# Ceramic production in Granada and in the southeast of the Iberian Peninsula during the late middle Ages

## Clays, tools and pots – some preliminary notes

**Alberto García Porras, Claudio Capelli, Roberto Cabella, Julia Romero Pastor and Carolina Cardell ***

*Summary*

*This work presents the preliminary features of ceramics production in the Southeast of the Iberian Peninsula and especially in Granada during the late middle Ages. This research is based on complementary archaeometrical analyses carried out on clays from traditional quarries used in the area, as well as on ceramics that were selected as representative due to their chronology, origin (the area where potters' workshops were located) and function (tools used by the potters).*

## Introduction

It is known that high quality ceramics were produced in the Southeast of the Iberian Peninsula during the late Middle Ages. The ceramics produced during the *Nasrid* kingdom of Granada (Figure 1), which was the last area under Islamic control (13th–15th centuries), circulated within the Mediterranean area reaching, as well, northern Europe. In fact, shards have been found in several assemblages in the British Isles (Gerrard et al 1999; Vince, 1980).

Even though this ceramic production is quite important, only a few things are known about it. The vast majority of research studies on ceramics produced in the Nasrid kingdom focus on the features of the decorative patterns (Flores Escobosa1998). Studies on domestic assemblages have always been carried out taking into account the general features of ceramics classes and forms. Studying technical aspects make it possible to understand the features of this production: raw material, specific production centres, techniques used during the manufacturing process andchanges in the technical process throughout time and especially after the conquest of the Nasrid kingdom. This paper consists of preliminary notes on the topic outlined above. For this reason we considered itappropriate to focus on archaeometrical analyses on the ceramics made by different workshops in Granada and Malaga, that is the most important production centre within the Nasrid kingdom. A central point is to identify the clay normally used by potters working in Granada or in diverse places in Malaga and its environs. The final aim is to understand the features of Nasrid ceramics, distinguishing those made in Granada and Malaga. Particularly interesting is the attempt to identify ceramics produced in the South-East of the Iberian Peninsula, and to distinguish productions from Malaga and Granada from diverse ones.

This paper summarises the preliminary results on the archaeometrical analyses concerning the technical and geological features of a representative sample of the ceramics referred to above. Different features are discussed, namely the ceramic composition (including component percentages), the raw materials used according to their function, and the temperature and type of atmosphere during the pottery firing processes. The potential raw materials, ie clays, are also analysed so as to distinguish locally made pottery from others produced elsewhere. The aims of this research are to distinguish local ceramic production (ie pottery made in Granada) from imports from neighbouring areas, to understand the techniques and raw materials employed

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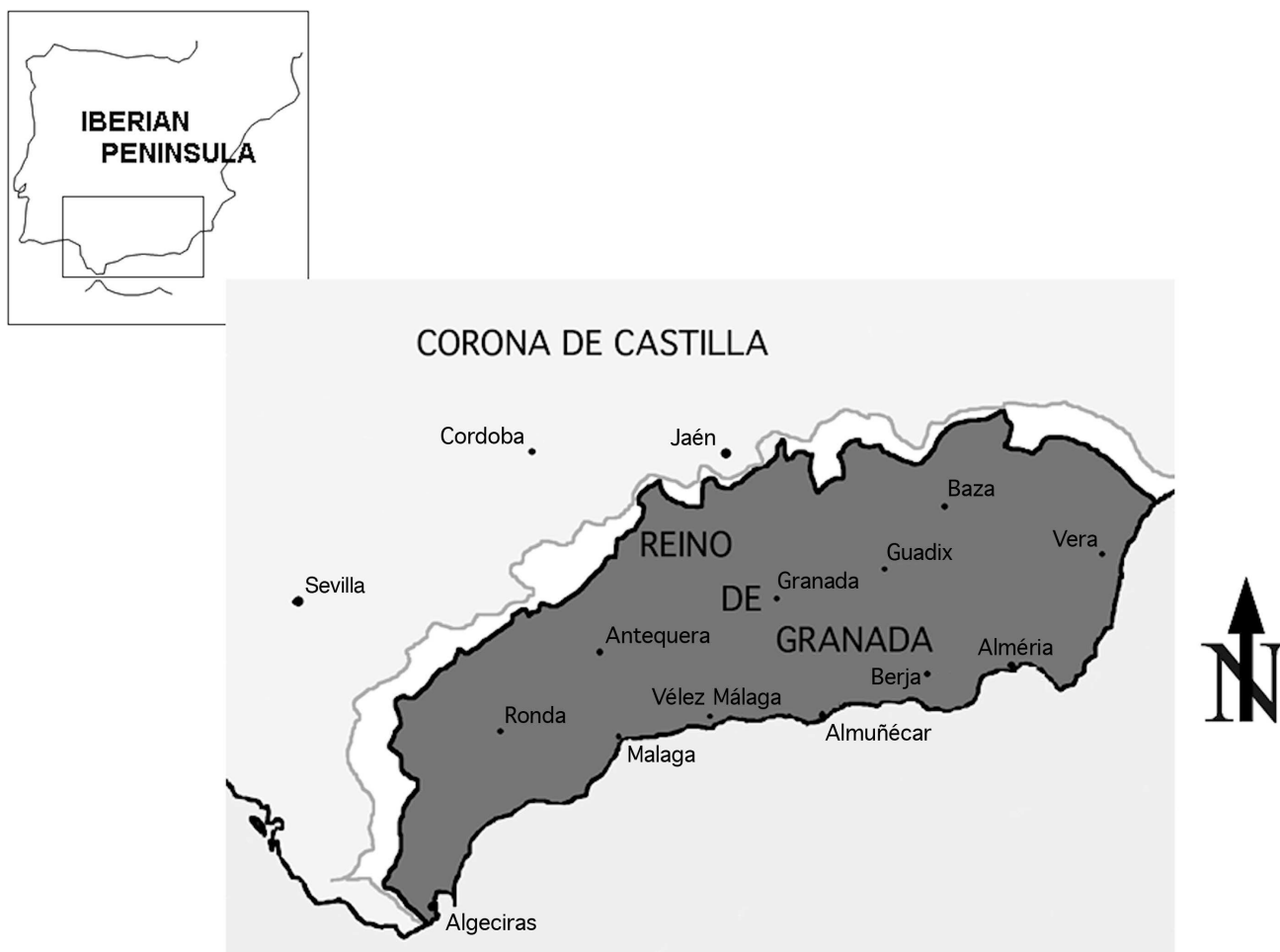Department of Mineralogy and Petrology, University of Granada.

**Figure 1**
The Nasrid kingdom of Granada (13th–15th centuries).

and, finally, define a reference group in order to be able to identify the productions of Granada–Malaga area recovered in extra-regional consumption sites. This is the first time that an archaeometric characterisation has been applied to the study of ceramic production from the South of the Iberian Peninsula during the late Middle Ages. The study undertaken includes chemical, mineralogical and textural analyses of selected ceramic samples from Granada that are representative of the whole production during the studied epoch. Additionally clay samples collected from some of the most important production areas of the Islamic Granada kingdom, as well as from the surrounding region of the ceramic workshops have been analysed.

## Studied materials and geological setting

The *Nasrid* kingdom of Granada was the last Islamic kingdom in the Iberian Peninsula (13th–15th centuries), which included the area of the current districts of Málaga, Granada and Almeria, in the Southeast of the Iberian Peninsula. The ceramics produced in the *Nasrid* kingdom were high standard products that circulated

within the trade network existing in the Mediterranean area and in the North Sea (García Porras and Fábregas García 2010; Vince 1980). As far as we know ceramic production centres were located in the major towns of the kingdom: Granada (the capital city), Malaga (the most important harbour of the kingdom) and Almeria (another important harbour), but minor cities like Ronda, Antequera and Guadix should also be mentioned.

