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RESEARCH

Tackling early medieval circulation of glazed ware in Sharq al-Andalus using a multidisciplinary approach: El Tolmo de Minateda (Spain)

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Abstract

This paper offers an analysis of a group of glazed ceramics that comes from El Tolmo de Minateda site and have been dated in the second half of the ninth century and beginning of the tenth century, before the proclamation of the Umayyad Caliphate by Abderraman III (929 CE). Three technological groups have been distinguished: transparent glazes of one or two colours, transparent polychrome glazes (represented by two pieces) and opaque polychrome glazes (represented by two ceramics) studied by SEM-EDS analysis. After the study, different al-Andalus glaze workshops have been identified as providers of glazed ware to El Tolmo de Minateda site. The initial hypothesis was that the ware consumed in El Tolmo was manufactured in Pechina, the closest early production centre. However, after the archaeometric analysis, it has been discarded, and all the indications of this study seem to point to Córdoba as a significant supplier. The data of this study provides a new perspective on how the internal regional distribution and marketing of goods took place in Al-Andalus during the late Emiral period (c. 875–929 CE), a subject that has yet to be explored.

Keywords Islamic glazed ceramic · Al-Andalus glaze workshops · Tin-opaque glaze · Lead glazed ware · Al-Andalus regional trade

Introduction

This article aims to study how the consumption of glazed ceramic ware worked in an inland settlement, Madīnat Iyyuh (El Tolmo de Minateda, Hellín), in the Sharq al-Andalus, in the east of the Iberian Peninsula (Fig. 1). At this time of the late Emirate, ninth- early tenth centuries, only 3–4 centres were producing glazed ware in al-Andalus. At this moment, neither this semi-luxury product's manufacturing nor consumption had become widespread. The initial hypothesis has been that the ware consumed in El Tolmo was manufactured in Pechina, as it was the closest early production centre.

Most glazed wares belong to closed forms (pitchers, flasks and oil lamps). Most are monochrome or bichrome glazed ware, while four examples are polychrome glazed ceramics. Three different glazed productions have been determined and analysed both from the stratigraphic view and the archaeometric methodology, which allows us to position the technical features of the glazed ceramic within the framework of stratified ceramic contexts of El Tolmo. This site was occupied between the middle of the sixth and the early tenth centuries. It is generally accepted that El Tolmo site was abandoned at the early tenth century, before the proclamation of the Caliphate, when the population moved to the near urban centre of Murcia (Abad et al. 2012).

Archaeological context

El Tolmo de Minateda[1] is located in the province of Albacete, about 10 km from the city of Hellín. The site is on a hill overlooking the natural route between two crucial communication nods, the plateau's interior and the Iberian Peninsula's southeastern coast (Fig. 2). El Tolmo was a prominent

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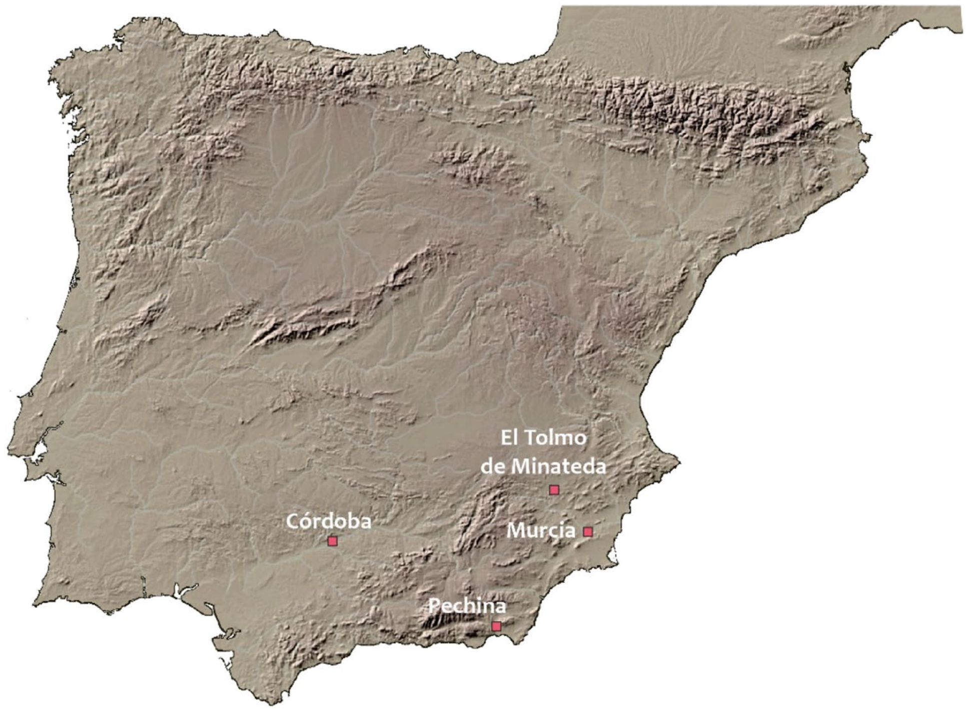

Fig. 1 Map of principal sites mentioned in the text

pre-roman and roman settlement. However, during the second century CE, it suffered a depopulation process, which lasted until it was occupied again in the second half of the sixth century. At this moment, a significant transformation affected the entire surface of the hill. In addition, the revitalisation of Tolmo was magnified by the presence of the episcopal seat of Elo, archaeologically documented by a church, a baptistery, an episcope, and a funerary area around the head and foot of the religious building.

The arrival of the Arab and Berber armies in the Peninsula in 711 CE did not produce the disappearance of these spaces; instead, the diocese's liturgical and administrative life must have maintained its original function until the middle of the eighth century when the meaning of the buildings changed. Hence, they become domestic areas and workspaces.

From the beginning of the ninth century, a dismantling of the old Visigoth buildings is documented, and new housing structures began to be built, which would form the backbone of an urban fabric throughout the ninth century that would remain fossilised after the site was abandoned at the beginning of the tenth century.

Fig. 2 Plan of the localisation of archaeological contexts where the glazed ceramics studied are from at the El Tolmo de Minateda archaeological site

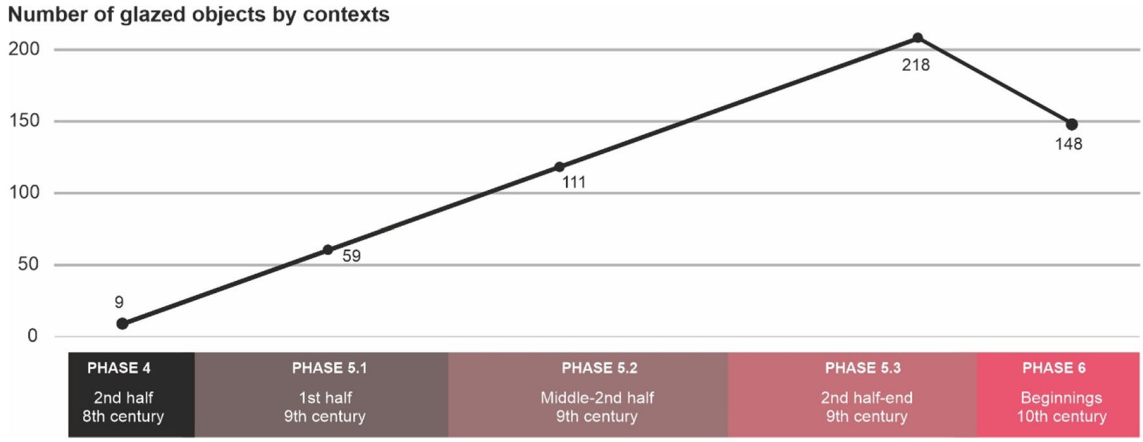

Fig. 3 Number of glazed objects by context from El Tolmo de Minateda archaeological site (based on Amorós-Ruiz and Gutiérrez 2021)

The extended research project at El Tolmo has allowed us to analyse the stratigraphy in-depth, especially that of the Early Middle Ages, where we distinguished six stratigraphic phases ranging from the resurgence of the city in the middle of the sixth century to its abandonment at the beginning of the tenth century (Amorós-Ruiz 2018: 75–116).

