), *Piscinas Municipales Poniente* (4) and *Madīnat al-Zahrā'* (5) archaeological excavations in which glazed ceramics were found.

Figure 2. Tin-glaze debris analysed from the *Zumbacón* craft area: (A) Z13, (B) Z20, (C) Z46.

Figure 3. Representative tin-glazed ceramics from Córdoba -*Ibn Zaydun* (IZ), *Piscina Municipal Poniente* (PM), *Palacio Episcopal* (PAL)- and *Madīnat al-Zahrā'*: (A) tin-glaze closed form (IZ4), (B) tin-glaze with partial relief decoration (PAL31), (C) tin-glaze dish (PAL27), (D) tin-glaze dish (MZ453), (E) tin-glaze dish (PAL14), (F) characteristic Caliphal tin-glaze dish (VV.AA. 2015).

Figure 4. (A) Vessel containing a protective calcareous layer and calx (Z57). (B) and (C) Optical image of a cross section showing the red body, white-yellowish protective calcareous-rich layer and the white calx layer; (D) BSE-SEM image of the calx; (E) BSE-SEM image and (F) SEM-EDX spectra corresponding to a glassy area with tin oxide crystallites (blue) and with precipitates of lead carbonate (red); (G) OM detail image and (H) μ -XRD analysis of the protective calcareous layer.

Figure 5. (A) Rod kiln with tin stuck (Z21). (B) Optical image of the tin-glaze drop; (C) Optical image of quartz grains surrounded by lead; (D) BSE-SEM image detail of small tin- particles; (E) micro-XRD analysis of the tin-glaze showing the presence of cassiterite nanoparticles.

Figure 6. Optical images of the ceramic fabrics. (A) Oxidised paste showing large white lime nodules (IZ11); (B) quartz grains, micas and red/black iron rich nodules (IZ14); (C) detail of two large lime nodules in an oxidise paste (IZ9); (D) detail of a large red iron rich nodule (IZ14); (E) geological soil of Córdoba showing the lime nodules.

Figure 7. (A) Elongated red iron rich nodule with quartz grains; (B) semicircular holes imprints of burned fossils; (C) globigerina foram and (D) micro-fossils showing the characteristic transformation from calcite into ankerite (iron carbonate), the iron probably from initially pyrite deposits from bacteria living in the shells.

Figure 8. Bodies chemical composition plots; A) Al_2O_3 versus CaO , and B) SiO_2 versus CaO .

Figure 9. Polychrome glazes from *Madīnat al-Zahrā'*. Optical images of the glazes from (A) white, (B) green, (C) brown and (D) honey.

Figure 10. SnO₂ versus PbO of the white opaque glazes.

Figure 11 (A) Na_2O^* , (B) CaO^* and (C) $\text{K}_2\text{O}+\text{FeO}^*$ versus Al_2O_3^* . The glaze components are those determined renormalising after removing the PbO and SnO_2 content.