Different areas have been considered as possible clay sources for the ceramics analysed in this work. For the ceramics from the district of Granada, these areas correspond to ancient quarries located in the *Granada Basin* (specifically the *Alhambra Formation* and *Víznar* area), and in the *Guadix Basin* (Cultrone et al 2001). Both *Basins* developed during the Alpine folding of the Baetic Cordilleras and contain Pliocene clay-rich materials (Figure 2). In the *Guadix Basin* siliciclastic deposits are predominant and derived from fluvial and alluvial environments with highly varied grain sizes. The *Granada Basin* is mainly composed of lacustrine materials and in particular of conglomerates, sands, silts and gravels. However, the *Alhambra Formation* (pertaining to the *Granada Basin*) is also rich in fluvial conglomerates and sands. Both basins

contain metamorphic and carbonate pebbles from the surrounding Sierra Nevada Mountains (Puga et al 2007, see Figure 3).

Two main geological complexes outcrop in the Sierra Nevada: the *Veleta* and the *Mulhacen* complex, both belonging to the *Nevado–Filábride* domain (Puga et al 2007). The *Veleta* domain is characterised by graphitic micaschists, quartzites, and amphibolites, while in the *Mulhacen* domain the main rocks are graphitic micaschists, gneisses, and marbles (Puga et al 2007).

Clays from *Guadix* and *Víznar* have been studied on different occasions; in fact the ancient quarries of these localities supplied the raw material to produce bricks (Cultrone et al 2001). *Guadix* clays are very rich in quartz and phyllosilicates with minor amounts of feldspars. *Víznar* clays have similar composition to Guadix clays but calcite and dolomite are abundant. Clays from the *Alhambra Formation* have been traditionally used to fabricate bricks, mortars, cements and *tapiales* (earthy construction) for the *Albayzín* walls and the Alhambra of Granada (De la Torre 1995; De la Torre et al 1996; Ontiveros et al 1999). These Ca-poor clays are very rich in phyllosilicates with minor amounts of quartz and dolomite; Fe oxi-hydroxides are also found.

The area of *Casabermeja* close to Málaga city was sampled as the clay supply for ceramics from the district of Málaga. In this area, the Maláguide Complex (Baetic Cordillera; Vera 2004) outcrops. Here it is important to note the presence of shales containing dykes of subvolcanic rocks, schists, quartzite, gneisses and micritic limestone. Clays are also abundant, and they
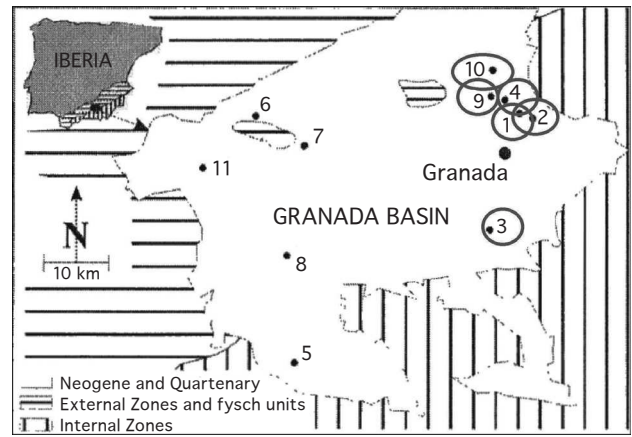


**Figure 2**
Ancient clay quarries located in the Granada Basin (**1**, **2**, **9** and **10**), the Víznar area marine sediments (**3** and **4**) and the Otura area marine-continental transition sediments.

have been used in the production of ancient ceramics as for instance Phoenician ceramics (Cardell et al 1999).

According to written sources and archaeological evidence, ceramic production during the late Middle Ages was mainly located in large towns. In Granada an important production area was the *rabad al-Fajjarin* (Álvarez García and García Porras 2000). In Malaga, potters' workshops were located in the area known as *Fontanalla* (López Chamizo et al 2009). At Almeria, we have some evidence of workshops outside the medieval town walls (Flores et al 1996).
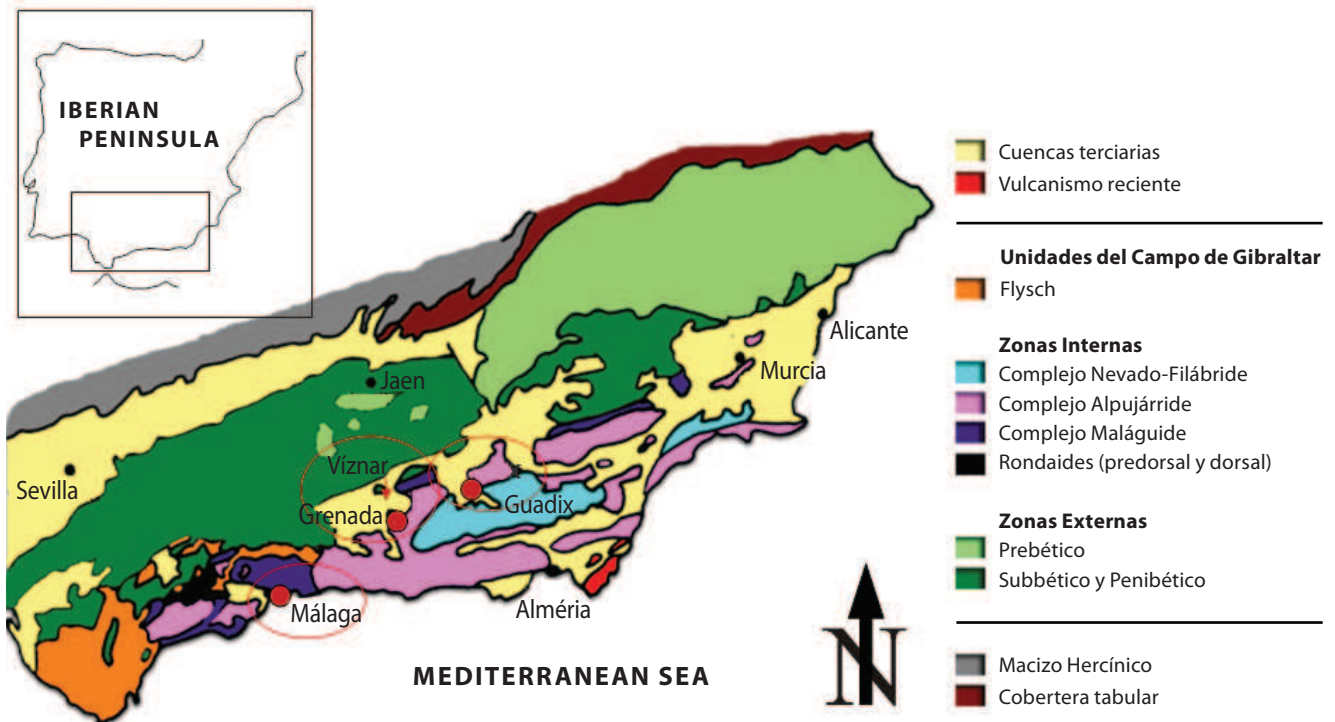


**Figure 3**
Geological location of ceramics and clays studied from Granada and Málaga (Andalusia, Spain).

A total of sixteen ceramic samples were studied (Table 1); several are tools used in the workshop (*atifle,* bars, discs). Thus, these objects are an important part of the ceramicproduction process in Granada during the middle Ages. Other samples correspond to different ceramics types: pottery for domestic use (trays, storage vessels, pots, dishes) as well as architectural elements (floor tiles).

## Analytical techniques used in the archaeometrical study

To perform the petrographic study (composition and texture) of the ceramics (paste and glaze) polished thin sections of the sixteen samples (Table 1) were prepared at the DipTeRis of the University of Genova. Firstly, they were examined by polarized light microscopy (Olympus BX51) equipped with digital microphotography. Later on, the chemical composition and microstructure of ten samples (all the glazed samples except GR15, whose glaze is highly weathered) were analysed with a Philips SEM 515 Scanning Electron Microscope (SEM) equipped with an energy-dispersive spectrometer (EDAX PV9100). Microanalyses of glazes (except for Sn) were carried out on at least three selected points (spot mode) along a cross section from the base to the surface of the glaze, avoiding alterations, reaction zones, opacifiers, and mineral inclusions. The presented mean values are normalised to 100wt%. Averaged Sn contents were obtained by window mode. Based on microscopic techniques, ceramics groups were established according to differences in mineralogy, morphology and distribution of inclusions, vitrification degree of the pastes and the glaze types.

