

RESEARCH

Open Access



Exploring Durrës between East and West: discovery of a protostonepaste—archaeological context and archaeometric analysis

Chiara Casolino^{1,3}, Francesca Falcone^{1,2,3,4*}, Maria Grazia Perna^{1,2,3,4}, Elvana Metalla⁵, Gianluigi Rosatelli^{1,2,3,4}, Francesco Stoppa^{1,2,3,4} and Sonia Antonelli^{1,3}

Abstract

This research delves into the investigation of a ceramic sample discovered in the southern sector of the Durrës Amphitheatre, with a primary focus on comprehending its composition, origin, and cultural importance. The sample reveals similarities with protostonepaste through meticulous chemical analysis, yet a more profound correlation with protostonepaste concerning normative composition. Despite its porcelain-like external appearance, the ceramic demonstrates chemical consistency with a finely balanced amalgamation of crushed kaolinised leucogranite, frits, and talc, accounting for a dominant proportion of 60% compared to the other constituents. Our findings suggest that the ceramic traces its origin to Iran, specifically the Kashan and Qamsar areas, dating back to the twelfth century. The geological attributes of the region have significantly influenced the choice of raw materials for producing high-temperature ceramics. Additionally, the presence of arsenic and cobalt in the glaze further corroborates its Iranian provenance. This discovery significantly accentuates Durrës' pivotal role as a crucial conduit for East–West interactions, including its historical ties with Venice. Trade links between Durrës and Syrian–Iranian area were established as early as the tenth century. Furthermore, the analysed ceramic fragment was unearthed within a layer corresponding to a period of abandonment within the productive context. This period dates to the late twelfth century—early thirteenth century. These findings offer compelling evidence of this urban sector's continued commercial and economic significance throughout the central centuries of the Middle Ages.

Keywords Protostonepaste, Islamic pottery, Ceramic mineralogy and chemistry, Ceramic raw materials, Transitional technology, Durrës amphitheater (Albania)

Introduction

In archaeology, classifying ceramics presents challenges in aligning the internal composition with external features, such as shape, decoration, use, and production techniques. Milanese [1] addresses the longstanding problem of pottery classification, striving to balance macroscopic features and archaeometric analysis, thereby avoiding nomenclature confusion and redundancies. Minimising the discrepancy between functional and technological classification and the internal structure of ceramics is difficult due to the unique mineralogical, chemical, and technological features of some pottery production. Taxonomy helps determine

*Correspondence:

Francesca Falcone
francesca.falcone@unich.it

¹ DiSPuTer - Department of Psychological, Health and Territorial Sciences
G. d'Annunzio University, Via Dei Vestini, 31 66100 Chieti, Italy

² CAST- Center for Advanced Studies and Technology G. d, Annunzio
University, Via Dei Vestini, 31 66100 Chieti, Italy

³ C.A.A.M.-Centro Di Ateneo Di Archeometria E Microanalisi G. d,
Annunzio University, Via Dei Vestini, 31 66100 Chieti, Italy

⁴ D.A.T.A.- U.d'A analyTicAl High-Tech Laboratory, G. d'Annunzio University,
Via Dei Vestini, 31 66100 Chieti, Italy

⁵ Institute of Archaeology in Tirana, Tirana, Albania



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

the origin and cultural significance, while chemistry, mineralogy, and firing temperature supply insights into composition, structure, and properties. Integrating these different points of view requires refining criteria and conducting precise analyses of microscopic and chemical characteristics to achieve a correct classification within a cultural context.

Ceramic archaeometrists employ sophisticated techniques such as microscopic analysis, spectroscopy, chemical examination, and radiometric dating. Although chemistry alone may not provide a comprehensive classification of ceramics, it does yield valuable insights into ceramic body mineralogy and firing temperatures. Through normative analysis (a specialised mineralogical computation), it is possible to retrace mineralogical reactions and determine the theoretical proportions of primary raw minerals such as quartz, alkaline feldspars, and clays. Incorporating physical parameters derived from normative calculations, such as density and melt viscosity, distinguishes between different types of ceramic bodies.

An illustrative case is Islamic pottery, which originated in the seventh century and spread to Persia, Byzantium, Mesopotamia, Anatolia, Egypt, and Andalusia. During the twelfth century and onwards, a ceramic stonepaste type (also known as glazed siliceous ware, fritware, quartz-frit, faïence, artificial paste) was introduced in Islamic ceramics production. This type of pottery combines ground quartz, clay, and a mixture of ground glaze and plastic resins [2]. Stonepaste has been the subject of morphotypological and archaeometrical studies [3–13].

