Polychrome glazed ware production in Tunisia during the Fatimid-Zirid period: New data on the question of the introduction of tin glazes in western Islamic lands

Elena Salinas[1], Paul Reynolds[2], Michael S. Tite[3] and Trinitat Pradell[1]

[1] Physics Department and Barcelona Research Centre in Multiscale Science and Engineering, Universitat Politècnica de Catalunya, Campus Diagonal Besòs, Av. Eduard Maristany, 10-14, 08019 Barcelona, Spain

[2] Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig de Lluis Companys 23, 08010 Barcelona, Spain; ERAAUB, Department de Prehistòria, Història Antiga i Arqueologia, Universitat de Barcelona, Carrer Montalegre 6 - 08001 Barcelona, Spain

[3] Research Laboratory for Archaeology and the History of Art, Dyson Perrins Building, South Parks Road, Oxford OX1 3QY, England

Abstract

The production of polychrome decorated ceramics began in *Ifriqiya* in the 9th century under Aghlabid rule, with continuity during the 10th century under the Fatimids. These comprised finely painted brown and green designs with a characteristic yellow background (a transparent lead glaze containing iron oxide). This production was substituted in the 11th century by a polychrome production over a white tin opaque glaze. The hypothesis stating that tin glazes were introduced in Tunisia after the Fatimids took over Egypt has been recently proposed. However, polychrome ceramics with a white opaque background have been found in 10th century archaeological sites which might indicate otherwise. A ceramic assemblage found at the site of *Bir Ftouha* dating from the *Fatimid-Zirid* period which contains polychrome with both transparent yellow and white opaque backgrounds has been analysed. The white opaque glazes do not contain tin but were opacified by the addition of large quartz particles. This study supports the theory that tin glazes reached Tunisia after the Fatimid occupation of Egypt and is the first step to answering many open questions regarding the spread of tin glaze in the Mediterranean, the role of the Fatimids and the connections of *Ifriqiya* with Islamic Spain and Sicily.

1. Introduction

Ifriqiya (including present Tunisia, western Libya and eastern Algeria) was probably the earliest production centre of polychrome glazed wares in the western Islamic lands of the Central and Western Mediterranean. This began during the 9^{th} century, under Aghlabid rule. Schematic geometric, epigraphic and bird designs were painted in green and brown colours with a bright yellow background. Carinated bowls were the most frequently decorated type of this ware which is known as 'Jaune de Raqqada', Raqqada yellow, due to the large number of these wares found at the Aghlabid palace of *Raqqada*, with an approximate dating of occupation of c. 868-921 CE (Gragueb 2017) (see Table 1 for the chronological relationship of the wares referred to in the Introduction). This polychrome glazed ware was made by applying manganese-brown and copper-green pigments under an iron-yellow lead transparent glaze (Ben Amara et al 2001). The ceramics underwent a double firing process, first with a biscuit firing of the ceramic and then, a second firing for the transparent lead glaze. A small polychrome glazed production with a white background, which has not been analysed, has also been associated with Raqqada ware (Gragueb 2011).

<Table 1 Chronology of Tunisian glazed ware>

The second most representative early polychrome glaze production is called 'Sabra glazed ware' because a large number were found in the Fatimid capital of *Sabra al-Mansuriyya* which was founded in 947/948 CE and continued under the Zirid dynasty (972-1057 CE). *Polychrome yellow glazed wares* and brown and green designs reproduced old and new patterns and shapes, incorporating the use of the human figure. In this case a lead transparent yellowish glaze and manganese-brown and copper-green pigments were also used, but the ceramics analysed so far were produced in a single firing (Ben Amara et al 2005).

The technological connections between Aghlabid *Ifriqiya* and other nearby Islamic territories have also been highlighted by many scholars; for example, Tahert in Central Maghreb (present Algeria) (Mokrani 1997) and Palermo in Sicily (Ardizzone & Nef 2014). Both show evidence of the local production of *polychrome yellow glazed* wares (Djellid 2011; Ardizzone et al 2017) which exhibit clear similarities with the Tunisian polychrome glazed wares. In the latter case, a brown and green with deep yellow background glazed ware known as *'giallo di Palermo'* was dated to the late 9^{th}-early 10^{th} centuries (Sacco 2017). It is accepted that polychrome glazed wares started to be produced in Sicily through the direct influence of Tunisian potters. The methods of production are the same than those identified for Raqqada Yellow, that is, underglaze brown and green decoration, double firing and a high lead transparent yellow glaze (Testolini 2018). It seems that the Tunisian influence continued in Sicily during the 10^{th} and 11^{th} centuries.

In parallel, a *polychrome with a white background* production has also been found; it is scarce in *Raqqada* while it seems be more abundant in *Sabra-al-Mansuriyy*a (Gragueb 2013). The white glaze surfaces appear rough and uneven, but its nature is unknown, since it has not been analysed. However, it is commonly assumed to be related to the presence of tin oxide (i.e.

Daoulatli 1995), and hence to other contemporary products, such as the Abbasid tin-opaque wares of Iraq and the 'verde y manganeso' (brown and green decorated tin-glaze) wares of *al-Andalus* (Islamic Spain and Portugal) (Salinas & Pradell 2018a). In fact, for a long time the Tunisian polychrome white ware has been considered the predecessor of the Andalusi 'verde y manganeso' tin-glaze ware of the Caliphate period (929-1031 CE) and the access route of tin-glaze technology into the Western Mediterranean Islamic regions (Rosselló 1995). However, recently, the beginning of the tin-glaze technology in *al-Andalus* has been dated earlier than was previously thought; that is, during the late Emirate period (c. 875-929 CE) (Salinas 2013; Salinas & Pradell 2018a), therefore making it contemporary with the 'Jaune de Raqqada' (Daoulatli 1994).

In a recent paper, we have argued that the tin-opaque white glaze and the lead antimonate yellow came from Egypt after the conquest of Egypt by the Fatimids (969 CE) (Salinas et al 2019). The Fatimids founded a new capital in Egypt, al-Qahira (972 CE), leaving *Ifriqiya* to be governed by the Berber Zirids (972-1048 CE) that continued with the seat in *Sabra al-Mansuriyya*, before moving to Mahdia in 1057 CE. Consequently, we argued that tin glaze wares could not have been produced in Tunisia before 969 CE.

In good agreement, local plain white tin-glazed, turquoise, and lustre wares found in *Sabra al-Mansuriyya* (Capelli et al 2011) (absent in our BFA assemblage) have been dated by radiocarbon to c. 1018-1157 CE (Cressier & Rammah 2007). On the one hand and contrary to what was thought before, our data and argument implies that tin glaze technology reached *al-Andalus* a century earlier than *Ifriqiya* and, on the other hand, and considering the direct connection between *Ifriqiya* and Islamic Sicily, that polychrome tin glazed wares were produced neither in Tunisia nor in Sicily before the very late 10th or early 11th centuries.

The existence of a 9th-10th century production of polychrome with white background in *Raqqada* and in *Sabra al-Mansuriyya* puts into question our theory. However, this ware has not yet been analysed and, consequently, the nature of the glazes and methods of production are still unknown. Thus, its analysis is the first step to answering many still open questions regarding the spread of tin glaze in the Central and Western Mediterranean during the Early Middle Ages, together with the role of the Fatimids in this technological transfer and the possible connections with Islamic Spain and Sicily.

The aim of this paper is to clarify some of these questions by studying a glazed ceramic assemblage dating to the second half of the 10th–early 11th centuries, found in the archaeological excavations of *Bir Ftouha*, near Carthage in Tunisia (Rossiter et al 2012). This assemblage contains both polychrome wares with yellow and white backgrounds and their analyses will provide the first data to shed some light on the beginning of polychrome opaque wares in the Central Mediterranean.

<Figure 1. Map of Tunisia and location of Bir Ftouha and other places mentioned in the text>

2. Materials and Methods

2.1. The Pottery from *Bir Ftouha*

Bir Ftouha is a site located 1 km northwest of Carthage. During the archaeological excavations a large Byzantine church and later Islamic occupation associated with a number of deep (grain) silos were found. These silos, after disuse, were filled with a dark carbon-rich organic soil, animal bones and pottery (Rossiter et al 2012).

The pottery recovered from *Bir Ftouha* was dated to the late 10^{th}-early 11^{th} centuries, and includes not only glazed wares, but also amphorae, cooking wares, unglazed plain wares and *sāqiya* irrigation pots (Reynolds 2012). Taking into consideration later archaeological excavations on a much larger scale of the same site, including more Islamic period silos (Stevens, Kalinowski & vanderLeest 2005; Kalinowski 2005), as well as earlier work on Islamic pottery in the Carthage area (i.e. Vitelli 1981), a typology based on forms and fabrics was determined. Different origins were proposed for the pottery: a north-western Tunisian provenance for the handmade cooking ware, Central Tunisia (the region of Kairouan, Raqqada and Sabra al-Mansuriyya) for the glazed wares and unglazed small carinated bowls, and a largely Sicilian provenance for the amphorae as well as some of the unglazed table wares and the irrigation pots.

A total of fourteen glazed sherds are here studied from *Bir Ftouha*: ten polychrome sherds and four monochrome~~s~~ (three yellow and one brown). They show differences regarding forms, colours and patterns. All the sherds and drawings of the shapes are represented in the **Figures 2** and **3**.

Following Reynolds' typology (Reynolds 2012), two main groups of glazed ware forms can be distinguished: carinated and open bowl forms. The carinated bowls have a short in-bent upper wall and, among them, two subtypes have been documented, corresponding to two different glazed wares: one with a rounded rim and somewhat irregular features (Glazed Bowl 1, **Fig. 2A-D**: in Raqqada Decorated Ware), the second, carinated with sharp features and a slightly pinched top rim (Glazed Bowl 7, **Fig. 3H**: in Sabra Plain Yellow Glaze Ware). The open bowls, all classified by Reynolds as Sabra products, decorated and plain, are primarily simple open shapes with an everted upper wall and plain rolled or pointed rim, a 'classic' Fatimid shape later also found in greenish-turquoise version (e.g. in Utica) (Glazed Bowls 3 and 4, **Fig. 3E**) or, occasionally, with a vertical rim (Glazed Bowl 5, **Fig. 3F**). Finally, a single hemispherical bowl with a ring foot and brown glaze was also identified (Glazed Bowl 8, **Fig. 3J**).