X-ray diffraction (XRD) was used (Department of Mineralogy and Petrology of the University of Granada) to determine the mineralogical composition of the clays and of the ceramic pastes, so to ascertain the firing temperature of the ceramic samples. A Philips PW 1710 diffractometer equipped with an automatic slit and Cu–K radiation was used. The diffractograms were interpreted using the *XPowder* software package (Martín 2004).

Bulk chemical quantitative analyses were performed (Department of Mineralogy and Petrology of the University of Granada) by means of X-ray fluorescence (XRF; S4 Pioneer, Bruker AXS) in both the clays and ceramic bodies analysed with XRD (see Table 1). Major and minor element contents are reported as wt% oxide normalised to 100%, while trace elements are expressed in ppm, LOI-free. Assuming that ceramics manufactured with similar raw material have similar chemical composition, differences in chemical composition can be interpreted as changes in the supply of local clays. Thus, the XRF data from ceramics and clays were analysed by chemometric tools, ie Principal Component Analysis (PCA)

to acquire information about their similarity and clustering. The product and Service Solutions program (SPSS, for Windows Ver. 15, USA) and Excel 2000 (Microsoft Corporation, USA) was used (Navas et al 2008; Cultrone et al 2010).

## Results and discussion

### Optical and electron microscopy

Ceramic pastes

The fabric of the ceramic pastes showed a relatively large compositional and textural variability. Nine main fabric groups, with few sub-groups, were recognised (see Table 2 for a detailed description). The variability concerns both the clay matrix (from Fe-oxide-rich to carbonate-rich) and the inclusions. Common characteristics are the presence of inclusions derived from acid metamorphic rocks and the prevalence of angular grains (Figure 4).

The main distinguishing features of the groups are the following (see also Table 2).

Group 1
Fe-rich matrix; abundant coarse-grained silicate inclusions; rock (mainly quartz-micaschist, often garnet-bearing) fragments predominant in the coarse fraction (Figures 4.1, 5.1); accessory presence of several heavy minerals.

Groups 2–4
Fe-Ca-rich matrix; relatively scarce sand inclusions (Figures 4.2, 5.2–3); presence of carbonate elements (limestone fragments and calcareous microfossils dissociated by firing); abundant fine-grained mica individuals.

Group 5
Fe-Ca-rich matrix; very abundant fine- to medium-grained inclusions of metamorphic and sedimentary origin (Figures 4.3, 5.4); frequent carbonate elements (also shell fragments).

Groups 6–7
Ca-rich matrix; abundant fine-grained inclusions; frequent carbonate elements (Figure 4.4).

Group 8
Ca-rich matrix; fine-grained and relatively scarce inclusions (Figures 4.5, 5.5); frequent carbonate elements.

Group 9
Ca-rich matrix; very abundant well-sorted inclusions (Figure 4.6); frequent micaschist/phyllite, quartz-micaschist and subordinate altered basaltic/dioritic fragments.

**Table 1**

Analysed samples (ceramics and clays).

The origin, ceramic type, function, chronology and type of archaeometrical analysis are noted.

| Samples | Origin | Ceramic type | Function | Cronology | Análisis | | |
|---|---|---|---|---|---|---|---|
| | | | | | OM body | SEM body & glazes | XRD & XRF |
| **GR1** | Cuarto Real de Santo Domingo (Granada) | Disco (disc) | workshop tool | 14th century | X | | X |
| **GR2** | Cuarto Real de Santo Domingo (Granada) | Atifle | workshop tool | 14th century | X | | X |
| **GR3** | Cuarto Real de Santo Domingo (Granada) | Barra (kiln bar) | workshop tool | 14th century | X | | X |
| **GR4** | Cuarto Real de Santo Domingo (Granada) | Ataifor blanco-verde (white-green tray) | Ceramics used at home – Eating | 14th century | X | X | |
| **GR5** | Cuarto Real de Santo Domingo (Granada) | Ataifor verde (green tray) | Ceramics used at home – Eating | 14th century | X | X | |
| **GR6** | C/ Solares (Granada) | Azulejo azul (blue tile) | Architectural use | 14th century | X | X | |
| **GR7** | C/ Solares (Granada) | Azulejo azul (blue tile) | Architectural use | 14th century | X | X | |
| **GR8** | C/ Solares (Granada) | Azulejo verde (green tile) | Architectural use | 14th century | X | X | X |
| **GR9** | C/ Solares (Granada) | Azulejo turquesa (turquese tile) | Architectural use | 14th century | X | X | |
| **GR10** | Cuarto Real de Santo Domingo (Granada) | Tinaja estampillada (storage jar with impressed decoration) | Ceramics used at home – storage use | 14th century | X | | |
| **GR11** | Cuarto Real de Santo Domingo (Granada) | Tinaja estampillada (storage jar with impressed decoration) | Ceramics used at home – storage use | 14th century | X | | |
| **GR12** | Cuarto Real de Santo Domingo (Granada) | Cazuela melada (cooking pot with Honey-coloured glaze) | Ceramics used at home – cooking | 14th century | X | X | |
| **GR13** | | Plato Fajalauza blanco-azul (white-blue Fajalauza dish) | Ceramics used at home – eating | 16th century | X | X | |
| **GR14** | Cuarto Real de Santo Domingo (Granada) | Ataifor melado-manganeso | Ceramics used at home – eating | 14th century | X | X | |
| **GR15** | Cuarto Real de Santo Domingo (Granada) | Ataifor blanco | Ceramics used at home – eating | 14th century | X | X | |
| **VAL100** | Cuarto Real de Santo Domingo (Granada) | Candil blanco-azul | Ceramics used at home – lighting | 14th century | X | X | |
| **ALH** | Cerro del Sol – Alhambra (Granada) | Clay | | | | | X |
| **VIZ** | Víznar (Granada) | Clay | | | | | X |
| **GUA** | Guadix (Granada) | Clay | | | | | X |
| **DES** | Casabermeja (Malaga) | Clay | | | | | X |
| **Nº 3** | Malaga | Clay | | | | | X |
| **Nº 6** | Malaga | Clay | | | | | X |
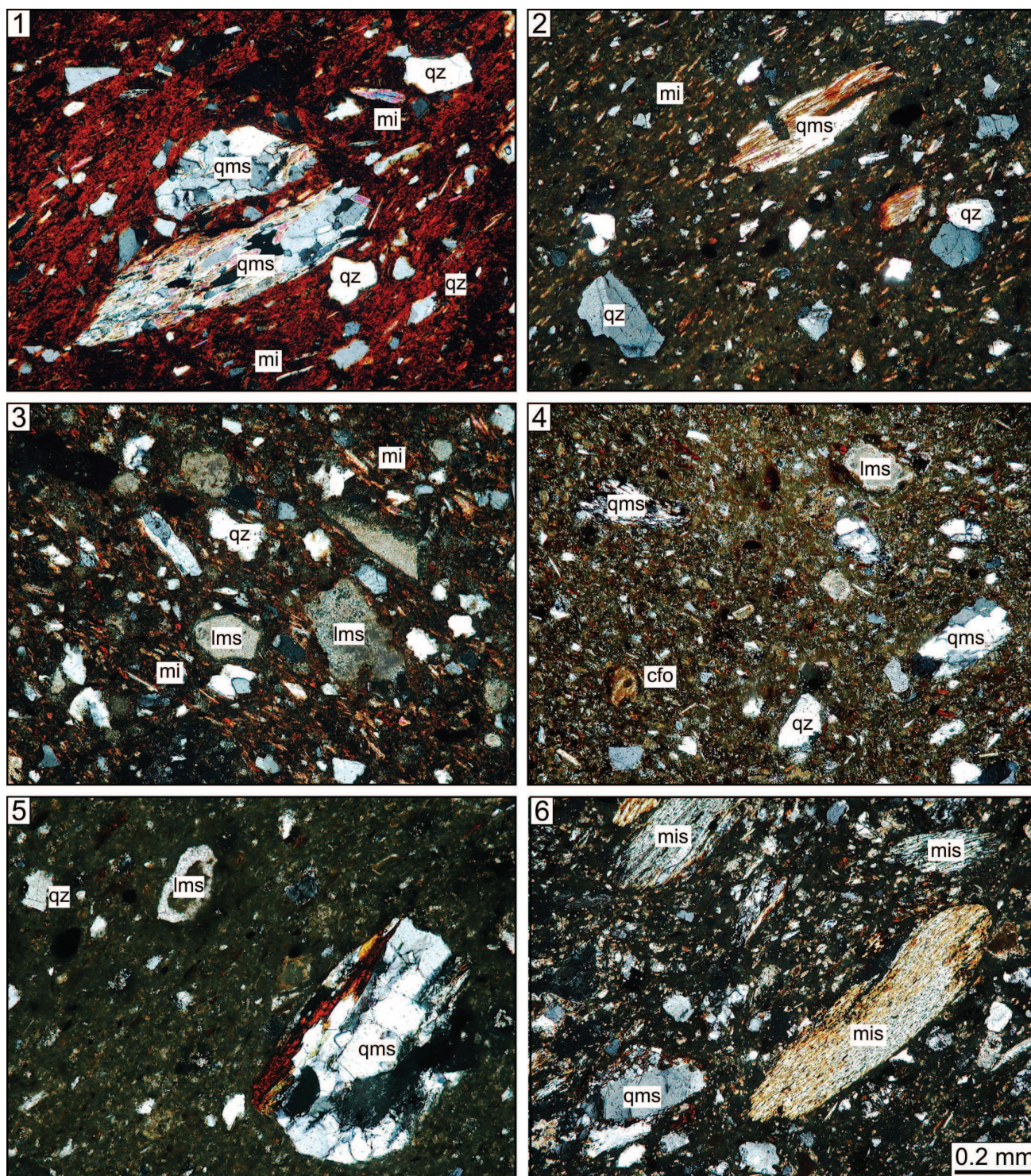
**Figure 4**
Microphotographs (crossed polar) of ceramic bodies.