The stratigraphic analysis provides a chronological framework for any material found in an excavation in El Tolmo. A typological and chronostratigraphic study of the pottery from El Tolmo was published in 2018, where a first approach to Tolmo's glazed ceramics was addressed, and their location within the site's stratigraphic sequence was analysed (Amorós-Ruiz 2018). A first approximation of the glazed ceramics from El Tolmo and their chrono-stratigraphic contextualisation has also been published, where information on the petrology and mineralogy of the composition and the texture of the materials within using a polarised light microscope to analyse thin sections is provided. A first spatial analysis of Tolmo's glazed pottery was presented too. (Amorós-Ruiz and Gutiérrez 2021).

The pottery from El Tolmo de Minateda

The analysis of the stratigraphy of El Tolmo de Minateda in the different excavated areas has allowed us to establish six stratigraphic phases for the Early Medieval stage of the site (Amorós-Ruiz 2018: 73–116). For this paper, we have focused on the glazed pottery of final phases (Phases 5.2. 5–3 and 6), which encompass the period between the mid-ninth century and the beginning of the tenth century (Fig. 3) (Amorós-Ruiz 2018: 73–116).

If we consider the number of ceramics found in strata with the presence of glazes, these represent a scarce representation of the total. Table 1 presents a summary of glazed ware versus their equivalents in unglazed vessels, so as to assess how representative the analysed glazed shards are within the whole assemblage.

Phase 5.2 has provided a total of 11.671 non glazed objects (105.080 fragments) and 111 glazed objects (127 fragments, 4 of which were analysed) were identified. This means that glazed ceramics only represent 0,95% of the total number of ceramics of this phase.

In the **Phase 5.3**, 18.139 non glazed ceramics (160.929 fragments) and 218 glazed objects (394 glazed fragments) were counted. Of these, 12 were analysed. The percentage of glazes is a 1,2% representation.

Finally, **Phase 6** has provided 13.395 non glazed objects (115.290 fragments) and 148 glazed vessels (287 glazes fragments), 12 of them analysed. Thus, glazed ceramics represent 1,1% of the total amount of ceramics recovered in this phase.

Materials and methods

The materials have been analysed using a multidisciplinary methodology, which includes archaeological stratigraphy, typological study of the material culture and archaeometry. Based on the localisation of these glazed ceramics within their stratigraphic sequence (Amorós-Ruiz 2018), a selection of glazed pieces have been analysed and not only the archaeometric data but also considering the historical information on the distribution and trade of semi-luxury wares in Sharq al-Andalus during the Emiral period.

Analyses of the glazed samples

Twenty-seven glazed shards from El Tolmo (8 monochrome, 14 bichrome, 2 polychrome transparent and 2 polychrome opaque fragments) here studied, as indicated in Table 2 and Fig. 4.

Table 1 Relative number of glazed samples by phases versus similar unglazed forms in El Tolmo, including their archaeological contexts and stratigraphic phase

RELATIONSHIP BETWEEN THE SAMPLES AND THE CONTEXTS WHERE THEY APPEARED							GLAZED CERAMIC BY STRATIGRAPHIC PHASE				
Sample	Stratigraphic Phase of the sampke	Context and number of inventory of the sample	Number of glazed fragments by contexts	Number of glazed objects by contexts	Number of non glazed fragments by contexts	Number of non glazed objects by contexts	Number of non glazed fragments by Phase	Number of non glazed medieval objects by Phase	Number of glazed fragments by Phase	Number of glazed objects by phase	Percentage glazed objects by phase
T6	5.2	61.102–1	3	3	179	27	105.080				
T36		64.582–31	2	1	2555	266					
T44		60.241–38	1	1	157	39		11.671	127	111	0,95%
T32		60.323–43	6	6	365	57					
T7	5.3	55.023–20	9	3	1428	202	160.929				
T1		80.021–5	7	7	3370	348					
T2		80.021–3									
T3		80.021–7									
T4		80.021–12									
T11		60.097–34	3	2	192	29					
T35		60.089–11	1	1	393	99					
T40		57.012–23	4	4	1604	241					
T33		60.094–44	1	1	173	45		18.139	394	218	1,2%
T39		55.010–31	8	8	2167	309					
T8		55.029–20	3	3	110	11					
T10		55.029–02									
T9		62.108–05	1	1	429	67					
T12		60.744–15	3	3	1869	188					
T30	6	55.005–3	1	1	265	35	115.290				
T41		64.511–27	4	4	2290	213					
T38		64.511–30						13.395			
T34		64.501–70	3	3	1402	51					
T43		64.501–71							287	148	1,1%
T37		64.501–72	7	6	9098	600					
T31		64.501–73									
T45		57.000–12	7	5	844	88					

Table 2 Classification of the glazed ware: g-green glaze, gs-greenish glaze, h-honey glaze, b-brown glaze, t-transparent, w-white glaze

Type		TOTAL SAMPLES	Samples by Colour	Colour Glaze	Shards
Transparent glazes	Monochrome (**MT**)	8	6	g	T2, T4, T10, T31, T36, T39
			1	gs	T7
			1/2	h	T41, T6?
	Bichrome (**BT**)	14	13	h/g	T3, T8, T11, T12, T30, T32, T33, T34, T35, T37, T38, T40, T42
			1	g/b	T44
	Polychrome (**PT**)	2	2	g/b/h/t	T1, T45
Opaque glazes	Polychrome tin opaque (**TO**)	2	2	g/b/w	T9, T43

After studying them, the shards have been classified into three groups shown in Table 2. The Tolmo glazes show similarities with the Córdoba glaze assemblage of Posada de la Herradura (pitchers, foot-free dish, oil-lamp), which was dated in the late Emiral period (c. 875–929 CE) and has different technological traditions: transparent lead glazes and tin-glazed wares. This repertoire's transparent and opaque polychrome ware was decorated over a transparent glaze (Salinas and Pradell 2018).

According to this scheme, the glazed wares are classified in three groups: monochrome/bichrome transparent, polychrome transparent and opaque polychrome glazes.

The **monochrome transparent glaze** group is composed of 9 samples: 6 green (T2, T4, T10, T31, T36, T39), 1 greenish (T7) and 2 honey (T41, T6?). All are closed forms, such as pitchers, flasks and oil lamps. Most are plain and do not present any decoration, except two: T10, an oil lamp and shows oblique incisions on this deposit, and T41, semicircular incised decoration on the outer surface.

The **bichrome transparent** group is the largest one and includes 14 samples (T3, T8, T11, T12, T30, T32, T33, T34, T35, T37, T38, T40, T42, T44). All are closed forms and combines one surface in green and the other in honey: 7 have a honey outer surface while the inner surface is green (T32, T33, T34, T37, T38, T40, T42), and 6 are green outside and honey inside (T3, T8, T11, T12, T30, T35). Two different decorations have been documented: decoration applied by vertical threads, like ribs, on the outer surface of the glaze (T11, T37 T38, T42) and incised semicircles (T8, T33). There is one exception (T44) that has brown splashed decoration over a greenish background in the outer surface and greenish monochrome colour in the inner surface.

The **polychrome transparent glaze group** is composed of two samples (T1, T45), with splashed colours decorations (honey, green, brown) applied on the outer transparent side because they are closed forms.

Finally, the **polychrome tin-opaque glazes** are represented by two examples (T9, T43) that combine brown and green geometrical motifs in a white background. T9 seems to be an open form with decoration inside, while T43 is a closed form with decoration outside.