< Figure 2. Bir Ftouha: Analysed glazed sherds>

<Figure 3. Bir Ftouha: Analysed glazed sherds (except top vessel bearing human figure decoration, not analysed: Reynolds 2012, fig. 22) >

Nevertheless, the assemblage is not well preserved and sometimes it is difficult to pinpoint the decoration or the original colour of the background. The range of colours identified for the background are white, bright yellow, pale yellow, cream and honey, while green and brown are used for the decoration. The decorative patterns vary between splashed, geometric, vegetal, and one human figure that could not be sampled (**Figure 3, top**).

After studying them the sherds have been classified into three groups: monochrome transparent glazes, polychrome transparent glazes and polychrome opaque glazes. The polychrome transparent glazed wares correspond to those designated previously by the archaeologist (Reynolds) as *polychrome with a yellow background* while the polychrome opaque glazed wares to those designated as *polychrome with a white background.*

<Figure 4. Representative glazed ceramics from *Bir Ftouha*>

2.2. Analytical techniques

Polished sections through the glazes and into the bodies of the sherds were prepared. The polished sections were examined both in reflected light (Bright and Dark field) with an optical microscope Nikon Eclipse LV100D equipped with a camera Infinity 1.3C and in a SEM with attached EDS. A crossbeam workstation (Zeiss Neon 40) equipped with SEM GEMINI (Shottky FE) column and EDS (INCAPentaFETx3 detector, 30mm^2, 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.

The chemical compositions of the bodies were determined by analysing at least one area, about 3 mm x 2 mm. Because of the porosity of the bodies, typical paste totals were about 60-65% and therefore, 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. As a result, the glaze totals varied between 97% and 99% mainly due to the variable state of preservation of the glazes, and therefore, the analyses were averaged without normalisation. A selection of the non-plastic inclusions within the bodies, and opacifiers and other particles in the glazes were also analysed. An EDS elemental microanalysis system calibrated with oxide and mineral standards and a high lead glass - K229- was used to determine the composition of the bodies and glazes (Geller Microanalytical Laboratory, MA, USA). Typical detection limits are 0.1% for Na, Mg, Al, P, K, Ca, Ti, Mn and Fe, 0.5% for Si and Cu, 0.3% for Sn and Sb and 0.4 for Pb.

3. Results

The chemical compositions of the bodies, obtained by SEM-EDS, and the paste type attribution after Optical and SEM investigation of the ceramic pastes are included in **Table 2**. The chemical compositions of the monochrome glazes are given in **Table 3,** those of the polychrome transparent in **Table 4,** and those of the polychrome opaque in **Table 5**.

3.1. Body composition

The ceramic bodies are all made of high calcareous clay (above 20% CaO) with a relatively high content of iron oxide (5-6% FeO) and titanium oxide (≈1% TiO_2), and low potassium (below 1% K_2O), sodium (about 1.5% Na_2O) and magnesium oxide (≈ 2% MgO). They show round quartz grains (**Figure 5A**), round and elongated porosity with white rims **Figure 5B** and **5C**), relics of foraminifera micro-fossils (**Figure 5D**, **5E**, **5F** and **5G**) and of burn-out straw fragments (**Figure 5H**). The porosity is most likely related to burnt-out lime inclusions, and the white rims are the reaction of the lime with the clay. The foraminifera micro-fossils present burnt out shells and they appear filled with clay (**Figure 5D**, **5F** and **5G**), raw materials from the ceramic workshop used to produce the glazes such as lead and copper (**Figure 6E**) and spherical 'bags' rich in iron oxide probably due to anaerobic bacteria (**Figure 5F**, **5G** and **5H**).

<Table 2. Bodies analysis>

<Figure 5. Fabric details>

In spite of similarities in chemical and mineralogical-petrographic composition, two types of fabrics are distinguished on the basis of colour; Type A has reddish colour with a creamy coloured surface layer (**Figure 6A** and **6B**) and Type B has creamy-greenish colour throughout its thickness (**Figure 6C** and **6D**). The relatively thick creamy coloured surface layer associated with Type A has the same composition as that of the bulk ceramic body and is most probably related to the use of salt water in forming the ceramic. During drying the salt migrates to the surface, enhancing the reactivity between the lime and the clay, and thus the development of calcium silicates and alumina-silicates together with a glass phase, both of which may incorporate iron and reduce the iron available to form iron oxides (Molera et al 1998). Consequently, a more compact and lighter coloured ceramic layer is produced. This process of production (the use of salt water) has an old tradition in the region (Peacock 1984).

The presence of this white layer must be associated with the biscuit firing of the ceramic before applying the glaze. In contrast, a single firing process for both the bodies and glazes will result in less oxidising conditions with the consequent formation of more reduced iron ions (Fe^{2+}). Reduced iron is also known to behave like a flux, favouring the formation of a silicate liquid and increasing the reactivity between lime and the clay. This is expected to reduce the red colour associated with haematite (iron oxide), and produce instead a greenish colour due to the increased vitreous phase incorporating reduced iron ions. Nevertheless, it cannot be certain that the salt whitening procedure was used in the case of fabric B case and therefore the use of a double firing cannot be completely ruled out. We have to mention that, the sherds have been buried or kept in silos and some appear blackened by the action of anaerobic bacteria, thus making it difficult in some cases to clarify which was the original colour of the ceramic.

<Figure 6. Fabric types>

The differences between both fabrics may be related mainly to the firing, but a double firing is certainly required for Type A.

The composition of ceramics and the presence of round quartz grains, lime and foraminifera micro-fossils are fully compatible with the early cretaceous fossiliferous clays with intercalations of micritic limestone and sandstone across the north eastern and central area of Tunisia (Zouaghi et al 2011, Melki et al 2012). The presence of many brine lakes in the area is also consistent with the use of salt water in the production of the ceramics.

The ceramic fabrics belonging to those ceramics found in *Raqqada* and *Sabra*, the analyses of which have been presented in the literature (Ben Amara et al 2001; 2005), are described as containing as main constituents quartz rounded particles and a porosity resulting from burned-out lime inclusions, and as being compatible with the clays of the Kairouan area. They are therefore similar to the ceramic fabrics of our sherds. The *Sabra al Mansuriyya* fabric was slightly CaO richer and SiO_2 poorer than that of *Raqqada* (Ben Amara et al 2001; 2005). Conversely, the *Bir Ftouha* ceramics are again slightly calcium oxide richer and silica poorer (24±3 CaO and 51±3% SiO_2) than those from *Sabra al Mansuriyya* (19±2 % CaO and 58±3% SiO_2) (Ben Amara et al 2005). This could suggest a progressive increase in the lime and a decrease in the quartz content between the 9th and the end of the 10th century, although a wider study is required to draw solid conclusions on the subject.

3.2 Monochrome glazed ware

The monochrome glazed wares analysed are transparent yellow, with one exception which is an *unicum* in the BFA assemblages, a transparent brown (BFA78) (**Figure 3J**). All the yellow glazed wares have Type B ceramic fabric and show very thick interfaces full of crystallites (mainly calcium and sodium alumino-silicates) **(Figure 7**) compatible with a single firing. The higher presence of Na, Al, Ca, K and Fe in the glazes also supports the argument that there was a single firing process in their production. In contrast, the brown glazed ware is double-fired, has Type A ceramic fabric and a thin interface **(Figure 7G**, **7H** and **7I**). The chemical analyses of the glazes are shown in **Table 3,** and indicate that they are all high lead glazes, 51-64% PbO with about 1.5 % FeO for the yellow glazes, and 66-67% PbO with 0.8% MnO and 0.3% FeO for the brown glaze. The yellow glazes have the tendency to peel off from the ceramic body as is shown in **Figure 7B** and **7C**. This may be explained by the cracks parallel to the surface that are seen at the interface.

<Table 3. Glazes analysis of the Monochrome glazed ware>

<Figure 7. Plain glaze wares>

3.3 Polychrome transparent glazed ware

As shown in **Table 4,** all these glazes are of the high lead type (60%-67% PbO) and of similar composition to that of the plain glazed wares (**Table 3**). Although most of them are double-fired and have type A fabric, two (BFA23 and BFA53A) have type B fabric. BFA23 (**Figure 3C**) shows thick uneven interfaces as can be seen in **Figure 8 B, C,** and **D**, which is compatible with a single firing.

The brown and green decoration seems to have been applied overglaze (the decorated areas of some of the samples have thicker glazes or even forming protrusions) (**Figure 8B** and **8F**) and the colourants, copper for the green and manganese for the brown, are absent from the interfaces below, as shown in **Figure 8A** and **8D**. Nevertheless, in some cases it is difficult to be certain, as the colourants are completely dissolved in the glaze. The brown and green areas of the glazes show frequent quartz grains **(Figure 8B**). The addition of quartz increases the viscosity of the melt, reducing the spreading of the colour. The yellow areas appear mainly free of quartz grains and are thinner. Associated with the copper, zinc and also tin have been determined in those glaze areas richer in copper, suggesting the use of brass as a copper pigment (Ponting 2008).

<Table 4. Glaze analysis of the polychrome transparent glazed ware>

<Figure 8. Polychrome transparent glazed wares>

There is one exception, BFA53A (**Figure 2D**), with an underglaze decoration with crystallites of manganese and copper along the interface, **Figure 8G**. The brown areas show the presence decomposing manganese oxide particles surrounded by growths of kentrolite (manganese lead silicate, $Pb_2Mn_2Si_2O9$) crystallites, **Figure 8H**. The manganese oxide, originally pyrolusite (MnO_2) is reduced at the same time that it reacts with the surrounding glaze; kentrolite is formed at the edge of the manganese oxide particles due to the reaction with the lead glaze. The presence of kentrolite indicates a firing temperature below 950ºC (Molera et al 2013; Pradell & Molera 2020).

The glazes of the ceramics found in *Raqqada* and *Sabra al Mansuriyya* (Ben Amara et al 2001 and 2005) were of the high lead type (57 ±5 PbO, 41 ±4% SiO_2, 1.0±0.3% Na_2O, 0.4 ±0.2% MgO, 3.4 ±1.0 % Al_2O3, 1.8 ±0.5% K_2O, 1.9 ±0.8% CaO, 2.1 ±0.6% Fe_2O_3). They contain higher alkali (≈ 3 % compared to ≈ 1 %), higher silica (≈40% compared to ≈ 30%) and lower lead oxide (≈ 50% compared to ≈ 64%) than the glazes from *Bir Ftouha*. They also contain a higher amount of iron oxide, which gives a deep yellow colour to the glazes, while the *Bir Ftouha* yellow glazes have less iron oxide and, consequently, show a lighter yellow colour. The brown and green colours are also due, respectively, to the manganese (1.2±0.5% MnO) and copper (2.1±0.9% CuO) in *Raqqada*. Although the data for *Sabra al Mansuriyya* glazes is not given, Ben Amara states (Ben Amara et al 2001; 2005) that the overall amount of copper is higher (3.6±0.1% CuO) than in the *Raqqada* glazes. The absence of developed interfaces in the *Raqqada* glazes and the presence of thick interfaces in the *Sabra al Mansuriyya* glazes was related to a change from double to single firing (Ben Amara et al 2001; 2005).