**1** GR1 (group 1)   **2** GR5 (group 3.1)   **3** GR4 (group 5)
**4** GR2 (group 6)   **5** GR9 (group 8)     **6** GR6 (group 9);

cfo  calcareous microfossil    mis  micaschist
lms  limestone                 qms  quartz-micaschist
mi  mica                       qz  quartz

**Table 2**

Main compositional and technical characteristics of the fabrics and glazes (from thin section and SEM-EDS analyses).

| B brown | C cobalt blue G green | O orange | R red | T turquoise |
|---|---|---|---|---|
| U uncoloured | Y yellow (body and glaze colour) | A abundant | L low | M medium |
| V very (various fields) | am amphibole | cfo calcareous microfossil | ep epidote | cht chert |
| fs feldspar | gt garnet | lms limestone | mi mica | mis micaschist |
| op opaque mineral | qms quartz-micaschist | | qz quartz | qzs quartzschist |
| rt rutile | sfo siliceous microfossil | shf shell fragment | sst sandstone | tm tourmaline |
| tt titanite | vol volcanite | zr zircon (inclusions) | OP opacified | TR transparent (glaze type) |

Ca carbonate-rich, Fe-oxide-rich (clay matrix)

| fabric group | sample no. | thin section no. | typology | macroscopical body colour | clay matrix | groundmass (inclusions <0.1 mm) % | sand inclusions % | sorting | max dimensions of inclusions (mm) | most frequent dimensions (sand fraction, mm) | predominant components | subordinate components | accessory/occasional components | vitrification degree (apparent firing T) of body | graze type | cassiterite % | glaze thickness (mm) | glaze-body interface thickness | regularity glaze-body contact | glaze colour in thin section | colouring agent | weathering | provenance hypothesis (integrated data) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | GR1 | 6656 | disco | R | Fe | A | M | M | 1.5 | <0.7 | qz, mi, qms | qzs | mis, fs, ep, gt, op, am, rt, tm, tt, zr | M | | | | | | | | | local (waster) |
| 1.1 | GR10 | 6665 | tinaja | R | Fe | A | A | M | 1.6 | <0.7 | qz, mi, qms | qzs | mis, fs, ep, gt, op, am, rt, tm, tt, zr | M | | | | | | | | | local |
| 1.1 | GR11 | 6666 | tinaja | R | Fe | A | A | M | 2 | <0.7 | qz, mi, qms | qzs | mis, fs, ep, gt, op, am, rt, tm, tt, zr | M | | | | | | | | | local |
| 1.2 | GR12 | 6667 | cazuela | R | Fe | A | A | L | 1.2 | <0.5 | qz, mi, qms | qzs | mis, fs, ep, gt, op, am, rt, tm, tt, zr | H | TR | | <0.10 | H | VL | Y | Fe | VL | local |
| 2.1 | GR3 | 6658 | barra | O | Fe-Ca | A | M | M | 1 | <0.5 | qz, mi | mis, qms, lms | qzt, cht, fs, op, tt, cfo? | H | | | | | | | | | local (waster) |
| 2.2 | GR13 | 6668 | plato | O | Fe-Ca | A | M | M | 0.5 | <0.3 | qz, mi | mis, qms | cht, fs, op, tt, cfo? | H | OP | M | 0.15-0.40 | L | M | U | Co | VL | local |
| 3.1 | GR5 | 6660 | ataifor | YO | Ca-Fe | M | M | M | 0.8 | <0.5 | qz, mi | qms, cfo? | mis, lms, cht, fs, op, gt | M | TR | | 0.10 | H | M | G | Cu | M | local (regional) |
| 3.2 | GR14 | 6669 | ataifor | O/Y | Ca-Fe | M | L | M | 1 | <0.5 | qz, mi | qms | mis, lms, fs, am, cfo? | H | TR | | 0.10-0.15 | M | M | U | | M | local (regional) |
| 4 | GR15 | 6670 | ataifor | RO | Fe-Ca | A | L | M | 0.5 | <0.3 | mi, qz | qms, cfo | mis, lms, cht, fs, ep, gt, tm, sfo | L | TR | | <0.10 | M | M | ? | | VH | regional |
| 5 | GR4 | 6659 | ataifor | O | Fe-Ca | VA | A | L | 0.7 | <0.2 | qz, mi, lms | qms, cfo? | cht, sst, fs, ep, am, gt, zr, shf | L | OP | L | 0.10-0.15 | H | M | U | | H | regional |
| 6 | GR2 | 6657 | atifle | Y | Ca | VA | VL | M | 1 | <0.2 | mi, qz, lms | cfo? | qms, fs, op, tt | L | | | | | | | | | local (waster) |
| 7 | GR8 | 6663 | azulejo | YO | Ca-Fe | VA | VL | L | 0.3 | <0.2 | mi, qz, lms | cfo? | qms, fs, tt, op | M | TR | | 0.30-0.50 | H | L | G | Cu | VL | local/regional |
| 8 | GR7 | 6662 | azulejo | Y | Ca | M | VL | L | 1 | <0.2 | qz, mi, lms | cfo? | qms, fs, tt, op | M | OP | H | 0.50-0.60 | M | M | T | Co | VL | local/regional |
| 8 | GR9 | 6664 | azulejo | YO | Ca | M | VL | L | 0.7 | <0.2 | qz, mi, lms | cfo? | qms, fs, tt, op | L | OP | H | 0.10-0.20 | H | M | T | Cu | M | local/regional |
| 9.1 | VAL100 | 9279 | candil | BY | Ca-Fe | A | M | H | 0.7 | <0.4 | qz, mi, mis, qms | lms, cfo, fs | vol, op, tt, am | M | OP | ? | <0.15 ? | M | M | U/C | Co | H | Malaga |
| 9.2 | GR6 | 6661 | azulejo | BY | Ca-Fe | A | VA | H | 1.5 | <0.5 | qz, mi, mis, qms | lms, vol, cfo, fs | cht, qzs, sst, tt, op, am | M | OP | M | 0.30-0.50 | L | H | T | Co | L | Malaga |

Group 1 (Fe-rich clay matrix) characterises the discs used in the kiln, the two *tinajas* (storage jars) and the piece of cooking ware. Groups 2–5 (Fe-Ca-rich clay matrix) correspond to all the tableware samples and the kiln bar sample. Finally, groups 6 to 9 (Ca-rich clay matrix) are characteristic of all the tiles and the *atifle*.