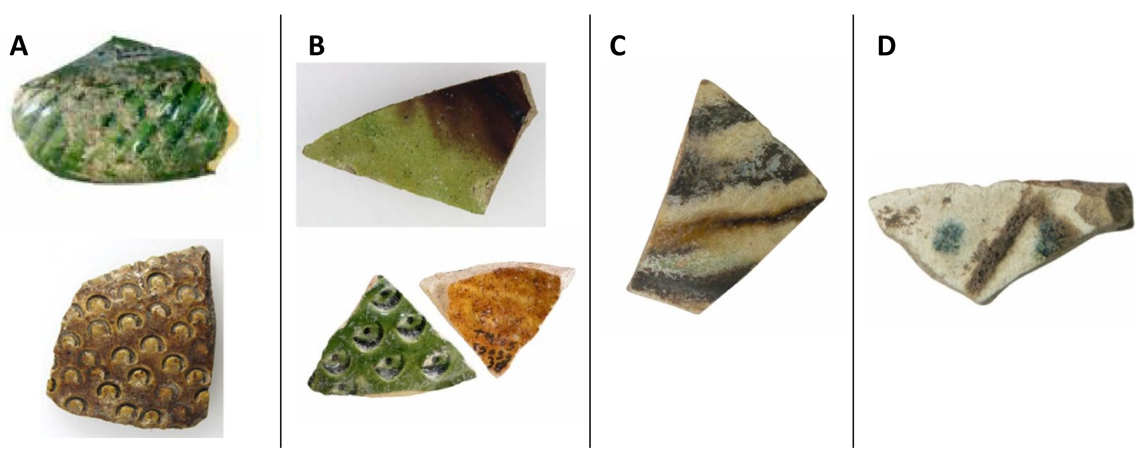

Fig. 4 Representative glazed ceramics from El Tolmo de Minateda: **a** Monochrome transparent glaze, **b** Bichrome transparent glaze, **c** Polychrome transparent glaze, **d** Polychrome tin-opaque glaze

Table 3 Chemical composition of Tolmo 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

	Sample	NaO_2	MgO	Al_2O3	SiO_2	K_2O	CaO	TiO_2	FeO	PbO	MnO	SO_3
MT	**T2**	0.8	2.6	15.5	52.2	2.6	17.7	0.8	6.7	1.3	-	-
	T4	0.6	2.9	14.3	55.9	2.8	16.3	0.9	6.4	-	-	0.0
	T10	0.7	2.5	14.8	51.4	2.9	20.5	0.7	5.4	-	0.3	0.7
	T31	0.6	2.7	14.4	58.0	3.0	14.5	0.9	6.0	-	-	-
	T36	0.7	3.9	13.8	54.3	3.4	17.0	0.9	5.8	0.3	-	-
	T39	1.0	2.4	15.8	52.9	2.6	16.6	0.9	6.8	1.1	-	-
	T7	0.6	4.1	11.4	47.4	2.2	27.5	0.7	4.8	0.5	-	0.8
	T41	1.1	2.9	16.2	50.6	1.8	19.1	0.8	6.7	0.9	-	-
	T6	0.6	2.5	11.4	40.2	1.9	35.5	0.5	4.5	2.9	-	-
BT	**T3**	1.5	2.7	15.4	53.5	1.4	16.7	0.9	6.9	1.1	-	-
	T8	0.9	2.4	15.4	55.5	2.5	15.7	0.7	6.1	-	-	-
	T11	1.3	2.8	15.3	55.8	2.5	14.0	0.8	6.5	-	-	-
	T12	1.0	2.9	14.4	50.0	2.0	21.3	0.8	5.6	-	-	0.7
	T30	0.7	2.4	15.5	54.4	2.7	15.4	0.7	6.7	-	-	-
	T32	1.1	3.1	15.0	46.7	1.4	24.1	0.8	6.3	-	-	-
	T33	1.3	2.9	15.4	54.6	1.6	16.0	1.0	6.4	-	-	0.4
	T34	0.9	2.8	14.5	54.5	2.6	16.6	0.7	6.3	-	-	-
	T35	1.1	2.9	14.5	55.0	2.9	16.0	0.8	6.0	-	-	0.5
	T37	0.8	2.8	14.3	51.2	2.7	20.3	0.7	6.2	-	-	-
	T38	1.3	2.9	15.2	55.0	2.5	14.4	0.9	6.7	-	-	-
	T40	1.3	2.9	18.3	47.9	3.2	17.3	0.8	6.8	-	-	-
	T42	0.7	2.3	13.9	49.4	2.6	23.4	0.4	5.6	-	-	-
	T44	0.9	2.6	14.6	49.8	2.1	20.8	0.7	6.7	-	-	-
PT	**T1**	1.1	2.8	15.7	52.9	2.1	16.7	0.8	6.6	0.8	-	0.5
	T45	1.3	3.0	16.8	51.3	2.2	16.2	0.9	6.9	-	-	-
TO	**T9**	0.4	2.3	13.0	49.4	2.7	25.3	0.6	5.4	0.9	-	-
	T43	0.5	2.3	13.7	49.5	2.8	22.9	0.8	5.8	-	0.0	0.7

Analytical techniques

Polished sections through the glazes and into the bodies of the shards 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 crossbeam workstation (Zeiss Neon 40) equipped with scanning electron microscopy (SEM) GEMINI (Shottky FE) column and EDS (INCAPentaFETx3 detector, $30mm^2$, ATW2 window), operating at 20 kV with 120s measuring times. 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. This analytical phase was carried out at the lab of the Universitat Politècnica de Catalunya (Barcelona).

The chemical compositions of the bodies were determined by analysing at least two areas, about 3 mm × 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 glazes' variable state of preservation; 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.

Results

The chemical compositions of the bodies, obtained by SEM–EDS, and the fabric type attribution after Optical and SEM investigation of the ceramic fabrics are included in

Table 4 Chemical compositions of Tolmo bulk monochrome/bichrome 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. Typical standard deviations are: 0.3 for Na_2O, MgO, K_2O, FeO and PbO, 0.4 for CuO, 0.9 for Al_2O_3 and SiO_2, and 1.5 for CaO. g-green glaze, h- honey glaze, gr-greenish, b- brown

	Sample	Glaze	NaO_2	MgO	Al_2O3	SiO_2	K_2O	CaO	MnO	FeO	CuO	PbO
MT	**T2**	g	0.7	0.2	1.2	32.9	0.9	1.7	-	0.7	2.5	59.3
		g	0.9	0.2	1.4	32.6	0.8	1.6	-	0.8	2.3	59.4
	T4	g	0.2	0.6	2.0	31.0	1.0	3.5	-	1.2	2.7	58.0
		g	0.5	0.3	1.8	30.1	0.9	2.8	-	1.2	2.8	59.7
	T5	g	0.4	0.4	2.0	31.5	0.5	1.9	-	1.1	6.5	55.8
		g	0.9	0.4	1.9	32.9	0.5	2.0	-	0.9	4.5	56.0
	T10	g	0.6	0.3	0.7	30.9	0.6	1.6	-	0.6	2.8	62.1
		g	0.6	0.3	1.0	30.3	0.7	2.5	-	0.7	3.0	61.0
	T31	g	0.6	0.6	2.4	34.7	0.6	3.2	-	1.5	5.1	51.4
	T36	g	-	1.0	2.1	26.0	0.8	3.6	-	1.1	3.3	62.2
		g	-	0.8	2.8	30.1	0.9	4.7	-	2.0	1.8	56.9
	T39	g	0.5	0.6	2.7	34.3	1.4	3.7	-	1.2	1.8	53.8
		g	0.2	0.1	2.5	32.6	1.3	3.2	-	1.3	2.6	56.2
	T7	gs	0.7	0.5	5.0	37.1	3.3	4.6	-	2.1	-	46.7
		gs	0.6	0.6	4.7	34.8	3.4	4.4	-	2.1	-	48.9
	T41	h	-	0.4	2.8	28.9	1.0	3.5	-	4.5	-	58.9
	T6	h	altered									
	T13	h	0.1	0.2	0.8	28.5	0.3	1.9	-	5.3	-	62.9
BT	**T3**	g	0.4	0.5	1.1	31.5	0.9	3.0	-	1.0	3.1	58.6
		h	0.6	0.5	2.1	34.3	1.5	3.3	-	4.8	-	52.9
	T8	g	0.2	0.4	1.6	30.9	0.8	2.4	-	0.8	2.5	60.5
		h	0.2	0.3	1.2	31.2	1.3	2.4	-	5.7	-	57.6
	T11	g	0.9	0.5	2.9	34.2	1.1	2.6	-	1.3	1.8	54.7
		h	0.6	0.6	2.4	34.4	1.2	2.8	-	3.7	-	53.9
	T12	g	0.5	0.2	1.9	31.7	2.0	2.8	-	1.5	1.9	57.6
		h/g	0.2	0.2	1.3	30.6	1.7	2.5	-	3.7	1.4	58.3
	T30	g	0.3	0.2	2.2	31.2	0.9	2.5	-	1.1	2.5	59.0
		h	0.2	0.5	1.1	31.5	1.1	2.7	-	5.6	-	57.3
	T32	g	0.2	0.8	3.1	33.3	2.3	4.0	-	1.9	0.9	53.6
		h	0.2	0.5	1.3	28.8	1.2	2.9	-	4.2	-	61.0
	T33	g	0.2	0.7	2.1	34.5	0.8	3.3	-	1.3	2.7	54.5
		h	0.3	0.3	1.7	30.1	0.5	1.6	-	4.1	-	61.6
	T34	g	0.5	0.7	3.5	38.4	2.0	4.7	-	1.6	1.6	47.0
		h	0.6	0.8	3.5	35.1	1.5	5.7	-	4.1	-	48.8
	T35	g	1.0	0.6	2.8	34.5	1.5	2.7	-	0.8	2.2	54.0
		h	0.4	0.6	2.5	32.9	0.9	3.6	-	5.6	-	53.4
	T37	g	0.1	0.7	3.2	30.7	0.8	3.0	-	1.2	0.8	59.6
		h	-	0.3	2.4	30.3	1.2	3.2	-	4.3	-	58.4
	T38	g	0.3	0.7	4.8	35.8	1.7	5.6	-	2.2	2.4	46.5
		h	0.5	0.7	5.4	36.0	2.3	4.7	-	4.6	-	45.8
	T40	g	1.4	0.2	3.1	28.8	1.6	3.8	-	1.8	1.6	57.8
		h	1.0	0.8	3.1	27.7	1.3	4.7	-	4.9	-	56.5
	T42	g	0.2	0.3	1.0	26.2	0.3	2.1	-	0.5	3.3	66.0
		h	0.2	0.3	0.8	26.7	0.2	2.0	-	3.8	-	65.9
	T44	g	0.3	0.5	2.3	32.0	1.7	3.4	-	1.3	0.4	58.2
		b	0.6	0.4	2.0	31.2	1.5	3.0	2.3	0.8	-	58.2