<Figure 9. Aghlabid polychrome glazed sample >

Although the method of application of the decoration is not commented in the Ben Amara paper (Ben Amara et al 2001), the fine lines of the designs suggest underglaze application and double firing, at least in the *Raqqada* ceramics. In order to assess this, we have also studied one sherd belonging to a private collection (CS66), which has the ceramic fabric, yellow glaze and brown and green designs characteristic of the classic *Raqqada* ware. The ceramic fabric shows the characteristic quartz round grains, elongated pores of burned out lime and some fossils (mainly orbulines). The glazes are of lead-alkali type (50.0 ±0.9 PbO, 39.7 ±1.0% SiO_2, 0.8±0.1% Na_2O, 0.3 ±0.1% MgO, 4.2 ±0.3% Al_2O3, 1.2 ±0.2% K_2O, 1.4 ±0.5% CaO, 1.4 ±0.2% FeO,) like those determined by Ben Amara, and contain about 1.2% CuO and 1.2 % MnO in the colour decoration. The SEM-BSE images of the glazes (**Figure 9**), in particular those related to the brown-coloured area, show that the decoration was applied underglaze and the objects submitted to a double firing.

3.4 Polychrome opaque glazed ware

The glazes contain large amounts of quartz grains as can be seen in **Figure 10A,** particularly high in the white areas, and the brown and green decorations are applied overglaze (**Figure 10B** and **Figure 10C**). Consequently, the coloured areas of the glaze are thicker than the white areas, as is seen in **Figure 10A**. The coloured areas contain less quartz than the white opaque glaze and contain also crystallites related to the colour pigments.

Nevertheless, due to the large amount of quartz present, it is very difficult to obtain a reliable average analysis of the glazes. For this reason we decided to analyse the vitreous areas avoiding the quartz particles. As the decorated areas have the coloured glaze on top and the white glaze below, in some cases both the colour glaze and the white glaze below have been analysed.

All the glazes are high lead but contain much less potassium, calcium, aluminium and iron than the polychrome or the plain transparent yellow glazes, in many cases at the limit of detection of the EDS. The interfaces are thin and flat (**Figure 10A** and **Figure 10B**), characteristic of a double firing process, and the fabrics are all of Type A (biscuit fired).

Manganese and copper are used respectively for the brown and green decoration. Manganese oxide grains appear not to be fully dissolved and crystalline growths of kentrolite are developing around them, as can be seen in **Figure 10B**, **Figure 10D** and **Figure 10E**. Zinc sometimes has been determined in those green glaze areas richer in copper which suggests the use of brass as copper pigment.

<Table 5. Glazes analysis of the polychrome opaque glazed ware>

<Figure 10. Polychrome opaque glazed ware>

The data obtained shows that these white glazed wares are actually opaque, but that the opacification was accomplished by adding large quartz particles, rather than tin oxide particles SnO_2. This method of opacification was not new, having been previously used in the pre-Islamic period (Mason and Tite 1997; McCarthy 1996).

3.5 Method of glazing

Considering that all the glazes, and in particular the transparent glazes, are of a high lead type, it is possible that PbO was applied directly to the surface of the ceramic body, a technique common in the production of Roman lead glazed wares (Walton & Tite 2010). To investigate this possibility, the SiO_2 and Al_2O_3 contents of the glazes were renormalized after subtraction of the PbO contents, and were compared to those of the ceramic bodies, the data obtained being plotted in **Figure 11**. The unity slope line (i. e., dissolution line) corresponds to a glaze obtained by the reaction of the ceramic body with PbO alone. The plot shows how that possibility can be excluded and, on the contrary, all transparent and opaque glazes were produced with a mixture of PbO and SiO_2. It is interesting to see that all the transparent glazes (plain yellow and polychrome) group together while the glassy areas of the opaque glazes group together with the plain brown transparent glazed sherd (BFA78) (fig. S2j). The vitreous phase of the opaque glazes and the brown transparent glaze contains a higher amount of SiO_2 (about 30% more) and lower of Al_2O_3 (about 40% less) than the transparent glazes, which indicates a lower reactivity between the glaze and the ceramic and consequently is consistent with a double firing process.

<Figure 11. Bodies-glaze composition>

When compared to the opaque glazes, the transparent glazes contain larger amounts of Al_2O_3 and lower of SiO_2, and are closer to the dissolution line. In contrast, the transparent and opaque glazes contain similar amounts of CaO+MgO. Moreover, the good correlation between Al_2O_3 and FeO content of the glazes suggests that the higher amount of Al_2O_3 in the transparent glazes might be related to the addition of iron-rich clay to give the yellow colour of the glazes.

We can therefore conclude that transparent glazes were also made of a mixture of lead oxide and sand, to which some iron rich clay was added to give the yellow colour.

4. Discussion

The results obtained so far demonstrate that the *polychrome with a yellow background* glazed wares from *Bir Ftouha* were obtained using an iron-enriched yellow transparent lead glaze similar to the earlier Raqqada yellow and Sabra yellow products. Nevertheless, some differences may be highlighted: on the one hand the glazes are richer in lead oxide (≈65% PbO) than those of the earliest productions (≈50% PbO) (Ben Amara et al 2001). On the other hand, the brown and green decorations seem to have been applied overglaze, at least in most of the sherds studied by us, in contrast to the earliest products of the Aghlabid period, where the decoration was applied underglaze. It is important to note that the ceramics sampled by Ben Amara from *Raqqada* and *Sabra al-Mansuriyya* are different in decorative schemes and colours to the glaze products at *Bir Ftouha*, hence are earlier in date.

The plain glazes of *Bir Ftouha* were produced most likely following a single firing. This simplification in the glaze production (from double to single firing) was reported also for the polychrome yellow ceramics from the *Sabra al-Mansuriyya* site (Ben Amara et al 2015). Our data confirms that this practice continued for the plain yellow ware during the *Fatimid-Zirid* period.

The *polychrome with a white backgro*und glazed wares are opaque, but the opacity was achieved by adding large amounts of quartz particles with the brown and green decoration applied overglaze. All them were produced using a double firing process. The application of the pigments overglaze was necessary because the dissolving quartz particles produce a high viscosity melt with a reduced diffusivity. In contrast, the addition of tin (Sn^{2+}) is known to reduce the viscosity of the melt and increase the diffusivity of the colourants. This means that most probably the overglaze application of the pigments was rather a technical necessity than a choice. Therefore, a substantial change in the Tunisian glaze tradition has been detected which does not seem to be due to external influences, but instead to a technological response to the need of the Tunisian potters to adapt to the possible lack of-knowledge regarding the use of the tin-glaze technology (calx recipe). It is important to emphasise that polychrome tin-glaze wares were being produced at that time in nearby Islamic regions, such as Egypt and *al-Andalus*.

In the case of the polychrome transparent glazed wares, the addition of quartz particles in the areas of brown and green glaze is quite limited and, as we indicated before, was probably in order to locally increase the viscosity and avoid the spread of the overglaze colorants. It seems to indicate some kind of connection between the opaque and the transparent glaze ware products. The underglaze decorated example (BFA53A) (**Figure 2D**) could therefore be a reminder that the underglaze technique continued in one of the workshops in the Kairouan region, in central Tunisia.

Therefore, on the one hand, there is a change in the way of applying the decoration after the Aghlabid period while, on the other hand, the technique of adding salt water to the clay is a continuation of a long tradition dating back to Punic and Roman pottery production in Tunisia (very clear in the white surfaces of certain amphorae produced on the coast), that continues to the present day (Peacock 1984). Salt water, whether from the sea or inland salt lakes, was used for clay preparation where it was readily available, not only for convenience but in order not to waste valuable drinking water. The white surfaces of the Roman amphorae, when fired, furthermore, could serve also as a perfect background for written information on the contents (epigraphic dipintos) or provided very pale surfaces well suited for the cooling of liquids in the case of ceramic water or wine jugs, the latter being equally the case for Islamic versions of these closed forms produced in Tunisia.

The existence of one or more workshops or production areas cannot be deduced from the limited sampling available, and the lack of other published analyses of contemporary Tunisian glazed assemblages for comparison. Nevertheless, the large variation in vessel forms and types of decoration (plain, polychrome transparent and opaque) indicates different purposes, a demand for ceramics of various qualities, in the case of the large dishes with figures as luxury and more expensive items, and could also denote several production sites.

Some relationship can be established between previous shape and fabric classification (Reynolds 2012) and our technological body Types. Type A is mainly composed of large open bowls (Reynolds Glazed Bowl 4.1 and 4.2) (Reynolds 2012, figs. 29, 31) and small carinated bowls with rounded rims (Reynolds Glazed Bowl 1, **Fig. 2A-D**). Type B includes mainly larger carinated bowls with in-bent upper wall and flattened rim top (Reynolds Glazed Bowl 7, **Fig. 1H**) and a thin-walled bowl with turned foot and concavity under base (Reynolds Glazed Bowl 8, **Fig. 1J**). Moreover, all the decorated wares, previously classified as Sabra or Raqqada and the Plain Brown glaze are Type A, while the Sabra Plain Straw Yellow Glaze wares are Type B.

Previously all the glazed wares were related to the same regional fabric, Fabric 3 (Reynolds classification), and a Central Tunisian origin was proposed. Our archaeometric analyses point also to a Tunisian origin with the differences between Type A and B being technological. Therefore, considering that Carthage was not a production centre but a consumption centre in the late 10th-early 11th centuries, the Kairouan area, including *Raqqada* and *Sabra al-Mansuriyya*, most probably remained the main production centre of glazed ware during the *Fatimid-Zirid* period.

The results obtained so far back up the previously proposed theory that tin glaze technology did not reach Tunisia before the Fatimids took over Egypt.