These results suggest the presence of different workshops and the use of different clay sources for the ceramic production in Granada and surrounding areas. Alluvial raw materials were probably employed for group 1 and possibly groups 2–4, whereas groups 5–9 were possibly made of marine sediments. Considering the typological attribution of the analysed pottery, a direct correlation between the clays used as raw materials and the function of the ceramic pieces was observed. Thus, storage jars (*tinajas estampilladas*) and cooking wares were made with Fe-rich clays and abundant silicate inclusions (heat resistant bodies) while tablewares and tiles were produced using Ca-rich clays (porous, light-coloured bodies).

Regarding the technique used to prepare the ceramic pastes, the colour of the Fe-rich components suggests that all samples were fired under oxidising conditions, whereas the variable degree of vitrification points to firing temperatures from relatively low to relatively high. The macroscopic colour of pastes also can be related to the nature of the clay source: thus yellowish pastes derive from Ca-rich sediments and reddish pastes from Fe-rich clays. In addition it was observed that the surface of some ceramics were bleached, particularly in samples GR14, 15 and VAL100, possibly intentionally (by adding salty water to the clay) to obtain a better background for enhancing the glaze colours. Finally only in samples belonging to group 9 do the textural features suggest the presence of added temper.

## Glazes

Like the ceramic pastes, the glazes showed large variability in textural and compositional features (Tables 2 and 3, Figures 5 and 6). However, with exceptions, the different glaze types were not directly correlated to the fabric groups mentioned above. The main distinguishing features of the analysed glazes are summarised below.

### Opacifiers

Transparent glazes characterise the cooking ware GR12, one tile (GR8), and three *ataifor* (GR5, 14, 15). The glaze of the other samples was opacified with cassiterite ($SnO_2$) microaggregates that are generally fine-grained and abundant, except for sample GR4. $SnO_2$ contents vary from 2.5% to 9% (GR4: 2.5%, GR6: 6%, GR7, GR9: 8%, GR13: 9%; approximate values by SEM-EDS analyses, window mode).

### Texture

In the cooking ware GR12 (Figure 5.1) and in the tile GR8, glazes were very irregular and the glaze-body

interface was strongly developed, but in the first sample it was thinner, while in the latter it was thicker. The tablewares GR5 (fig. 5.3), GR4 (Figure 5.4), GR14, 15 and VAL100 were characterised by thin glazes with an interface from moderately to well developed. Tiles GR7 (Figure 5.5), GR6 and GR 9 showed moderately to very thick glazes, with regular glaze-body contact; the interface was poorly (GR6) to well developed (GR9).

The *fajalauza plate* sample GR13 was characterised by the presence of abundant relict inclusions (quartz, subordinate K-feldspar and rare mica individuals, up to 0.2 mm in size) and bubbles (Figure 5.2). The neoformed silicate phases mostly developed at the base of the glazes were represented by K, Pb-feldspars and Ca-clinopyroxenes (diopside and wollastonite). Their relative ratios mainly depend on the body matrix composition (in agreement with Molera et al 2001). Feldspars were the only neoformed phase in GR12 (Fe-rich clay matrix), while pyroxenes predominated in samples with Ca-rich matrix. Glazes were generally poorly affected by post-depositional weathering, except for samples GR4 (Figure 5.4), VAL100 and especially GR15. In these cases, the glaze was extensively or completely devitrified (with the crystallisation of Ca-phosphates and Pb-carbonates in particular) nd partially removed.

### Chemical composition

All glazes were Si, Pb-rich, with subordinate contents in alkalis, Al, Ca, and Fe. However, their compositional range was quite wide (Table 3, Figure 6). No clear differences exist between transparent and tin-opacified glazes. Due to glaze-body interactions, compositional variations from the base to the surface of glazes were generally observed. In most cases, Pb contents increased and Si, Al, K, Fe, and Ca contents decreased.

No definite chemical groups were evident. However, some distinctions could be made especially considering typological data. The transparent glaze of cooking ware GR12 was characterised by high Pb, Al, Fe, (Ti) and low Si, Ca, alkali contents. The tin-opacified glazes of the tiles GR6, GR7 and GR9 were characterised by high Na values. GR6 and GR7 showed intermediate contents in Si, Pb, and Ca; the anomalous higher Si, Ca and Mg values observed in GR9 were probably due to interaction processes with the body, as suggested by the thick interface. The transparent glaze of tile GR8 showed very low alkali (Na) and relatively high Pb contents, the other elements showing intermediate values. Finally, the glazes of tablewares showed intermediate Si, Pb, Na, Ca, and Al contents; GR13 and especially VAL100 samples were distinguished from the other samples by their higher K/Na ratios.

### Colouring agents

Oxidised Fe was responsible for the yellow colour of glaze GR12. The very high Fe content (FeO ~4%) suggests that Fe oxides were present in the glaze mixture (added), but a contribution from the
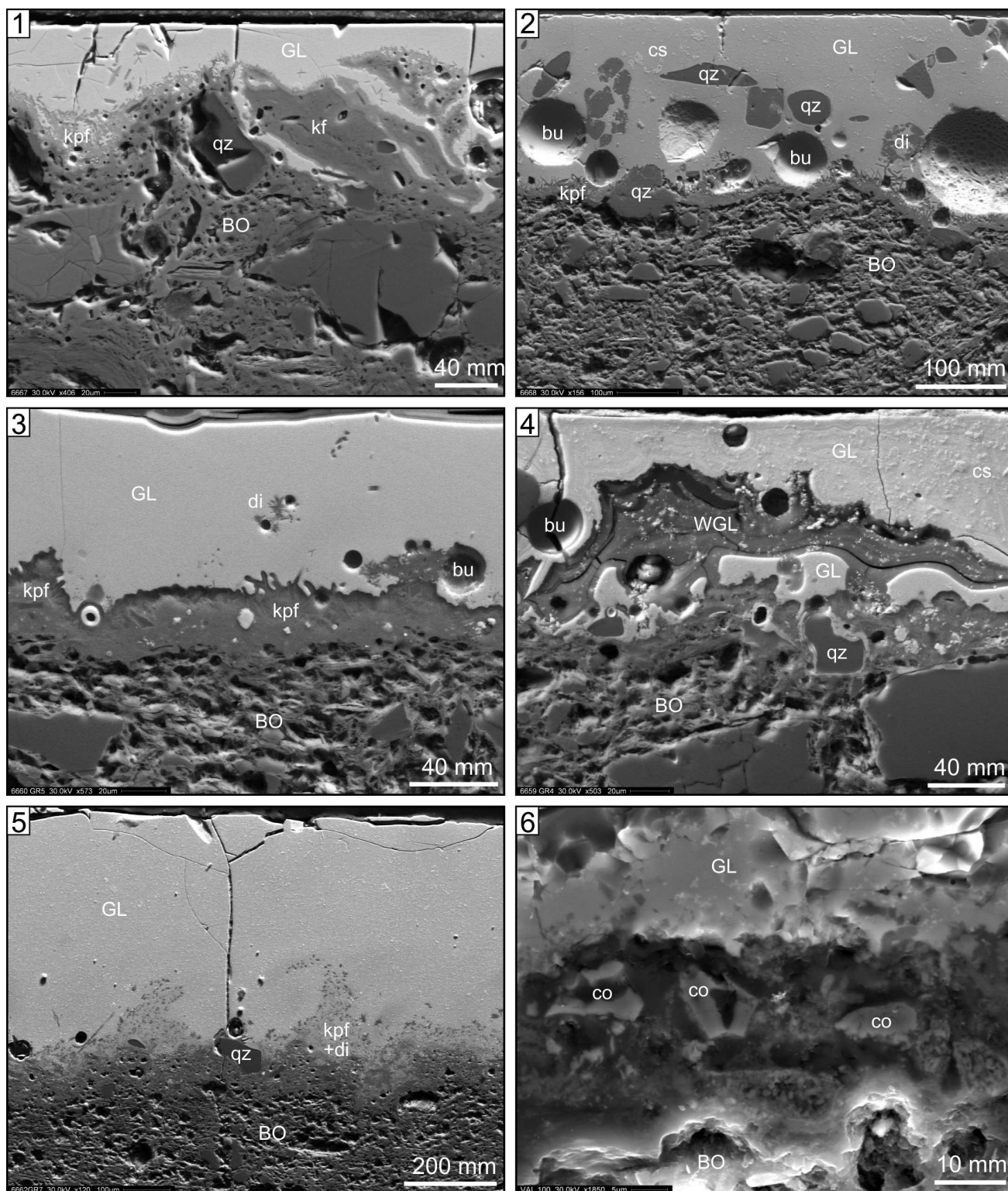
**Figure 5**
SEM images of glazes (and bodies).