Table 5 Chemical compositions of Tolmo bulk polychrome glazes determined by SEM–EDS (wt% normalised to 100 wt%). The data are the average over at least two analuses taken in different areas of the glazes. Typical standard deviations are: 0.3 for Na_2O, MgO, K_2O, FeO and PbO, 0.4 for CuO, Sn_2O, 0.9 for Al_2O_3 and SiO_2, and 1.5 for CaO. g-green glaze, h-honey glaze, w-white glaze, t-transparent glaze, u-undecorated side

			NaO_2	MgO	Al_2O_3	SiO_2	K_2O	CaO	MnO	FeO	CuO	SnO_2	PbO
PT	**T1**	T	0.3	0.3	1.9	31.5	1.1	2.0	-	2.9	-	-	60.0
		b/g	0.1	0.5	1.5	29.3	1.0	2.4	4.0	0.9	1.4	-	59.1
		t (u)	0.5	0.4	2.8	33.6	1.9	2.4	-	1.1	-	-	57.3
	T45	T	0.6	0.4	2.0	34.0	1.2	2.6	-	1.2	-	-	58.0
		B	0.3	0.3	1.0	30.6	0.7	1.6	2.3	0.9	-	-	62.3
TO	**T9**	B	2.5	0.3	1.2	44.4	0.9	0.8	4.6	1.3	-	-	44.1
		w/b	2.1	0.3	0.9	36.8	0.9	3.4	0.7	0.7	-	9.2	45.0
		w/g	2.5	0.4	0.6	34.7	1.2	2.5	-	0.5	1.5	10.0	46.1
		G	1.1	0.1	0.7	45.2	0.5	1.9	-	0.4	5.9	1.0	43.2
		g (u)	0.5	0.2	0.8	27.8	0.5	1.8	-	0.4	1.4	0.3	66.9
	T43	B	2.4	0.2	1.0	36.6	1.0	1.6	4.0	0.6	-	10.7	42.0
		w/b	2.8	0.4	0.6	36.2	1.1	2.6	-	0.9	-	10.3	45.1
		G	1.1	0.3	0.8	35.7	0.7	3.0	-	0.8	7.9	3.3	46.3
		w (u)	0.5	0.4	2.1	28.7	0.8	2.4	-	0.7	-	0.3	64.3

Table 3. The chemical composition of the monochrome and bichrome glazes is shown in Table 4, and Table 5 for polychrome ones.

Body composition

The ceramic bodies are of calcareous type clay, and their chemical composition shows a specific variability, ranging the calcium contents from 14 to 24% CaO. Only three pieces contain more than 25% CaO: T6, T7 and T9. They have an aluminium content of ~ 14.7% Al_2O_3 and an iron content of ~ 6.1% FeO. Silicon contents are pretty high (47–60% SiO_2), except T6 (40% SiO_2), and they are generally low in sodium (< 1.5% NaO_2). Magnesium contents are below 3.1% MgO, except for two slightly higher pieces (T7, T36). The average potassium contents are ~ 2.5% K_2O and titanium contents are below 1% (~ 0.8% TiO_2). The presence of lead oxide in the pastes (~ 1% PbO) may be due to the contamination of the glazes in the fabric when modelling the piece or to the alteration that occurs during burial once the piece is discarded.

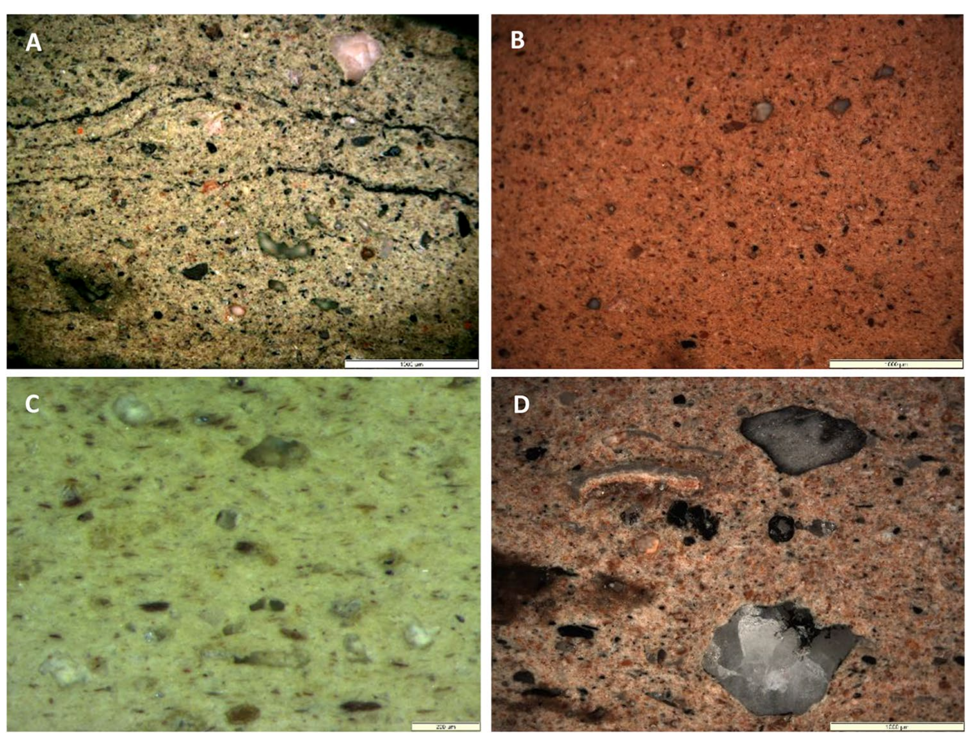

Fig. 5 Ceramic fabrics. Optical microscope images of ceramic bodies found at Tolmo: **a** T33, grey calcareous body; **b** T9, red calcareous body; **c** T40, beige calcareous fabric; **d** T7 larger inclusions and chamotte