5. Conclusions

The ceramics studied were recovered from silos located in *Bir Ftouha.* All of them have a contemporary dating of the late 10th -early 11th century. All have calcareous clay fabrics with a similar chemical composition and contain quartz round particles, burned out lime inclusions (porosity) and foraminifera microfossils. The fabrics are fully compatible with the early cretaceous fossiliferous clays with intercalations of micritic limestone and sandstone found across the north eastern and central area of Tunisia. Two fabric types are here now distinguished, *Type A* with a characteristic whitened surface and red clay probably produced by adding salt water and biscuit firing before glazing. *Type B* showing a homogeneous creamy-greenish colour which could be obtained following a single firing of ceramic and glaze. Both types of ceramic fabrics are also documented (Louhichi 2003) in Sousse during the Fatimid period. At this point, it is not possible to determine if the ceramics belong to one or more workshops or identify their more precise location, though a source close to Kairouan is likely, since contemporary workshops have not been discovered so far –the production waste found in Sabra is later- and compatible clay sediments are widely spread in many places in Tunisia. Here, another ongoing project focusing on the Islamic pottery of Bir Ftouha and excavated Islamic 10th

to 11th century ceramic sequences in Utica (Tunisia), aims to clarify more definitively the sourcing of the glazed wares, plain wares and amphorae, most of the pottery being common to both sites, through petrology and chemical analyses of over 200 samples from these sites and comparison with present knowledge of Roman and Islamic production sites and fabrics across Tunisia and Sicily.[1]

Nevertheless several different glazed ware products are identified:

1. *Polychrome transparent yellow glazed* wares with carinated shapes similar to the earliest Aghlabid products continued being manufactured. However, some important differences can be identified; on the one hand the glazes are richer in lead, the yellow glazes contain less iron and the brown and green decorations were applied overglaze in most of the cases. The ceramics were produced following a double firing process.

2. *Monochrome yellow transparent glazed wares* with carinated and other shape bowls, a glaze composition matching those of the Polychrome transparent yellow glazes and probably manufactured following a single firing process.

3. *Polychrome opaque white glaze ware*. This is characterised by larger open dishes, with more complex brown designs coloured in green. The opaque glazes are obtained adding large quantities of quartz particles which remain mainly undissolved in a high lead glaze with the decorations applied overglaze. The ceramics were produced also following a double firing process.

4. *Monochrome brown transparent glazed* ware. A single small bowl (BFA78) (**Figure 3J**) has a glaze composition matching those of the polychrome opaque white glazes and was produced following a double firing process.

Some important novelties appear in the *Fatimid-Zirid* period; that is, a change in the glaze composition from ≈50% PbO to ≈65% PbO, the overglaze application of the decoration and the diversification of the ceramic production (polychrome opaque yellow and white glazes, monochrome transparent and brown transparent glazes).

The polychrome and monochrome transparent yellow glazed wares show shapes, colours and simple decoration, some of which recall earlier Aghlabid production and denote the continuity of a long-established ceramic tradition. In contrast, the new polychrome opaque white glazed wares decorated a new shape, a large open dish, which, related to a new design of tableware, was an innovation. Nevertheless, the most striking novelty is the use of quartz as an opacifier, contrary to earlier and contemporary wares of the Middle East as well as those of *al-Andalus,* at the other end of the Mediterranean, which used tin as an opacifier (Salinas & Pradell 2018a).

Again in contrast, the identification of two polychrome decorated carinated bowls found in a 10th century context in Palermo also bearing a polychrome decoration over a quartz opaque lead

[1] The project *Early Islamic ceramics and culture in Tunisia: chronologies, sources and vessel use*, directed by Paul Reynolds, is funded by a grant from the Barakat Trust (2019-2022). The petrology will be undertaken by Claudio Capelli, the chemical work by the ERAAUB (University of Barcelona).

glaze and with a calcareous ceramic fabric (Arcifa & Bagnera 2017, fig.19.5; Testolini 2018, appendix 2: 24-25), suggests that tin was not used in Sicily either. However, a more extensive study is required in order to verify the chronology and extension of this tin-free production.

The lack of local/regional tin ores in Tunisia may be responsible for the absence of tin in the white opaque production. Consequently, the potters had to find alternative methods for obtaining a white opaque background for the polychrome decoration. It is also possible that the use of quartz particles for the opacification was responsible for the change from underglaze to overglaze painting, a technique which might have also been transferred to polychrome yellow glazed wares.

The lack of tin in the second half of the 10th century polychrome glazed wares in Tunisia is in good agreement with our prior hypothesis that tin glazing did not reach *Ifriqiya* before the Fatimid conquest of Egypt (969 CE) (Salinas et al 2019). The transfer of the Fatimid Caliphate seat from Kairouan (Tunisia) to al-Qahira (Egypt), where tin glazed wares were produced, was the means by which tin technology reached Tunisia.

We should mention that after the collapse of the Umayyad Caliphate in *al-Andalus*, at the beginning of the 11th century, the Fatimids took control of the Mediterranean Sea routes, and tin trade started across the Mediterranean, as is documented in the Geniza archive (Goitein, 1973: 293; McSweeney 2011).

Acknowledgments

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Figure captions

Figure 1. Map of Tunisia and location of *Bir Ftouha* and other places mentioned in the text.

Figure 2. Bir Ftouha: Analysed glazed sherds.

Figure 3. Bir Ftouha: Analysed glazed sherds (except top vessel bearing human figure decoration, not analysed: Reynolds 2012, fig 22).

Figure 4. Representative glazed ceramics from Bir Ftouha: (A) yellow monochrome (T4), (B) brown monochrome (BFA78), (C) polychrome yellow (T6), (D) polychrome white (53B).

Figure 5. (A) Small quartz grains and porosity of BFA57; (B) white reaction rims around pores of fired lime inclusions of BFA23; (C) Calcium carbonate crystallites growing inside pores (BFA59); Micro-fossils with the shells completely burned out (D) orbulinas (T2), (E) miliolida filled with material from the workshop (T3), (F) miliolida filled with sediment (T3), (G) orbulinas (T1) showing iron rich oxide spheres corresponding to bacteria; and (H) burned out straw showing some calcium phosphate precipitates (BFA22).

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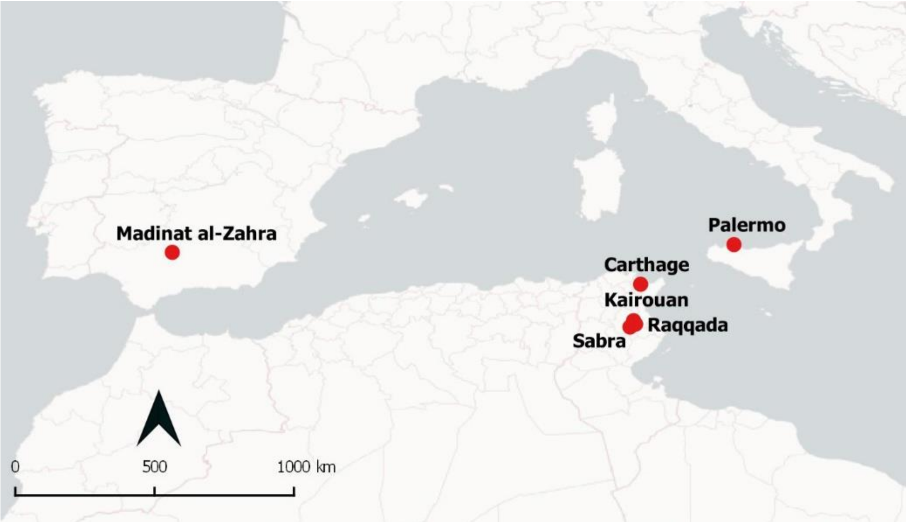

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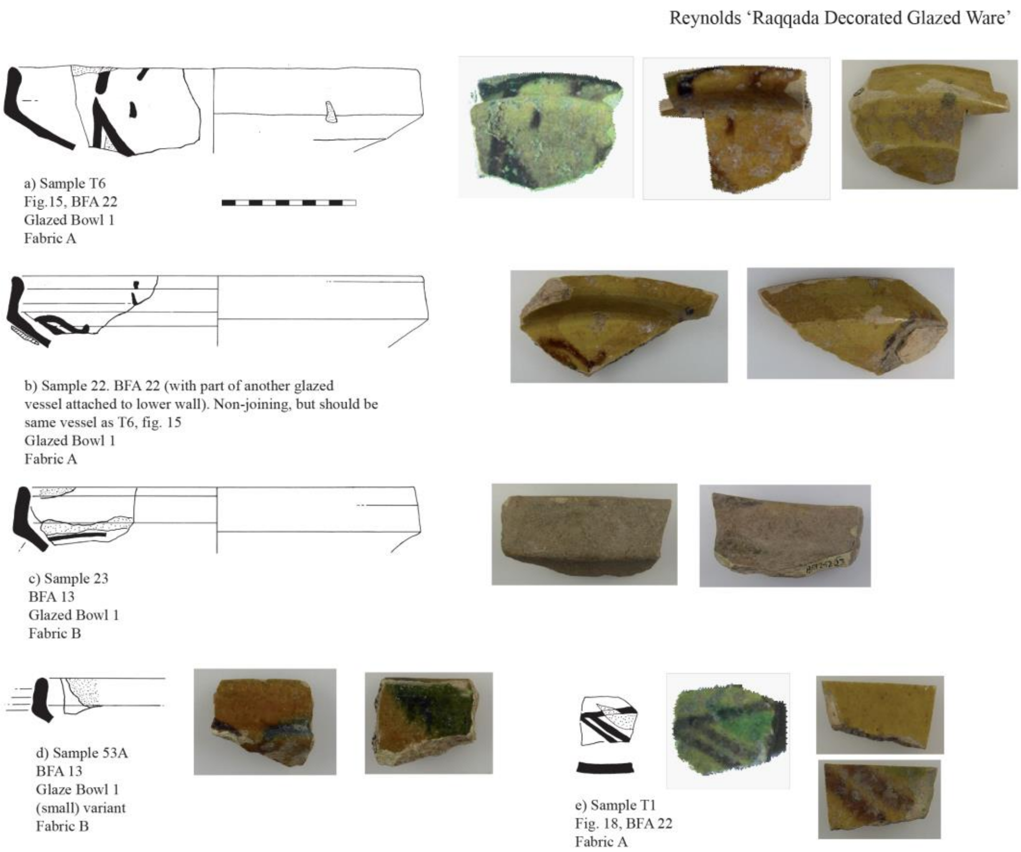