1 GR12 (fabric group 1)    2 GR13 (fabric group 2)    3 GR5 (fabric group 3.1)
4 GR4 (fabric group 5)    5 GR7 (fabric group 8)    6 VAL100

BO body                   bu bubble                  k K-feldspar
GL glaze                  cs cassiterite             kpf K-Pb-feldspar
WGL weathered glaze       co Fe-Co-Ni-rich grains    qz quartz
                                                     di diopside

**Table 3**
Chemical composition of glazes (without SnO$_2$).
SEM-EDS microanalyses were carried out on selected points (spot mode) avoiding alterations, reaction zones, opacifiers, and mineral inclusions. The reported values are the mean of at least 3 analyses (normalized to 100 wt%).

| wt% | GR4 | GR5 | GR6 | GR7 | GR8 | GR9 | GR12 | GR13 | GR14 | VAL100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Na$_2$O | 4.11 | 1.76 | 4.96 | 5.42 | <0.20 | 4.56 | 0.47 | 1.72 | 4.44 | 2.49 |
| MgO | 0.41 | 0.52 | 0.47 | 0.52 | 0.72 | 1.28 | 0.59 | 0.54 | 0.78 | 0.42 |
| Al$_2$O$_3$ | 3.37 | 1.63 | 0.60 | 0.83 | 2.02 | 1.93 | 6.29 | 3.47 | 2.72 | 0.89 |
| SiO$_2$ | 38.06 | 35.18 | 38.46 | 40.73 | 34.69 | 47.84 | 30.01 | 45.33 | 40.45 | 38.04 |
| PbO | 49.25 | 51.36 | 48.87 | 39.64 | 51.79 | 31.86 | 56.14 | 43.31 | 43.34 | 49.70 |
| K$_2$O | 1.12 | 0.69 | 1.08 | 1.68 | 0.85 | 2.00 | 0.47 | 2.12 | 2.24 | 3.00 |
| CaO | 1.98 | 2.83 | 1.98 | 3.22 | 3.43 | 5.46 | 1.62 | 2.34 | 4.09 | 2.17 |
| TiO$_2$ | 0.48 | 0.25 | <0.20 | 0.22 | 0.26 | 0.25 | 0.45 | 0.32 | 0.25 | 0.14 |
| Cr$_2$O$_3$ | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| MnO | <0.20 | <0.20 | 0.54 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| FeO | 1.22 | 1.60 | 1.60 | 3.00 | 1.43 | 2.27 | 3.96 | 0.85 | 1.69 | 3.15 |
| CoO | <0.20 | <0.20 | 0.42 | 1.02 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| CuO | <0.20 | 4.18 | 0.42 | 1.87 | 4.81 | 2.55 | <0.20 | <0.20 | <0.20 | <0.20 |
| ZnO | <0.20 | <0.20 | 0.60 | 1.85 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
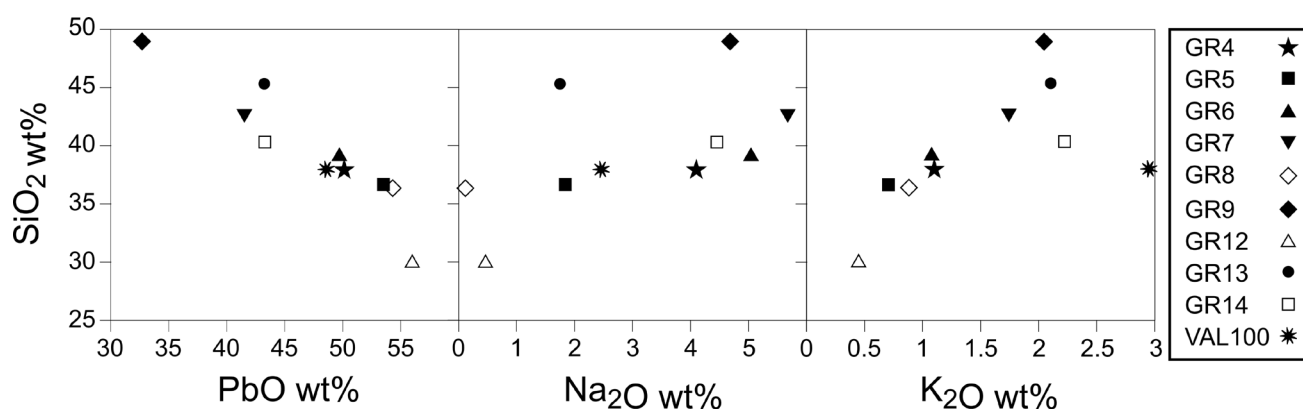


**Figure 6**
Glaze composition in the binary plots SiO$_2$ vs. PbO, Na$_2$O, K$_2$O (from mean values normalized to 100 wt% excluding opacifiers and colouring agents: SnO$_2$, CuO, CoO, ZnO).
open symbols: transparent glazes
full symbols: tin-opacified glazes.

interaction between the thin glaze and the very Fe-rich body cannot be neglected. Also the high Al and Ti contents in the glaze should derive from the body. In the green glazes of samples GR5 and GR8, Cu was the added colouring agent. The high Cu content (CuO>4%) was associated with low alkali values. On the other hand, the turquoise colour of GR9 glaze was due to Cu amounts (CuO ~2.5%) in association with moderate alkali contents. On the other hand the sky blue colour of glazes in samples GR6 and GR7 was mainly due to Co contents. Here Co was associated with Cu, Zn, Fe and moderate alkali contents. In GR6 sample, Mn was detected as well. Finally, Co was also

responsible for the blue decorations of sample VAL100. These decorations were directly applied on the ceramic body, under the opacified glaze (Figure B.6), and frequent relict angular grains were detected. Most of these grains were Fe-Co-Ni-rich phases (possibly oxides, with average composition: FeO: 66%, CoO: 22%, NiO: 11%, CuO: 1%), however pure Fe-oxide grains were also present.