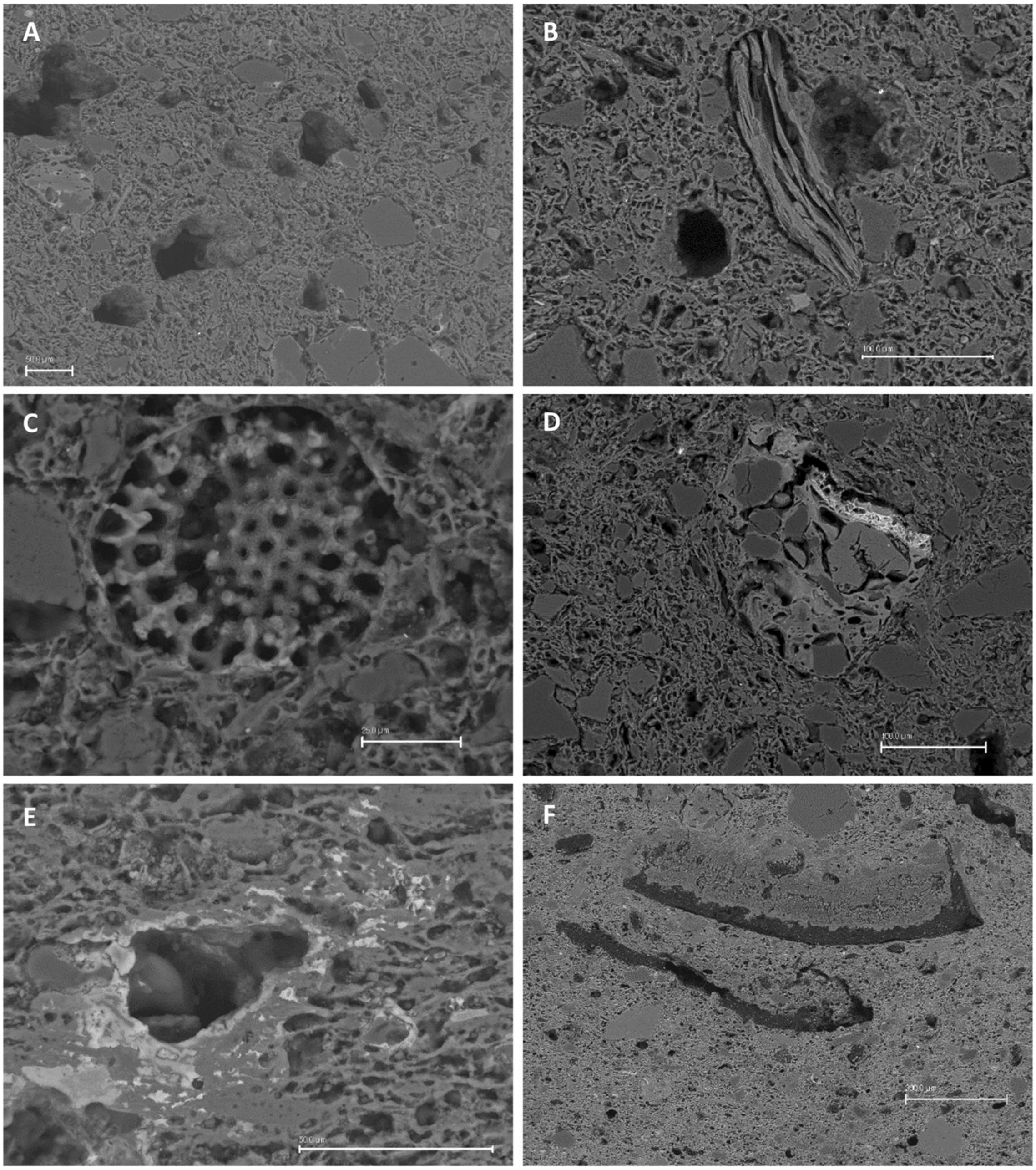

Fig. 6 Ceramic fabrics details. Back scattering images of **a** T30, quartz grains and porosity; **b** T31, mica; **c** T3, foraminifera microfossil; **d** T31, conglomerate; **e** T40, lead fragment; **f** T7, chamotte

The colours of the fabrics vary, with the majority being reddish (Figs. 5b, d), and buff colour (Fig. 5c), fired in an oxidising atmosphere, to grey colour, from a reducing firing atmosphere (Fig. 5a).

Overall, the fabric's microstructure shows the predominance of quartz grains (Fig. 6a), micas (Fig. 6b) and feldspars. Some conglomerates (Fig. 6d) and chamotte (Figs. 5d, 6f) are also detected.

Microscopically, the ceramic bodies can be divided into three groups, which seem to be compatible with different provenances. The first group is the one that includes more pieces (T1, T2, T3, T4, T8, T9, T10, T11, T12, T30, T31, T32, T33, T34, T35, T37, T38, T39, T41, T42, T43, T44) and therefore presents a more significant variability. It has reddish/buff fabrics with porosity, angular quartz (Fig. 6a) and elongated biotite mica inclusions (Fig. 6b), white-yellowish calcareous clay nodules and red/black iron oxide particles, sometimes arranged in elongated bands. Some of the bodies also have foraminifera microfossils (Fig. 6c) or porosities from skipped inclusions (Fig. 6a), or even

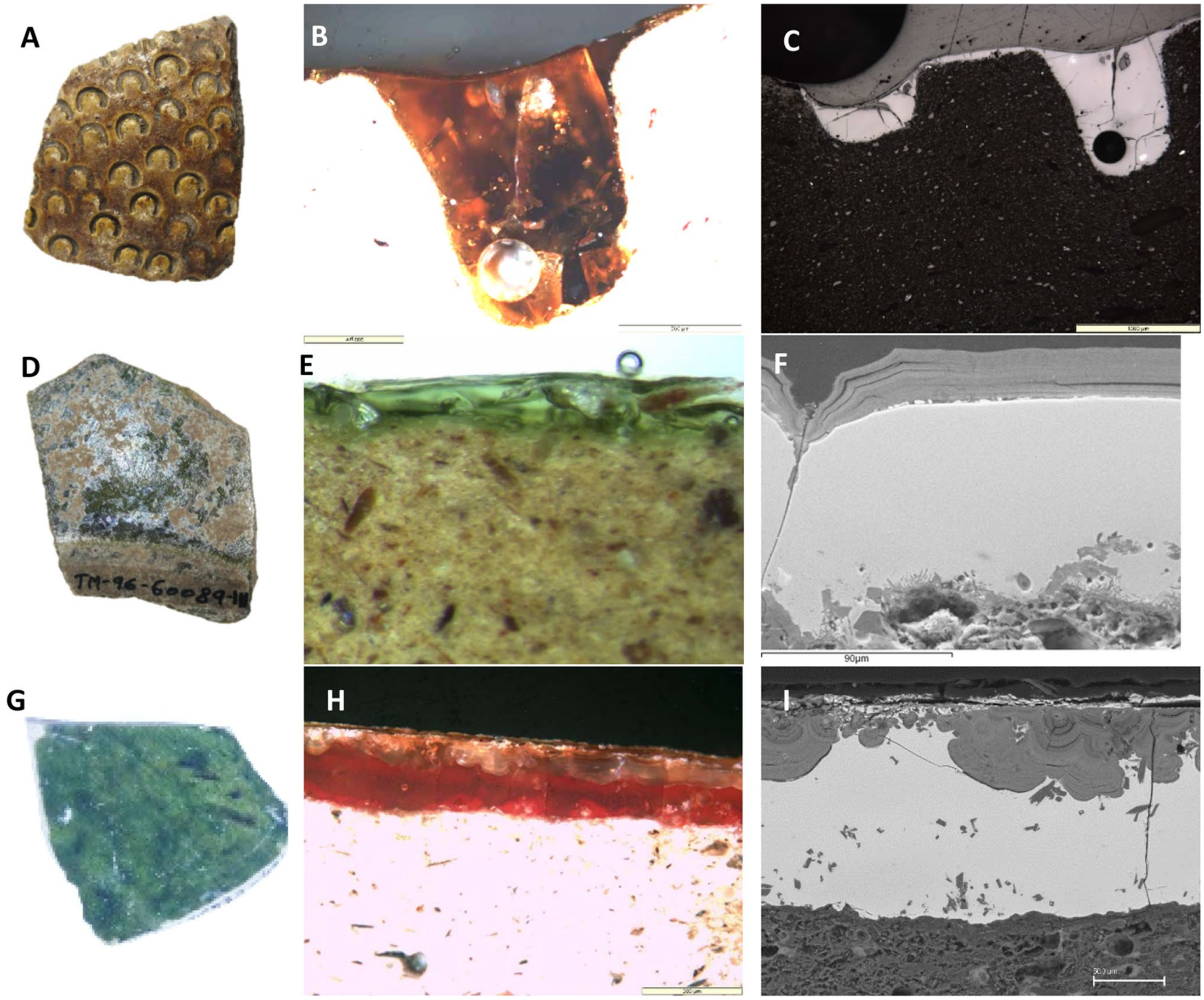

Fig. 7 Transparent lead glazes (**a**-**c** T41, honey glaze); **d**-**f** T35, green glaze; **g**-**i** T32, red glaze

conglomerates (Fig. 6d). All these features are similar to those observed in glazed ceramics from two places in the town of Cordoba, an area of pottery workshops Known as Zumbancón (Salinas and Pradell 2021) and another one of residential quarters (Posada de la Herradura, Salinas and Pradell 2018, 2020).