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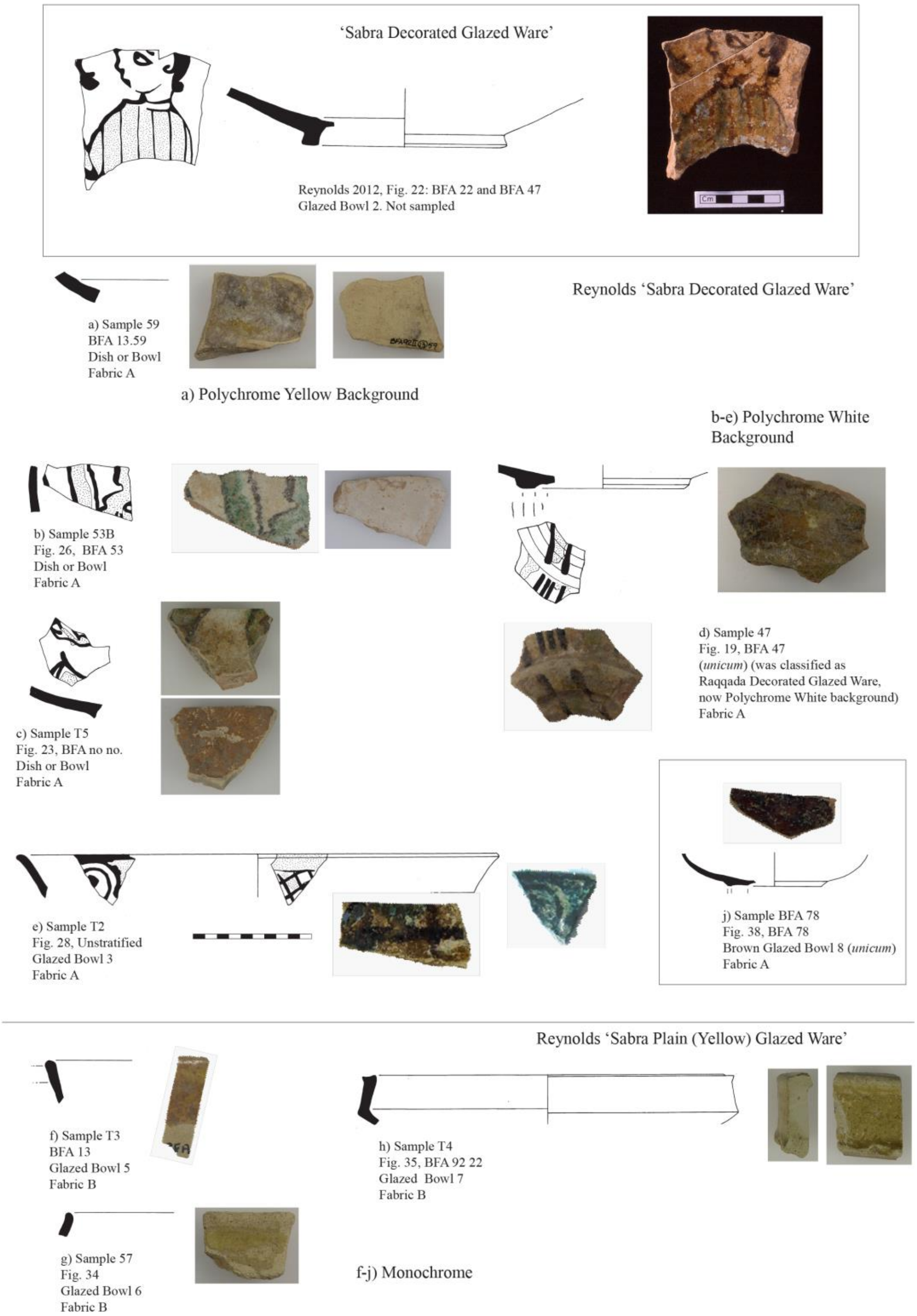

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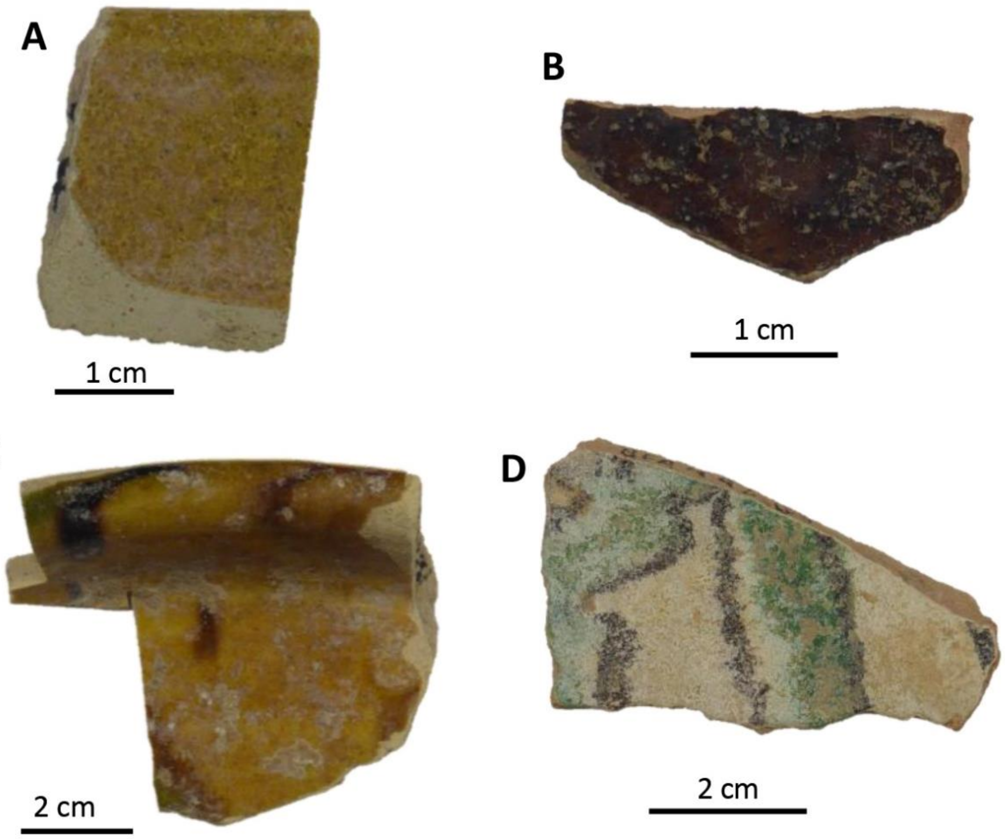

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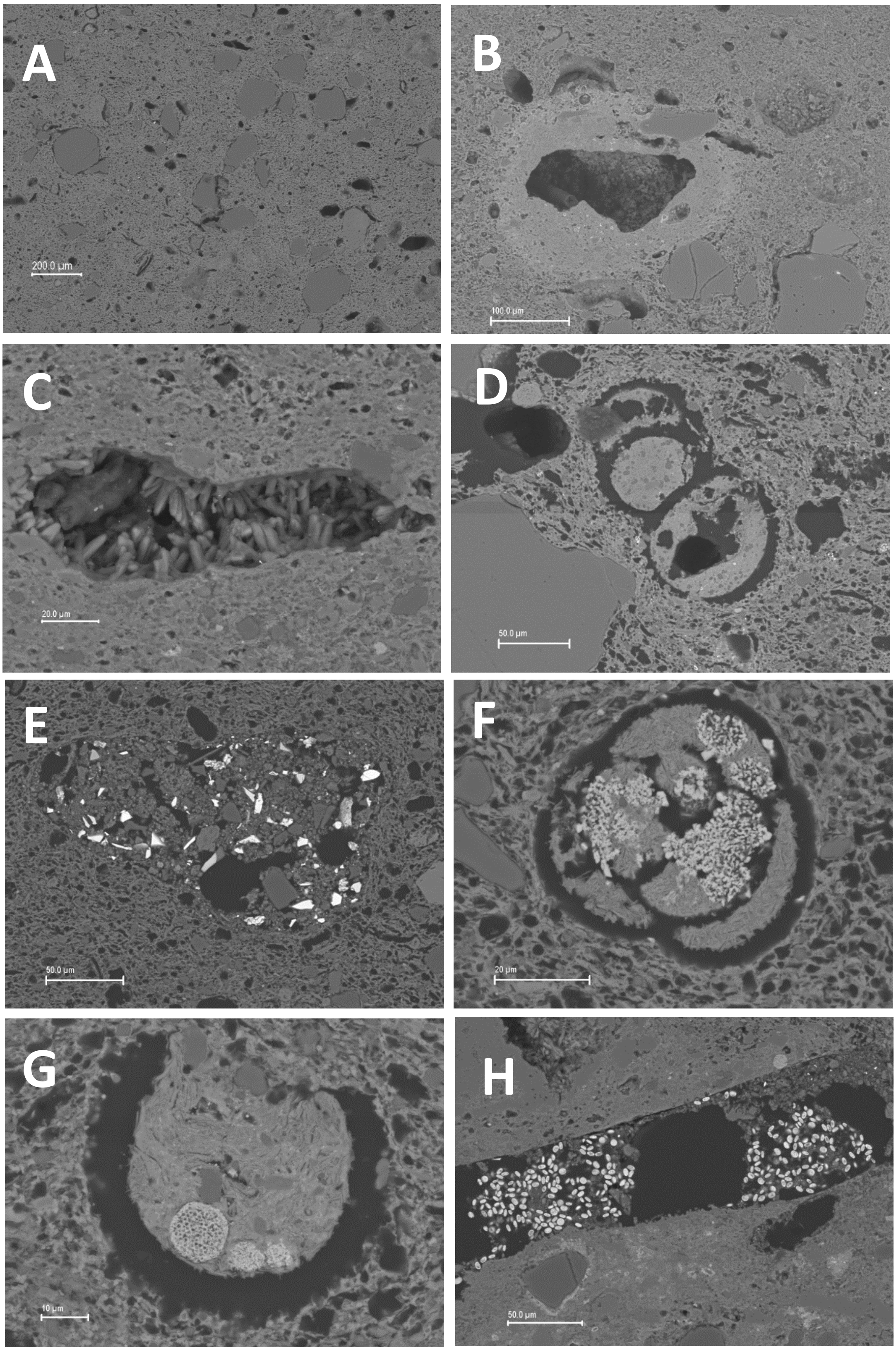