Technique
For most of the analysed samples, the homogeneously oxidised body, the regular glaze-body contact and the poorly or moderately developed interface suggest

a double firing procedure. However for GR8 and GR12 a single firing cannot be excluded, though the homogeneous oxidation of the body supports the idea of a double firing. At this point it must be noted that the particular clay composition of the ceramic pastes, the firing temperatures and firing duration, and the cooling rates could influence the development of thick interfaces even in cases of double firing (Tite et al 1998).

Sample GR13 was the only sample preserving relicts of the raw materials used in theglazing process (Figure 5.2). In this case the use of a frit should be excluded, but the use of an impure quartz-rich sand (possibly alluvial) is probable. Glazes of samples GR8 and GR12 were made by mixing Si-rich raw materials with Pb compounds only. In the majority of the other samples, the relatively high alkali contents (generally rich in Na) may suggest the use of secondary fluxes (e.g. plant ashes) in association with Pb. In glaze GR13, the melted K-feldspar grains were responsible for the relatively high K contents.

## X-ray diffraction and X-ray fluorescence results

### Ceramic bodies

Mineralogical composition is crucial to evaluate the temperatures (Ts) at which the pieces were fired, as well as to characterise the clayey raw materials. The procedure followed for this estimate is based on the presence or absence of mineral phases such as illite and micas (ie phyllosilicates), which suggests firing temperatures lower than 900°C; calcite that indicates temperatures below ~850°C, and dolomite which decomposes around 700°C. As regards the development of new silicate phases, the presence of diopside in Ca-rich clays suggests that temperatures of 900–1000°C were reached in the oven. Moreover gehlenite and hedenbergite appear at ~T>800°C from illite-calcite reaction, while diopside forms through quartz-dolomite reaction at T>900°C.

Table 4 shows the mineralogical composition obtained with XRD (semi-quantitative estimation) of selected ceramic pastes and clays samples. Results reveal high though variable amounts of quartz ($SiO_2$) in all the samples and the absence of calcite $CaCO_3$ in all the ceramics, which indicate that firing Ts>850°C were reached in all of them, except in sample GR1. Here the high illite/muscovite content and the calcite absence indicate a Ca-poor ceramic fired at low Ts, ie <850°C. The results also indicate that the rest of the samples are Ca-rich ceramics showing low concentrations of hematite and variable amounts of feldspars and new silicate phases. The highest contents in hematite and feldspars were found in samples GR2 and GR3 A. The fact that diopside was detected suggests that Mg-rich minerals as dolomite ($CaMg(CO_3)_2$) or biotites have to be present in the raw clay materials. As mentioned above

**Table 4**
XRD analysis of ceramic and clays samples.

| | Qz | Cal | Dol | Phy | Hem | Di | Hd | Gh | Fds |
|---|---|---|---|---|---|---|---|---|---|
| **Ceramic** | | | | | | | | | |
| GR1 | xx | | | xx | t | | | | |
| GR2 | xx | | | | x | xx | | x | xx |
| GR3 | xx | | | | x | x | | | xx |
| GR8 | xxx | | | | x | x | x | t | x |
| **Clays** | | | | | | | | | |
| ALH | xxx | | | t | | | | | |
| VIZ | xx | x | x | x | | | | | t |
| GUA | xxx | | | x | | | | | t |
| DES | xx | | x | xx | t | | | | x |
| Nº3 | xxx | x | | xx | | | | | t |
| Nº6 | xxx | x | | x | | | | | t |

| | |
|---|---|
| Qtz  quartz | t  traces |
| Cal  calcite | x  scarce |
| Dol  dolomite | xx  abundant |
| Phy  phyllosilicates (in general) | xxx  very abundant |
| Hem  hematite | |
| Di  diopside | |
| Hd  hedembergite | |
| Geh  gehlenite | |
| Fds  feldspars (in general) | |

dolomite was not identified in the samples because it decomposes at T~700°C, a temperature always reached during the firing. These data suggest that samples can be divided into two groups and that may be related with different raw materials employed: group 1=sample GR1 and group 2= samples GR2, GR3 and GR-8.

### Clays

Three clay samples from Granada (ALH, VIZ, GUA) and three from Malaga (DES, nº3 and nº6) were analysed with XRD (Table 4). In the group from Granada, sample ALH (from the *Alhambra Formation*, Sanz de Galdeano and López-Garrido 1999) was found to be very rich in quartz with traces of phyllosilicates. Samples GUA (from the *Guadix Bassin*) and VIZ (from *Víznar*) showed significant amounts of quartz (higher in GUA) and phyllosilicates (illite/kaolinite) with little feldspars. In addition sample VIZ was rich in calcite and dolomite contents (Cultrone et al 2001). These results suggest that clays from the *Alhambra Formation* could have been used as raw material for sample GR1, while clays from *Víznar* (rich in Mg contents) were used for the rest of the Granada ceramics. Concerning the clays of the Málaga group, samples nº3 and nº6 showed similar mineralogical composition with large amounts of quartz, moderate contents of phyllosilicates and calcite, and little percentages of feldspars. Instead, sample DES presented lower quartz content and higher

| Wt% | GR1 | GR2 | GR3 | GR8 | ALH | VIZ | GUA | DES | Nº3 | Nº6 |
|---|---|---|---|---|---|---|---|---|---|---|
| $Na_2O$ | 0.59 | 0.80 | 0.88 | 0.60 | 0.90 | 0.73 | 1.09 | 0.21 | 0.62 | 1.06 |
| $MgO$ | 1.38 | 4.20 | 4.03 | 3.84 | 1.32 | 4.23 | 1.57 | 4.83 | 2.03 | 2.08 |
| $Al_2O_3$ | 26.44 | 17.45 | 20.53 | 17.04 | 19.71 | 17.17 | 25.66 | 19.62 | 15.27 | 15.55 |
| $SiO_2$ | 54.54 | 44.68 | 53.18 | 46.32 | 63.34 | 42.20 | 55.37 | 48.86 | 51.37 | 59.25 |
| $P_2O_5$ | 0.17 | 0.41 | 0.21 | 0.38 | 0.01 | 0.13 | 0.13 | 0.17 | 0.13 | 0.19 |
| $K_2O$ | 3.33 | 3.07 | 3.69 | 2.80 | 2.70 | 3.23 | 3.76 | 6.49 | 3.09 | 2.67 |
| $CaO$ | 2.40 | 16.51 | 8.78 | 13.73 | 1.50 | 13.30 | 0.60 | 4.48 | 8.68 | 5.97 |
| $TiO_2$ | 0.73 | 0.78 | 0.85 | 0.82 | 1 | 0.73 | 0.99 | 0.80 | 0.73 | 0.68 |
| $MnO$ | 0.06 | 0.11 | 0.08 | 0.11 | 0.09 | 0.07 | 0.10 | 0.15 | 0.05 | 0.08 |
| $Fe_2O_3$ | 9.91 | 6.64 | 7.06 | 6.30 | 6.58 | 4.90 | 8.39 | 7.09 | 5.30 | 6.24 |
| Ti | 4867 | 4694 | 5109 | 4948 | 5994 | 4388 | 5898 | 4802 | 4361 | 4099 |
| Cr | 173 | 113 | 174 | 164 | 130 | 140 | 162 | 117 | 140 | 129 |
| Mn | 725 | 835 | 675 | 890 | 738 | 550 | 768 | 1170 | 415 | 603 |
| Ni | 72 | 67 | 75 | 67 | 58 | 52 | 68 | 58 | 49 | 46 |
| Cu | 98 | 87 | 108 | 122 | 61 | 63 | 87 | 48 | 64 | 86 |
| Zn | 117 | 138 | 146 | 134 | 93 | 108 | 122 | 132 | 94 | 75 |
| Rb | 135 | 136 | 159 | 129 | 99 | 124 | 142 | 206 | 111 | 98 |
| Sr | 321 | 587 | 396 | 475 | 166 | 439 | 129 | 127 | 189 | 120 |
| Y | 23 | 10 | 13 | 23 | 19 | 19 | 35 | 22 | 18 | 17 |
| Zr | 226 | 219 | 231 | 278 | 373 | 195 | 325 | 187 | 208 | 150 |
| **Ba** | 400 | 660 | 640 | 720 | 420 | 460 | 510 | 560 | 360 | 390 |

**Table 5**

XRF analysis of selected major (in %), minor (in %) and trace elements (in ppm) of ceramic and clays samples; data are normalised to 100% (LOI-free).

amounts of phyllosilicates (illite/kaolinite), feldspar and hematite.