The second group (T6, T40) includes bodies with inclusions such as exfoliated muscovite micas, biotites, quartz, some microfossils and some lead fragments (Fig. 6f). This petrology is consistent with the one from analysed sherds from the Pechina workshop (Salinas et al. 2019). Moreover, one of the form (T6) is similar to the pitchers made in this workshop (Castillo and Martínez 1993). The main problem with this ceramic is its high alteration, both body and glaze, due to a post-burial alteration (Pradell and Molera 2020), which means that its chemical composition and microstructure are different from that of the same piece in a good state of preservation, explaining why the calcium levels are so high (35.6% CaO). This has prevented the results of the chemical analysis of the bodies and glazes from being compared with the rest of the compositions.

The third group (T7, T36) presents some prominent inclusions, of metamorphic type, among which phyllite stands out. It also contains large quartz, micas and chamotte (Fig. 6d). This is compatible with Murcia. For this, they have been compared with pieces from the Murcia glaze workshop, which have been partially published (Molera et al. 2009; Pradell and Molera 2020).

Monochrome/bichrome Transparent lead glazed ware (MT/BT)

The chemical analyses of the monochrome and bichrome transparent glazes are shown in Table 4. They include lead

(< 55% PbO) and high lead glazes (> 55% PbO) and offer a large variability (47–66% PbO). Calcium contents are variable (1.6–5.7% CaO) and aluminum one too (0.7–5.4% Al_2O_3) (Salinas and Pradell 2018). Sodium and magnesium contents are below 1%, except one case (T40 higher sodium amount).

Glazes show a minimal glaze-ceramic interface and parallel and perpendicular fissures (Fig. 7c, f, j). These are the characteristic features of a glaze made like a lead glass and applied on the biscuit surface, probably with Arabic gum (Salinas and Pradell 2018; Salinas et al. 2019) or a flour-based paste, as well as other factors, such as the firing time/temperatures and the clay composition (Pradell and Molera 2020). Moreover, some glazes present small bubbles (Fig. 7c).

Glaze colours are green obtained by the addition of copper, ranging from 1.8 to 6.5% CuO (Fig. 7d, e), honey with higher amount of iron (3.7–5.6% FeO) (Fig. 7a, b), and fired in an oxidising atmosphere, or greenish containing higher amount of iron than the copper-green ones (T7, 2.1% FeO), and fired in a reducing atmosphere. One glaze is red (T32) due to the solid reducing atmosphere in the copper green glaze that has provoked the presence of metallic copper nanoparticles (Fig. 7g, h, i). This peculiarity has also identified in one glazed ceramic from Córdoba (Salinas and Pradell 2018). Only one brown example was obtained by adding manganese (T44, 2.3% MnO).

Polychrome Transparent lead glazed ware (PT)

This group is characterised by applying iron honey, copper green and manganese brown decorations over a creamy transparent glaze. That is to say, the decoration was applied overglaze, not underglaze. All glazes are high lead (57–62% PbO) (Table 5) and rather pure, with very low sodium, magnesium, potassium, calcium and iron contents. Glazes also show a minimal glaze-ceramic interface.

Polychrome Tin-Opaque glazed ware (TO)

The chemical analyses of the polychrome tin-opaque glazes are shown in Table 5. Glazes are lead-alkali for the decorated side (~ 44.5% PbO) and high lead type for the outer plain glaze (~ 65.6% PbO). Moreover, they have a higher content of sodium than the transparent glazes of the undecorated surface (0.5% NaO_2), and that varies from the green glaze (1.1 NaO_2) to the brown (2.5 NaO_2) and the white glazes (2.1–2.8 NaO_2). They also have low amounts of magnesium (< 0.6% MgO), aluminium (0.6–1.2% Al_2O_3) and calcium (0.8–3.4% CaO). Tin is in the form of small cassiterite particles and is present in the decorated side in a high amount (9–10.7% SnO_2) and only in a small amount for the monochrome undecorated transparent glaze (0.3% SnO_2).

The colour decoration is the same as the polychrome transparent glazes: copper green and manganese brown are applied overglaze, as we can see clearly in the optical microscope images and are thicker than the white glaze (Fig. 8a, b, c, d). Green glaze comprises bubbles, partially dissolved quartz grains, and shiny copper particles accumulated on the surface (Fig. 8c, d). The brown glazed colour shows some undissolved manganese particles (Fig. 8e), while the white glaze is opacified with tiny cassiterite crystals (Fig. 8g).

Discussion

With the data available, no evidence of glazed ceramic production has been detected in El Tolmo. In the more than 30 years of the project, 553 glazed ceramic fragments of the 1.131.557 fragments inventoried up to 2014 have been located (Amorós-Ruiz 2018: 49), so it does not represent more than 0,005% of the ceramics documented at the site. Islamic glazed pottery appears associated with the stratigraphy of the entire ninth century. Although for this work, we have focused on the productions that span from the middle and second half of the ninth century (Phase 5.2), the end of the ninth century and early tenth century (Phase 5.3) and the beginning of the tenth century (Phase 6).

The data in percentage shows us that the arrival of glazed ceramics increased in the second half of the ninth century and grew at the end of this century and the beginning of the tenth century. It is mainly documented in domestic settings (Amorós-Ruiz and Gutiérrez 2021: 42–43) (Fig. 3).

In recent years we have been able to establish that in al-Andalus monochrome and bichrome transparent lead-glazed ceramics began to be produced first, during the ninth century. Shortly after, transparent glazes with more than two colours were produced, incorporating manganese oxide. By the early tenth century, tin-glaze technology was already being introduced (Salinas and Pradell 2018; Salinas et al. 2019). Furthermore, we have fully characterised the four earliest glaze production centres in the Iberian Peninsula (Salinas and Pradell 2020; 2021; Salinas et al. 2019; 2022).

Though, if we look at the phases, the samples of Phase 5.2 (middle and second half of the ninth century) have the same technology, monochrome/bichrome transparent lead-glazed ware. The last two Phases (5.3 and 6) show two novelties: the use of manganese for the polychrome transparent lead glazes and the use of tin in the polychrome opaque glazes for opacify the white background. This early presence of tin-glazed ceramic, before the Caliphate period, has been documented only in Cordoba (Salinas and Pradell 2018) and Madīnat Ilbira and Loja (Molera et al. 2018), as far as we know. Otherwise, there is no difference in the technologies consumed between these last