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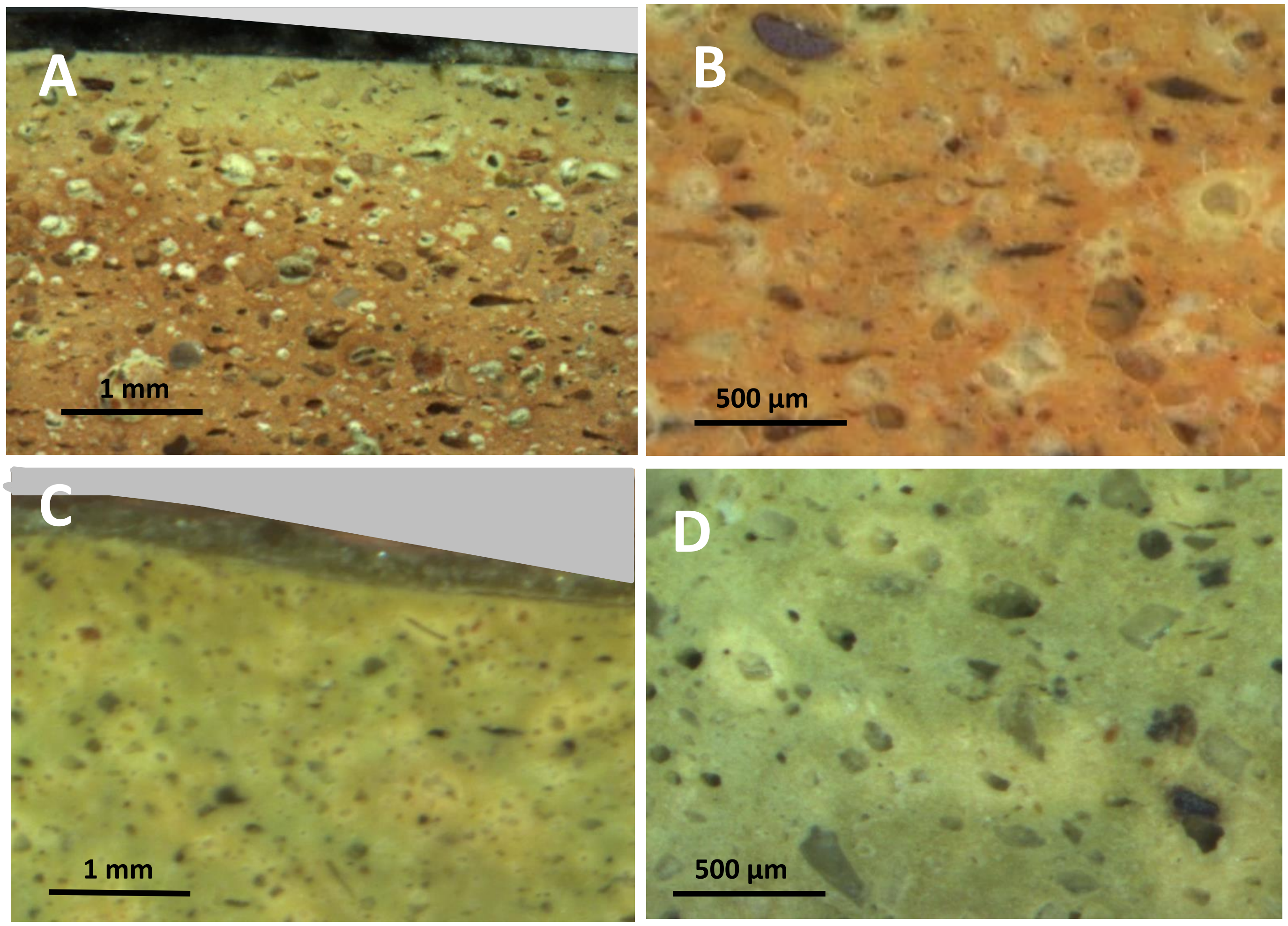

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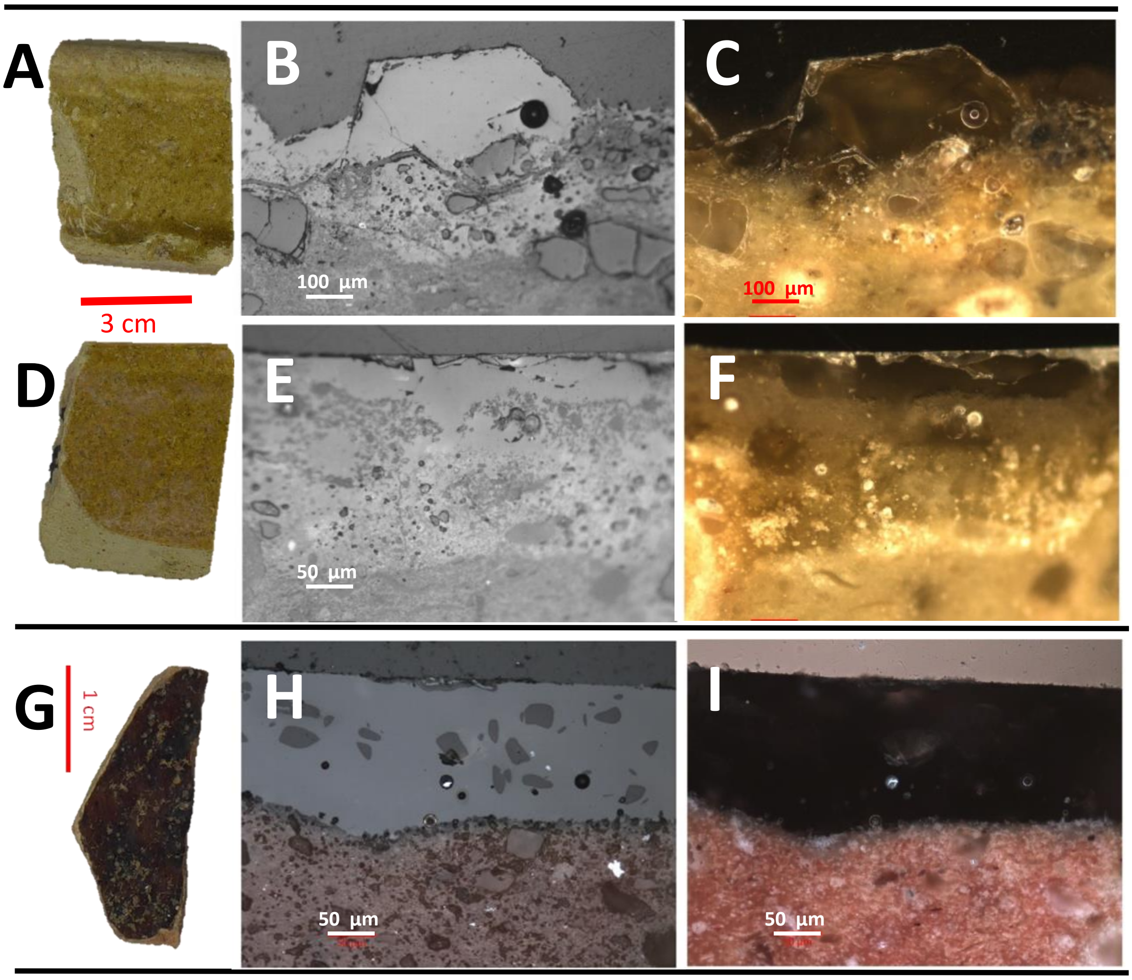

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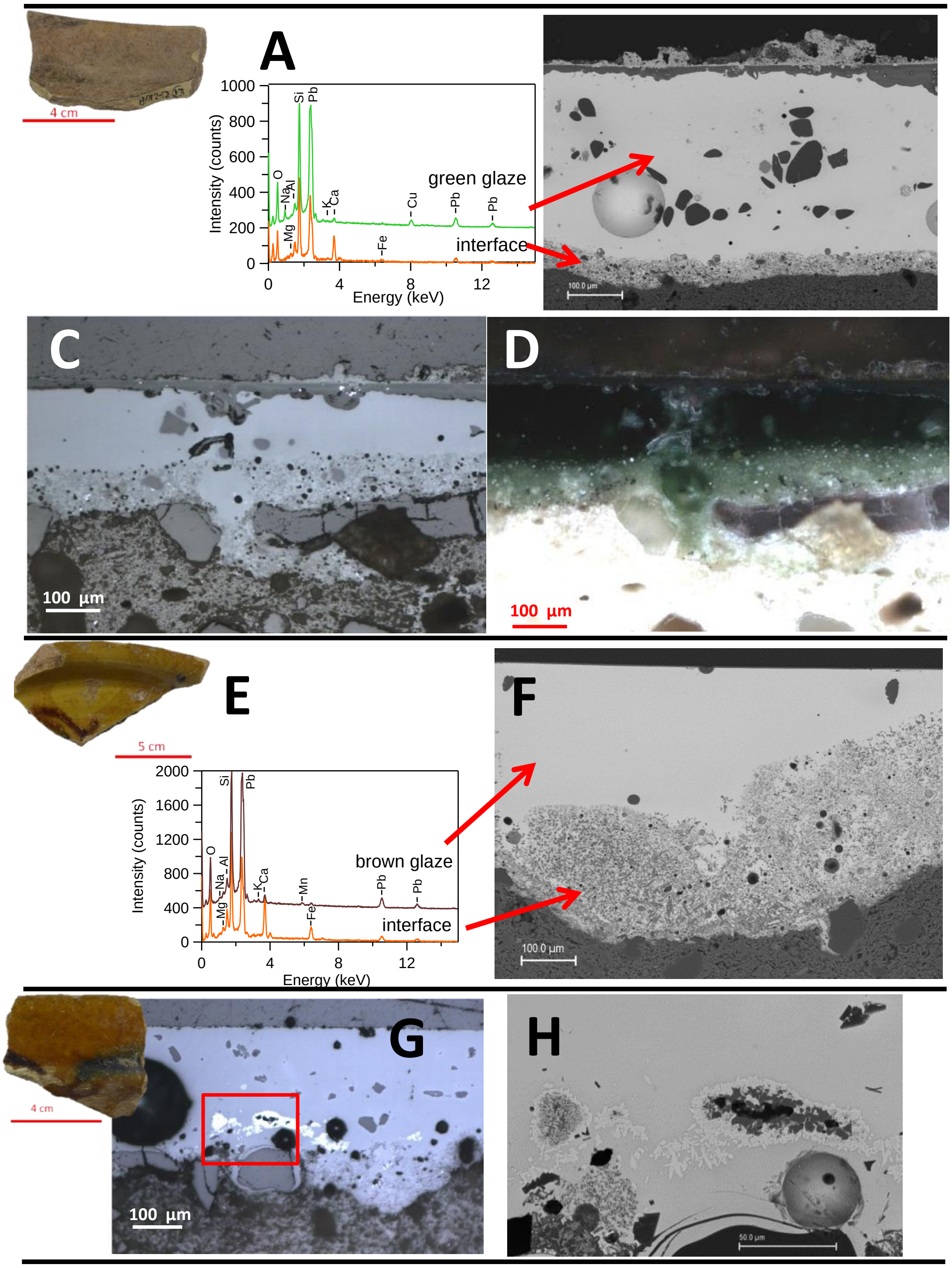