Table 5 shows the XRF results of both the ceramic pastes and the clays. In agreement with XRD data, among the ceramics the largest $Al_2O_3$ content was found in sample GR1. The lowest CaO and MgO contents were detected in sample GR1 (2.40 and 1.38 wt% respectively), while medium CaO content was found in sample GR3 (8.78 wt%) and larger CaO values in the rest of the ceramics, particularly in sample GR2 (16.51 wt%). High $Fe_2O_3$ (> 5 wt%) amount was also detected in all samples, mostly in GR1. In the clay samples, ALH sample had the highest $SiO_2$ content (63.34 wt%) and the lowest MgO content (1.32 wt%), while the largest MgO values were for samples VIZ (4.23 wt%) and DES (4.83 wt%). The latter presents the largest $K_2O$ amount (6.49 wt%) of all clay samples, while the highest $Fe_2O_3$ content was found in sample GUA.

XRF data of the minor and trace elements detected in the ceramic pastes and clays samples (Table 4) show slight variations that can provide relevant information to be used for grouping the ceramics. Thus, sample GR8 showed the highest Mn (890 ppm), Cu (122 ppm) and Zr (278 ppm) contents compared to the other ceramics. Concerning clays samples, ALH had the largest amounts of Ti (5994 ppm) and Zr (373 ppm) and sample nº6 the lowest values (4099 and 150 ppm respectively), while sample DES presented the highest values in Mn (1170 ppm) and in Sr (206 ppm). Later on, the chemical variables in the XRF data set were analysed by the multivariate statistical procedure PCA. The PCA revealed likewise high spectral variability (ie PC1=26,57, PC2=18,35%, PC3=16,77%). However, the PCA study was able to group ceramic samples GR3 and GR2, which appeared apart from samples GR1 and GR8. Concerning the clay samples, samples nº3 and

nº6, both from Malaga, are grouped together and shows different features than the clays sampled in Granada.

# Conclusions

The aim of this work was to present some preliminary notes on the features of ceramic production in the district of Granada during the late Middle Ages. To this end, archaeometrical analyses were undertaken on clay samples collected from the most important production centres in this area (Malaga, Granada, Víznar y Guadix) and on selected potsherds. The latter were chosen as representative of the whole production, because most of them were recovered at potters' workshops sites in Granada, the capital city of the *Nasrid* kingdom and an important production centre. By undertaking archaeometrical analyses, we wanted to understand the features of raw materials used by the Nasrid potters. By these means we hoped it might possible to reconstruct, at least in part, the techniques used by potters during the production process. At the same time, we have attempted to establish from where exactly the clay was taken from.

This is the first work that addresses the archaeo-metrical characterisation of ceramics and their potential raw materials from the South of the Iberian Peninsula during the late medieval Ages. Describing the features of Nasrid ceramics has been a central part in this work, taking into account the body, the glaze and the pigments used for the decoration. Thanks to this research it has been possible to ascertain and to have conclusive results on raw material supply and on the composition of the glazes. Thus, it has been possible to outline the major features of this production that are central to distinguish local productions from different ceramics produced within the same regional area as well as from imports. Apart from that, it has been possible to get a better understanding of this assemblage and of the techniques used during the manufacturing process. Finally, it has been possible to understand what the differences are between the Nasrid ceramics analysed and other ceramics produced at the same time (like the ceramics from the Valencia area during the late Middle ages), as well as later productions (like the one that started in Granada after the Nasrid kingdom of Granada was conquered by the Christian kingdom of Castilla).

The most relevant results obtained so far are presented below.

*i* As for provenance studies, a reference group was obtained in order to find out the productions of the Granada–Malaga area in extra-regional consumption sites. On the other hand, the analyses allowed the distinction between the strictly local production and imports from surrounding areas, namely Malaga. Nine ceramic groups were recognised considering their fabric characteristics. This could be correlated to different local or regional workshops, distant in space and/or in time.

*ii* Different clay sources were used for ceramic production. Results suggest that clays from both the *Alhambra Formation* and from the *Víznar* region were employed as raw materials.

*iii* The identification of metamorphic inclusions and microfossil characteristics from the *Granada Basin* suggests that group 1 and group 2–4 were local productions from Granada. The presence of basaltic fragments in group 9 indicates that they are imported ceramics from Malaga. The provenance of the rest of the samples was not possible to ascertain. However, the peculiar fabric of the GR4 sample suggests that possibly is an imported object.

*iv* As for technique, all ceramic pastes were fired at temperatures between 900–1000 ºC, except for the disc GR1 that was fired at a lower T (<850ºC). All pieces were fired under oxidising conditions.

*v* A correlation between the clays used and the function of the ceramics was observed. Thus, *tinajas* (storage jars used for storing food in the house) and cooking wares were made with Fe-rich clays and abundant silicate inclusions (heat resistant bodies), while tablewares and tiles were produced using Ca-rich clays (porous, light-coloured bodies).

*vi* The glazes do not show evident compositional or technical features that make possible to distinguish local and regional production. However, a common feature of the tin-opacified glazes is the relatively high alkali (Na) content, which could represent a regional marker. It was found that Cu is the colouring agent either for green (plus low alkali contents) or turquoise (plus moderate alkali contents) glazes, and that Co can be associated either with Zn or with Ni in decorations of tableware, which suggest the use of different mineral sources in different workshops. It should be noted that Co is associated with Zn in glazes of Mediterranean ceramics dated to the 13th–14th centuries, while it is related to Ni in ceramics dating to the end of the 14th to the beginning of the 15th century (Gratuze et al 1996).

*vii* The peculiar decoration technique observed in the tableware piece imported from Malaga (VAL100), shows striking similarities with the coeval tableware productions of Valencia (Coll Conesa et al 2002). This possibly suggests a direct technological link between the two coastal production centres.

*viii* A major technological change was detected throughout time. In particular, differences were observed between the glazes of most of the studied samples dated to the 14th century, and the only post-medieval sample (ie GR13 *plato de fajalauza*) dated to the 16th century. In fact, the glaze of the latter is characterised by the presence of abundant relict (natural sand) inclusions. This suggests that a frit

was not used in this case, possibly as a result of a new technological tradition established after the Christian conquest of the *Nasrid* kingdom of Granada in 1492.

## Acknowledgements

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## Résumé

Le présent ouvrage expose les caractéristiques préliminaires de la production céramique dans le sud-est de la péninsule ibérique, et en particulier à Grenade, à la fin du Moyen Âge. Cette recherche est fondée sur des analyses archéométriques complémentaires réalisées sur des glaises provenant de carrières traditionnelles exploitées dans cette région, ainsi que sur des céramiques sélectionnées comme représentatives du point de vue chronologique, et de par leur origine (l'emplacement des ateliers de potiers) et leur fonction (outils employés par les artisans).

## Zusammenfassung

Diese Arbeit stellt vorläufigen Erkenntnisse zur Keramikherstellung im Südosten der iberischen Halbinsel und insbesondere in Granada während des Spätmittelalters vor. Diese Forschungsarbeit basiert auf ergänzenden archäometrischen Analysen, die an Tonsorten aus traditionell in diesem Gebiet benutzten Abbaustellen durchgeführt wurden, sowie an Keramik, die wegen ihrer Chronologie, ihres Ursprungs (Gegenden, in denen die Töpferwerkstätten lagen) und ihrer Funktion (von den Töpfern benutzten Werkzeugen) als repräsentativ ausgewählt wurden.