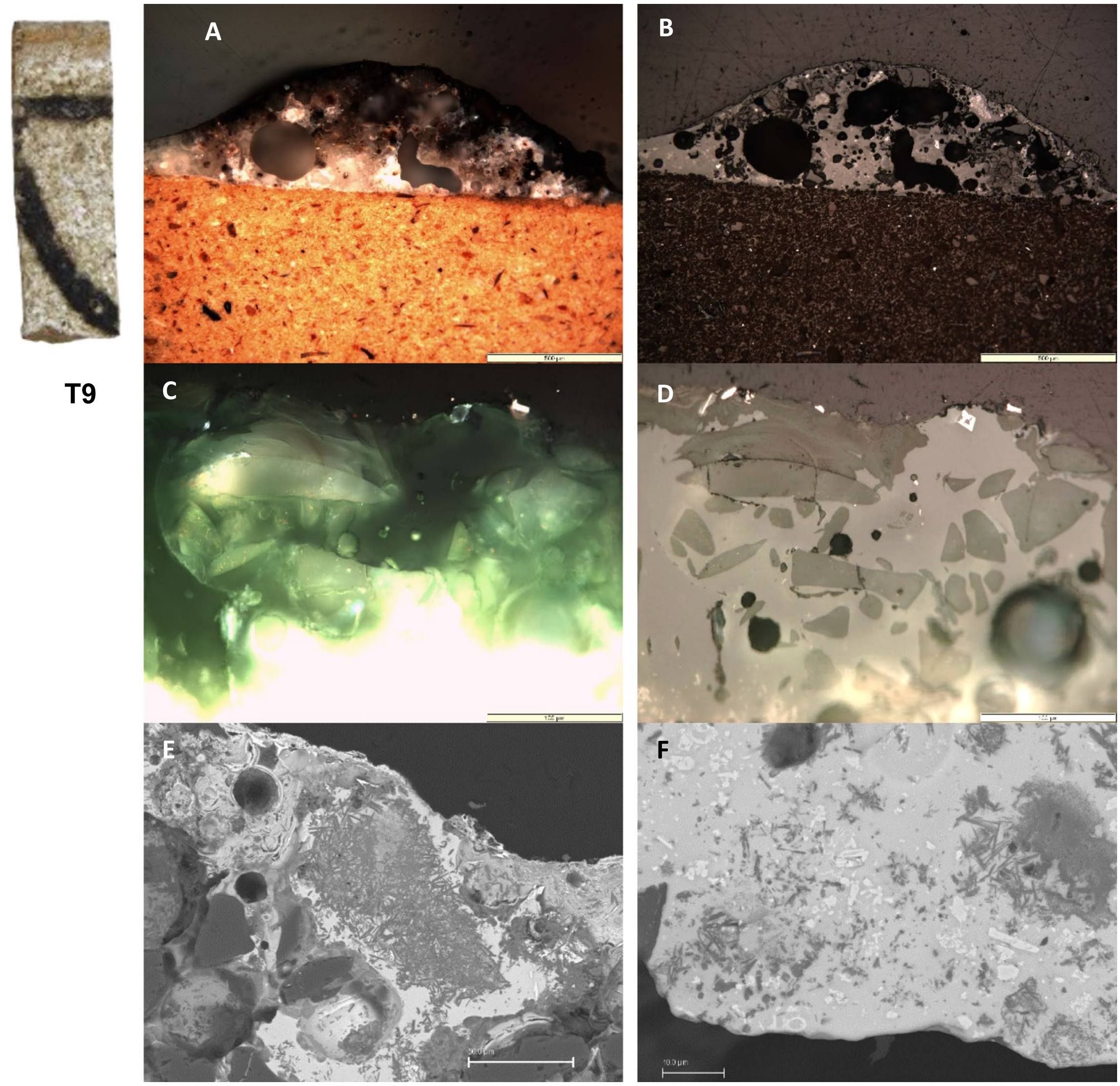

Fig. 8 **a** Tin-Opaque glaze T9. Optical and back scattering images of glaze colours: **b**-**c** brown colour applied over white glaze; **d**-**e** green glaze with numerous quartz grains and some bubbles, and shiny copper particles accumulated in the surface; **f** detail of manganese particle; **g** detail of the cassiterite crystals

two Phases, since monochrome transparent, polychrome transparent and tin-opaque glazes have been documented in both, which might suggest that there is not much time lag between the construction of houses/occupation (Phase 5.3), dated in the end of the ninth century, and the abandonment of El Tolmo (Phase 6), dated to the early tenth century (before or around 929 CE).

The ceramic shards' variability of the three Phases in terms of the chemical composition of fabrics and glazes corresponds to the fact that they are ceramics manufactured using different techniques (transparent and opaque glazes) and from other workshops. There does not seem to be any local production of glazed pottery in El Tolmo. Furthermore, the low percentage of glazed pottery (around 1%) in relation to the rest of the earthenware recovered from the contexts confirms that glazed pottery was a semi-luxury item in al-Andalus during the Emirate period. There are glazed ceramics from regional Andalusi workshops:

A majority group is represented by transparent monochrome, bichrome and polychrome glazes, and opaque polychrome glaze (Verde y manganeso), whose chemical composition and mineralogy are consistent to the Córdoba glazed ceramics (Fig. 9). This leads us to think that these ceramics could come from Córdoba since their physical characteristics, determined by the data offered in this work, lead us to rule out Pechina and Murcia as the origin of this group of glazes.

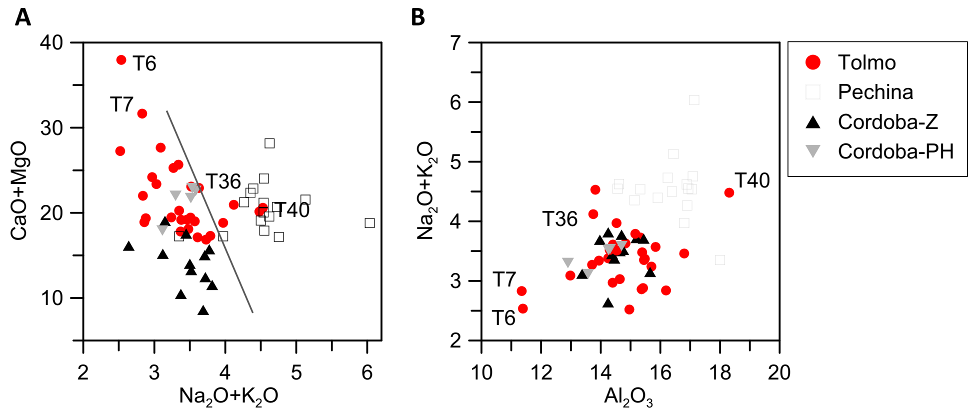

Fig. 9 Body chemical composition plots: **a** correlation of CaO + MgO versus $Na_2O + K_2O$; **b** correlation of $Na_2O + K_2O$ versus Al_2O_3. Compositions from the Cordoba (Z) and Pechina workshops and Córdoba residential context (PH) have been added

Apart from this, four pieces are "loners" (T6, T7, T36, T41) and do not fit in with the majority group. There are clearly detected in the correlation CaO + MgO versus $Na_2O + K_2O$ and fabrics without calcium and $Na_2O + K_2O$ versus Al_2O_3 correlated (Fig. 9a, b). T6 and T41 could be from Pechina, both in terms of typology and petrology, and T40 in terms of chemical composition. T6 is a pitcher like the forms made in Pechina's workshop and shows a high calcareous body and much altered glaze because of a post-burial alteration. T7 and T36 have a fabric and chemical composition very similar to others analysed from Murcia (partially published in Molera et al. 2009).

The most thrilling result is that pottery manufactured in Cordoba was being consumed at El Tolmo, which appears in more significant numbers than that of another early and nearby production centre, Pechina. Until a few years ago, it was thought that Pechina was the main production centre supplying al-Andalus in the Emirate period (Salinas and Zozaya 2016). Among other reasons, because the Cordoba Emirate glazed production had not yet been identified. El Tolmo group that includes these 27 ceramics has many similarities with the one found at Posada de la Herradura (Córdoba) (Salinas and Pradell 2018), where the three glazing techniques are also represented. This is the first time that we have found parallels of transparent and opaque polychrome glazes like those from Posada de la Herradura outside Córdoba.

A pitcher seems to be from Pechina, and there are probably more in El Tolmo, although they are not among those we have analysed. From the data we have (IGATO project), the distribution of Pechina ceramics was by sea and concentrated in the southeast of the peninsula. At the same time, the Cordoba workshops supplied the peninsula's interior (Salinas 2019). This confirms the existence of an internal regional trade in al-Andalus, which supplied, among other objects, semi-luxury glazed ceramics, and which would have started in the Umayyad capital of Córdoba and reached El Tolmo.

Furthermore, the presence of a ceramic sherd probably produced in Murcia leads us to consider whether we should revise the dating with two possibilities: 1) the workshop in Murcia began to produce glazed pottery in the Late Emirate period and not the Caliphate period; 2) the definitive abandonment of El Tolmo took place in the tenth century, in the Caliphate period, later than traditionally proposed. Nevertheless, archaeological evidence does not support the second possibility, including the ceramic forms documented in the last levels of occupation, where no caliphal-type records are documented. Due to archaeological evidence, the site had to be abandoned before or around the creation of the Caliphate of Córdoba in 929 CE (Amorós-Ruiz 2018, 371–373). On the other hand, the publication on Alfar de San Nicolás in Murcia indicates that the oldest ceramics, including glazes, can be dated in general terms to the Caliphate period; however, there are indications by shape and manufacture that these could predate the Caliphate, including some forms with second half of the ninth century parallels (Navarro Palazón 1990: 39–42; Gutiérrez 1996: 273–274).