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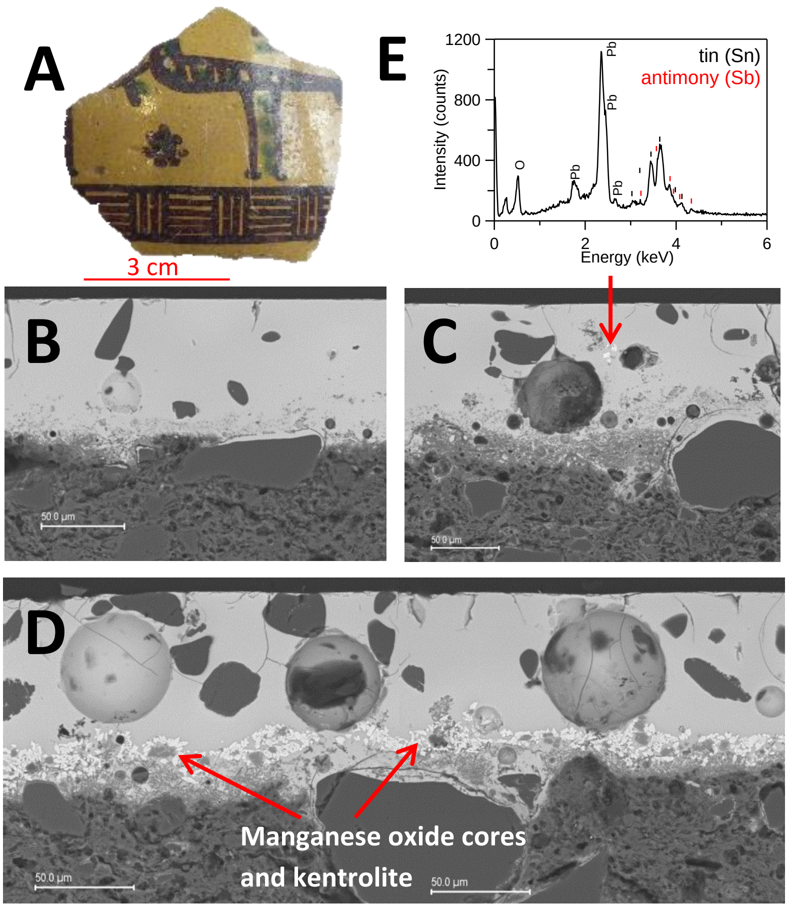

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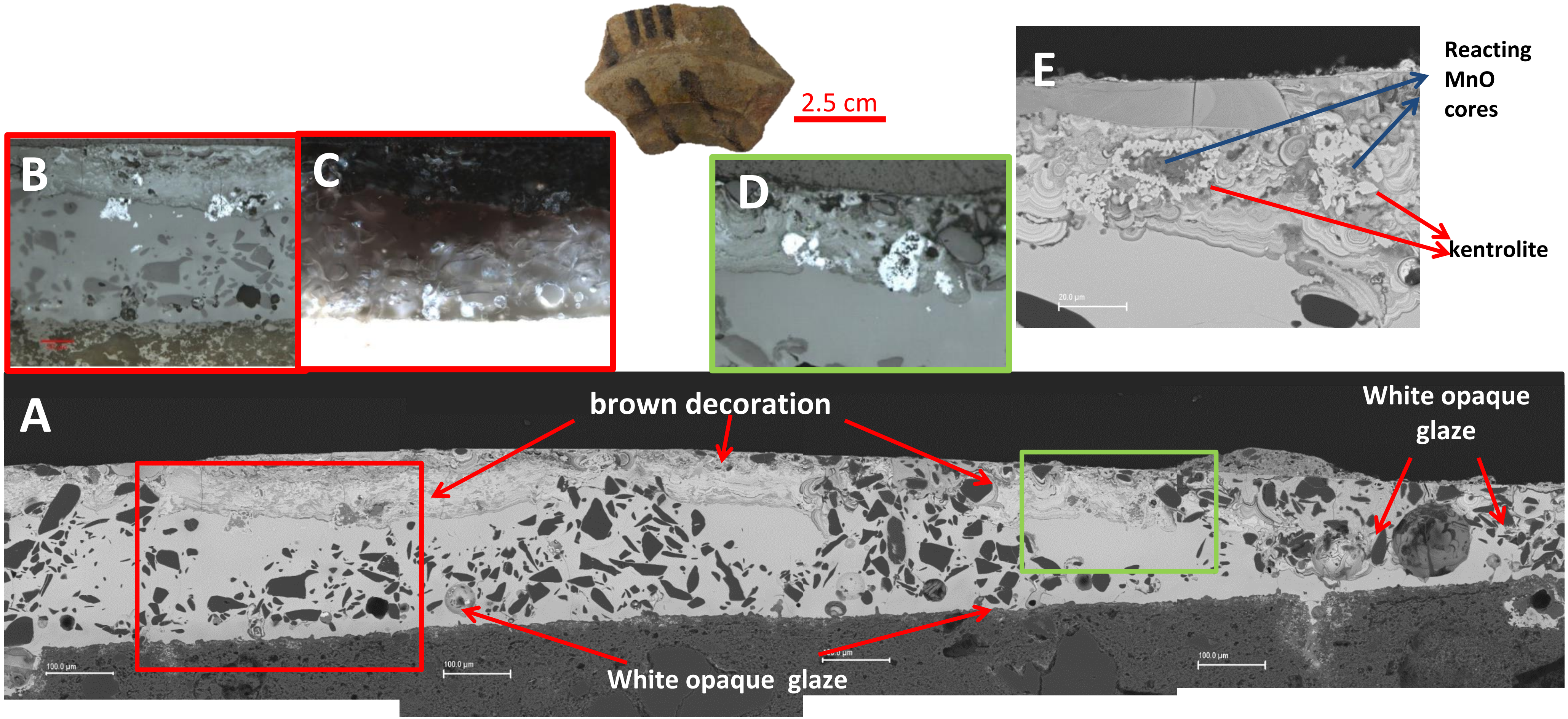

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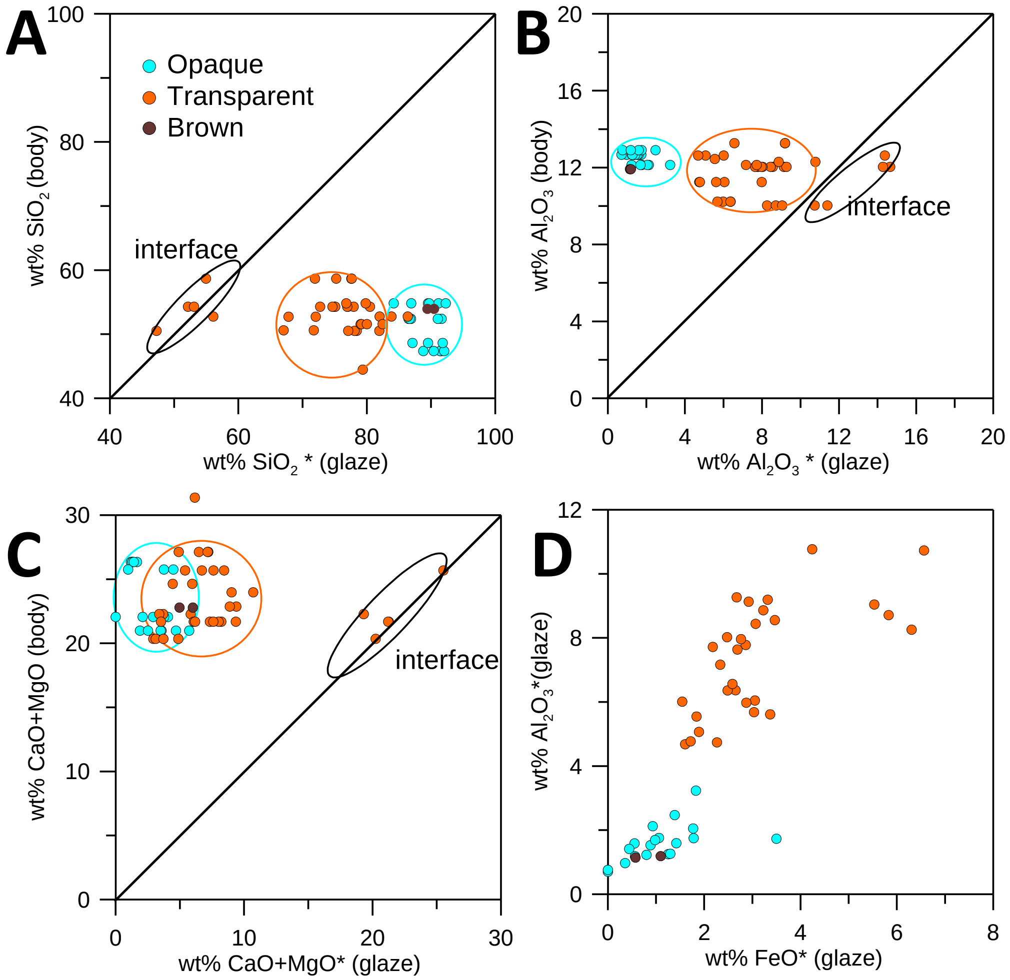

Table 1. Approximate date of the beginning of the Tunisian and close connected glazed productions: (1) Testolini 2018, (2) Salinas et al 2019.

	Spain	Tunisia	Sicily	Egypt
850	Late Emirate	Aghlabid: Raqqada yellow / white	Aghlabid	Abbasid
900	Late Emirate: Verde y manganeso Tin-glaze	Fatimid	Aghlabid: Giallo di Palermo; Fatimid	Abbasid: Group II[2] Tin white Antimony yellow
950	Umayyad Caliphate	Fatimid: Sabra yellow/ white; BIR FTOUHA	Fatimid; Kalbid	Abbasid; Fatimid: Group III[2]
1000	Umayyad Caliphate	Zirid: Tin-glaze Lustre	Kalbid: Tin White[1] Antimony yellow[1]	Fatimid
1050		Zirid		Fatimid

Table 2. Bodies analysis.