What is more apparent is that different glazed ceramic workshops seem to have been working simultaneously in the second half of the ninth century and the beginning of the tenth. According to the data that we have at present, at least three of these identified glazed ceramic workshops point out Cordoba, Pechina and Murcia. The leading information collected in this work is that although these workshops did not start producing glazed pottery at the same time, they were all operating simultaneously (Tolmo Phases 5.2, 5.3 and 6) in the second half of the ninth century and at the beginning of the tenth century and supplying other Andalusi cities beyond their local radius. This confirms that the consumption of glazed ceramics in the Iberian Peninsula at the end of the Emirate was consolidated, although not popularised, as the percentage is still meagre, and was able to supply a market more than 300 km away by land, which was more expensive to transport. This is the same trend documented in other Islamic regions, in which the consumption of glazed ceramics also strengthened in the ninth century.

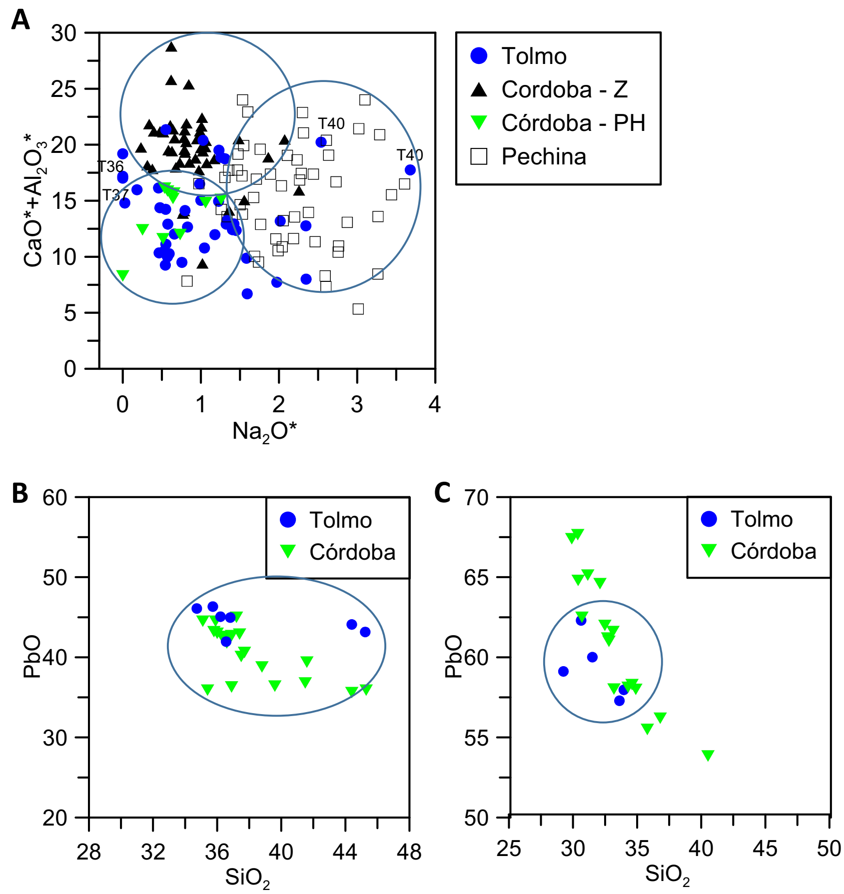

Fig. 10 Glaze chemical composition plots of El Tolmo: **a** correlation of $CaO + Al_2O_3$ versus Na_2O in the monochrome/bichrome transparent glazes; **b** correlation of PbO versus SiO_2 in the opaque glazes; **c** correlation of PbO versus SiO_2 in the polychrome transparent glazes

Concerning glaze technology of the three workshops represented, no major differences can be seen, as they all worked with the same glaze technique of making a lead glass and adhering it to the biscuit surface (Salinas et al. 2019, 2022). As we can see in the Fig. 10, after copper, iron and manganese colourants been removed, monochrome and bichrome transparent glaze base compositions have been compared: $CaO + Al_2O_3$ versus Na_2O show that there is more similarity with the Cordoba workshops, except for T40 which is more compatible with a Pechina provenance (Fig. 10a). The correlation PbO versus SiO_2 have been employed for the polychrome glazes, both transparent (Fig. 10c) and opaque (Fig. 10b). Both show affinity with Córdoba.

Conclusions

The chemical composition and optical microscopy of the bodies and glazes show pretty homogeneous characteristics, with some exceptions, with no differences related to the use of different technology, i.e. the leading group of fabrics integrates both transparent and opaque glazes. This fact points to a prominent centre for the supply of glazed wares to El Tolmo de Minateda.

We have therefore distinguished three possible provenIences. The largest group corresponds to those with very similar characteristics to the Cordoban workshops, and the characteristics of the other two groups point to Pechina and Murcia. The first is compatible with Córdoba, especially with the Posada de la Herradura group. Both have similar technological characteristics (transparent 1–2 coloured glazes, transparent polychrome and opaque tin glazes), and mineralogical and chemical characteristics in the pastes and glazes. A minor grade of affinity is with the defective glazed ceramics recovered at the Zumbacón artisanal area of Córdoba, where another set of pottery workshops was found. Research (Salinas and Pradell 2021) indicates that glazed pottery production at the Zumbacón would use another clay quarry, without so many limestone nodules and somewhat richer in calcium, aluminium and magnesium. There are also some differences in the composition of the glazes, with those from El Tolmo and Posada de la Herradura being richer in lead. They probably used a glaze manufacturing recipe with a higher lead oxide content. However, it should not be forgotten that the glazed ceramics from the Zumbacón are workshop material which, in many cases, has been over-fired or, on the contrary, under-fired, which affects the composition of the glazes, compared to those which are not defective, and which finished their manufacturing process correctly.

In any case, the relationship between Tolmo samples and Córdoba seems to indicate the existence of more than one glazed ceramics workshop in Córdoba operating at the end of the Emirate. A second one of these workshops has not yet been identified and could be close to the Zumbacón artisanal area. We must also point out how the evidence from El Tolmo shows an increase in the arrival of Cordoba products at the end of the ninth century. Therefore, the existence of several workshops in Córdoba would be justifiable given the increased demand for these products and distribution routes between the capital and a large part of the peninsula's interior.

The main hypothesis, that there was no local production of glazed ware and that many of the pieces came from the production centre of Pechina, located more than 200 km away, has been discarded, although the most likely provenance of two ceramics (T40 and T6) is still there. However, the largest ceramics group probably came from the Córdoba production centre, located some 350 kms away, where transparent and tin-opaque glazed ceramics were produced. A third production centre has been identified and it may possibly correspond to Murcia. It is the closest workshop, located some 75 kms away. Two ceramics are compatible with this provenance (T36 and T7). We know that this workshop was in operation in the Caliphate period. However, the same researcher who studied the deposit in Murcia in 1990 contemplated the possibility of a pre-Caliphate production associated with closed forms and pitchers (Navarro Palazón 1990: 42). The evidence of glazed pitchers from Murcia could corroborate a production from the second half of the ninth century in Murcia, which was already intuited in the 1990s (Gutiérrez 1996: 273–274). In any case, archaeological evidence of the presence of pottery opacified with tin, of the "verde and manganeso" type, of late Emiral chronology, points to a date of the beginning of the tenth century for the stratigraphic contexts of the Tolmo where these two pieces were found. We know that this production started in Córdoba in the late 9th- early tenth centuries (Salinas and Pradell 2018; 2020).

The main suggestion of this paper is, in the end, that most of the glazed ceramics found in the relevant phases of El Tolmo de Minateda came from the workshops of Cordoba, and arrived by land, showing an active regional distribution route for early glazed pottery in al-Andalus, while some glazed ceramics supplied from Pechina by sea/land and from Murcia, by land. The latter, the head of the Kura, is the closest procuring centre, somewhat later than the first two, and was not known to have been in operation at the beginning of the tenth century.

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Author contributions E.S and V. A-R wrote the main manuscript text.
V. A-R prepared figures 1-4
E.S. prepared figures 5-10
E.S and V. A-R prepared table 1
E.S. prepared tables 2-5
All authors reviewed the manuscript

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Data Availability The authors confirm that all data generated or analysed during this study are included in this published article.

Declarations

Competing interests The authors declare no competing interests.

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