	Sample	Fig.	Fabric	Equivalence (Reynolds 2012)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	K_2O	CaO	TiO_2	FeO	PbO
Monochrome transparent	BFA57	3G	B	BFA 92 II 13.57	1.3	2.3	14.0	50.7	b.d.	0.2	0.6	24.0	0.8	6.5	-
	T3	3F	B	BFA92 Context 13	1.5	2.4	12.5	50.9	0.3	0.5	0.8	24.6	0.9	5.5	0.3
	T4	3H	B	BFA22	1.6	2.0	12.9	52.5	0.5	0.2	0.5	22.9	0.6	6.4	0.5
	BFA78	3J	A	BFA 92 I.78	1.6	2.2	12.4	53.3	0.5	0.3	1.1	22.8	0.6	5.2	0.4
Polychrome transparent yellow	BFA23	2C	B	BFA II 92, Context 13	1.7	2.3	13.1	52.0	0.3	0.4	0.7	22.3	0.7	5.9	1.0
	T1	2E	A	BFA22	1.4	2.1	12.7	54.3	0.3	0.4	1.3	21.7	0.7	5.4	-
	BFA53A	2D	B	BFA IV 92 Context 53	1.3	2.0	10.3	57.0	0.5	0.6	0.9	20.4	0.9	4.2	2.2
	BFA22	2E	A	BFA22	1.2	2.2	11.8	50.4	0.3	0.1	0.9	25.7	0.8	5.1	2.0
	T6	2A	A	BFA22	1.5	1.9	10.7	51.4	0.3	0.3	0.9	27.1	0.4	4.9	0.4
	BFA59	3A	A	BFA 92 II 13.59	1.2	2.4	13.0	44.0	0.4	0.3	0.5	31.4	0.8	5.6	0.5
Polychrome opaque white	BFA53B	3B	A	BFA IV 92 Context 53	1.5	2.3	13.3	47.4	b.d.	0.2	0.9	26.4	0.9	6.3	0.9
	BFA47	3D	A	BFA47	1.3	2.1	13.3	48.6	0.3	0.2	1.0	25.8	0.9	5.5	1.3
	T2	3E	A	BFA unstratified	1.4	2.1	12.7	54.7	0.2	0.3	0.9	21.0	0.8	5.9	-
	T5	3C	A	BFA no	1.3	1.9	13.3	51.4	b.d.	0.3	0.9	22.1	0.8	6.4	1.8

Table 3. Glazes analysis of the monochrome glazed ware. Int: Interior; Ext: Exterior; Y: yellow; B: brown.

sample	side	glaze colour	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO	PbO
BFA57	Ext	Y	1.2	0.7	4.7	32.7	2.4	5.2	0.5	0.0	1.6	0.0	0.0	51.2
	Int	Y	1.2	0.6	3.4	35.0	2.6	4.4	0.5	0.0	1.3	0.0	0.0	51.3
T3	Ext	Y	0.7	0.2	3.3	31.0	1.4	2.4	0.3	0.0	0.9	0.0	0.4	59.6
	Int	Y	0.6	0.3	2.7	28.7	1.2	1.6	0.3	0.0	0.8	0.0	0.0	64.0
T4	Ext	Y	1.1	0.9	5.0	30.2	1.3	4.0	0.4	0.0	1.9	0.0	0.0	55.4
	Int	Y	0.7	0.5	3.7	28.4	1.0	3.7	0.3	0.0	1.3	0.0	0.0	60.6
BFA78	Ext	B	0.1	0.2	0.4	30.1	0.4	1.7	0.3	0.8	0.2	0.0	0.0	66.0
	Int	B	0.2	0.0	0.4	28.6	0.5	1.9	0.0	0.7	0.4	0.0	0.0	67.3

Table 4. Glazes analysis of the polychrome transparent glazed wares. Int: Interior; Ext: Exterior; Y: yellow; B: brown; G: green. Above: taken near the surface; Below: taken near the interface.

sample	side	glaze colour	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO	PbO
BFA23	Int	B/G	0.1	0.3	2.0	26.1	0.0	0.2	1.2	0.0	0.4	0.5	5.7	1.0	62.8
		B/G (interface)	0.4	0.5	7.1	26.5	0.0	0.7	9.1	0.2	0.0	3.1	0.0	0.0	49.2
	Ext	Y	0.6	0.4	1.9	28.6	0.0	0.7	2.0	0.2	0.0	0.7	0.0	0.0	65.1
		G	0.5	0.4	1.6	27.5	0.0	0.4	1.1	0.0	0.2	0.5	0.2	0.0	67.8
T1	Ext	Y	0.4	0.3	3.1	30.1	0.0	1.1	1.3	0.2	0.0	1.1	0.0	0.0	62.6
	Int	B-Y	0.3	0.5	3.0	24.9	0.0	0.9	2.7	0.0	1.0	1.2	0.0	0.0	65.8
		B-Y (interface)	0.6	1.7	9.0	30.5	0.0	0.9	12.4	0.4	0.4	3.3	0.0	0.0	40.5
		B (above)	0.3	0.5	3.2	24.7	0.0	0.8	2.4	0.2	1.1	1.0	0.0	0.0	66.2
		B (below)	0.4	0.4	3.4	25.0	0.0	1.0	3.2	0.2	1.0	0.9	0.0	0.0	64.5
		B (interface)	0.5	1.3	8.3	29.2	0.0	1.0	11.7	0.4	0.7	3.1	0.0	0.0	44.3
		G (above)	0.4	0.3	2.6	25.2	0.2	0.9	2.0	0.4	0.0	0.9	0.6	0.0	66.7
		G (below)	0.4	0.3	2.8	25.8	0.0	0.7	2.1	0.3	0.0	0.8	0.5	0.0	66.4
		G (interface)	0.1	0.4	2.8	25.9	0.3	0.6	2.6	0.1	0.0	0.9	0.5	0.0	65.9
BFA53A	Ext	Y	0.4	0.2	3.1	27.8	0.0	1.1	1.1	0.0	0.0	2.3	0.0	0.0	64.2
		Y (interface)	0.3	1.5	6.4	29.2	0.0	0.8	10.8	0.4	0.0	4.2	0.0	0.0	46.9
	Int	Y	0.3	0.5	3.1	26.4	0.0	0.9	1.1	0.0	0.0	2.0	0.0	0.0	66.0
		G	0.4	0.2	3.8	24.3	0.0	0.9	1.7	0.5	0.0	2.2	1.6	0.0	64.6
		B	0.7	0.4	3.3	26.1	0.0	0.8	1.3	0.4	0.7	1.9	0.0	0.0	64.6
BFA22	Ext	Y	0.6	0.2	2.1	32.8	0.0	1.5	2.9	0.3	0.5	0.8	0.0	0.0	58.5
	Int	Y	0.6	0.2	2.3	27.9	0.0	0.8	2.7	0.3	0.0	1.1	0.0	0.0	64.3
		B	0.6	0.7	2.1	27.5	0.0	0.6	2.4	0.4	1.1	1.2	0.0	0.2	63.3
		B (interface)	0.3	1.4	4.8	26.9	0.0	0.3	14.5	0.0	0.0	9.0	0.0	0.0	42.6
T6		Y	0.3	0.4	2.4	27.5	0.0	0.8	2.4	0.3	0.0	1.0	0.0	0.0	65.2
		G	0.3	0.4	2.1	27.5	0.0	0.5	2.0	0.2	0.0	0.9	0.7	0.0	65.5
BFA59		Y	0.9	0.3	2.0	27.2	0.0	1.3	2.1	0.0	0.0	0.6	0.0	0.0	65.8

Table 5. Glazes analysis of the polychrome opaque wares. Int: Interior; Ext: Exterior; W: white; B: brown; G: green.

sample	side	glaze colour	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO	PbO
BFA53B	Int	W	0.1	0.1	0.5	26.5	0.4	0.8	0.5	0.0	0.0	0.2	0.0	0.0	70.9
		B	0.1	0.0	0.5	26.1	0.4	0.9	0.4	0.0	1.0	1.0	0.0	0.0	69.5
		W below B	0.2	0.2	0.3	28.2	0.6	0.9	0.4	0.0	0.0	0.1	0.0	0.0	69.2
		G	0.2	0.0	0.5	27.0	0.4	0.6	0.4	0.0	0.0	0.3	0.7	0.0	69.9
	Ext	W	0.3	0.1	0.2	29.5	0.9	1.1	0.5	0.0	0.0	0.0	0.0	0.0	67.4
BFA47	Ext	W	0.6	0.1	0.5	31.1	0.0	1.2	0.3	0.0	0.0	0.2	0.0	0.0	66.1
		B	0.4	0.2	0.5	31.4	0.0	0.9	1.3	0.0	3.4	0.4	0.0	0.0	61.5
		W below B	0.6	0.1	0.5	31.1	0.0	1.2	0.3	0.0	0.0	0.2	0.0	0.0	66.1
	Int	W	0.1	0.3	0.4	27.6	0.0	1.2	0.3	0.0	0.0	0.4	0.0	0.0	68.4
T2	Ext	G (above)	0.7	0.2	0.7	32.1	0.0	0.6	1.3	0.0	0.0	0.4	4.3	0.0	59.9
		G (below)	0.8	0.3	1.4	34.1	0.0	1.0	2.3	0.0	0.0	0.7	3.7	0.0	55.8
		B	0.4	0.3	0.8	31.3	0.0	0.6	0.7	0.0	1.9	0.3	0.0	0.0	63.7
		W below B	0.3	0.2	0.8	33.9	0.3	1.1	1.8	0.0	0.0	0.7	0.6	0.0	60.4
	Int	B-G	0.2	0.2	0.5	32.3	0.0	0.7	0.9	0.0	2.4	0.3	2.8	0.0	59.7
		G	0.1	0.1	0.6	30.2	0.0	0.4	1.2	0.0	0.5	0.3	6.2	0.8	59.8
T5	Ext	G	0.3	0.1	0.9	28.7	0.5	1.0	1.4	0.0	0.0	0.5	1.7	0.0	65.2
		B-G (above)	0.4	0.3	0.6	29.8	0.6	0.9	1.0	0.1	1.0	0.6	2.0	0.0	62.7
		B-G (below)	0.3	0.2	0.6	29.9	0.7	1.0	1.3	0.2	0.8	0.5	1.9	0.0	62.8
		W	0.3	0.1	0.4	30.7	0.0	1.3	0.7	0.0	0.0	0.2	0.0	0.0	66.3