We focused on analysing poorly known transitional ceramics, like the protostonepaste sample, which offers valuable insights into sophisticated production processes. Protostonepastes likely originated in Iraq in the eighth and ninth centuries, spreading to Egypt and Iran [3]. Protostonepaste production involved technical expedients, utilising specific minerals like talc as a fluxing agent without depending on kaolin clays or high-temperature technology. Islamic potters adapted their techniques to local raw materials, incorporating modifying agents like frit and organic materials into the ceramic body. Therefore, the protostonepaste sherd found in Durrës, of Iranian provenance [14], proves the production of 'transitional' ceramics in Iran in the first half of the twelfth century. This fact could be corroborated by the discovery of protostonepaste, dated to the twelfth–thirteenth centuries, in Afghanistan [15]. On the other hand, it has been hypothesised that there was also a period of technological experimentation and standardisation in the production of stonepaste in Syria during the twelfth century [13, 16].

This research enriches knowledge about protostonepaste production sites in regions like north-central Iran. It sheds light on Islamic ceramic technology, which bridged Chinese and Byzantine influences. This paper also explores the reintroduction of cobalt/arsenic blue glaze as a protostonepaste pottery decoration, possibly due to contacts with Chinese ceramics in Iraq, Egypt, Syria, and Iran during the ninth–twelfth centuries [14, 17–19]. Despite their distinct chemical compositions, Stonepaste and protostonepaste exhibit similarities in their composition, manufacturing processes, and resulting characteristics. Both involve crushed quartz, often with feldspars and a moderate amount of highly plastic clay. The mixture mainly incorporates crushed alkaline-lead glaze with an organic binder commonly used for moulding. The limited amount of clay and glass frits during firing forms a fused glassy network that fills areas around quartz crystals, creating a porous structure. The glassy matrix from the clay-frit mixture holds together the crushed quartz particles.

The case of the sample analysed in this study resolves the dichotomy between external features and internal composition. Therefore, this research proves helpful in systematising the morpho-typological macroscopic features and the compositional or technological ones to arrive at an objective determination. In conclusion, this research significantly contributes to our understanding of early Islamic ceramics. This paper delves into a comprehensive investigation encompassing various aspects, such as pottery typology, matrix composition, glaze, and production techniques. Additionally, it explores the origins of these artefacts and their significance in trade connections within the context of Mediterranean commercial and cultural routes. Furthermore, the research also endeavours to shed light on the geological origin of the raw materials used in pottery production.

The archaeological context

The archaeological excavations (2018–2022) at the southern sector of Durrës amphitheater (Fig. 1) have revealed a complex stratigraphic sequence that has advanced our knowledge of the function of this part of the amphitheater and, thus, the role of the city during the medieval period [20].

Notable results came from the excavation of sector α . Earlier excavation activities had already highlighted a continuity of frequentation of the area following the earthquake of 1270 [21, 22] through rearrangements and re-functionalisation of the collapses from the amphitheater structure. The collapse occurred on a level corresponding to an external area relating to the 'palatium' investigated in the southern area of the amphitheater. The archaeological materials in



Fig. 1 Localisation and general view of excavation area; **a** City of Durrës; **b** Amphitheater and localization of sector α ; **c** Sector α

the stratigraphy, associated with this level confirm the chronology of the earthquake between the second-last and last quarter of the thirteenth century [23]. The pre-existing amphitheater influenced the medieval structures, delineating a residential architecture inscribed and modelled within the galleries of the amphitheater.

During the archaeological campaign in 2022, the investigation documented the archaeological deposit before the 1270 earthquake. The area was configured as a residential and productive zone during this period. In the centre of sector α , a kiln for pottery production was revealed, with a diameter of approximately 1.5 m, built with stone material and some reused tiles. The furnace was created using the southwestern part of the amphitheatre's levelled western septum of gallery IX. The level relating to the firing chamber consists of reused tiles found unstructured. In front of the furnace (Fig. 2), the *praefurnium* was identified and partially excavated. The exact typology of the kiln will be determined as archaeological investigations continue, allowing for a complete characterisation of the plant and its value in technological-productive terms.

It is possible to date the construction of the furnace to the early twelfth century, with a phase of use of approximately one century. The deconstruction of the furnace can be dated to the end of the twelfth to the beginning of the thirteenth century when the area was re-functionalised [24]. The chronology of the furnace was recognized on a chrono-stratigraphic basis.

In the deconstruction layers facing the furnace, a fragment of a bowl with light blue glazing and dark blue painted interior decoration was identified (Fig. 3). More precisely, the sherd can be attributed to a biconical bowl [25] overglazed painted [14]. The form is compared with an ASH20 lustre-painted bowl from Iran dated to around 1125–1150 [25]. The interior decoration can be traced back to the 'arc-back' motifs SS11 found on stonepastes from Syria [25], deriving from the 'knot-back' motifs attested in Iran in Group Two, which can be dated to around 1125–1150 [25]. The archaeological sequence confirms this dating: the sherd pottery appears to be residual to the furnace's disuse phase, while it is in phase to use the furnace (early—late twelfth century). Few finds of so-called stonepaste or fritware ceramics exist in the



Fig. 2 Furnace and *prae-furnium* of the invested archaeological area

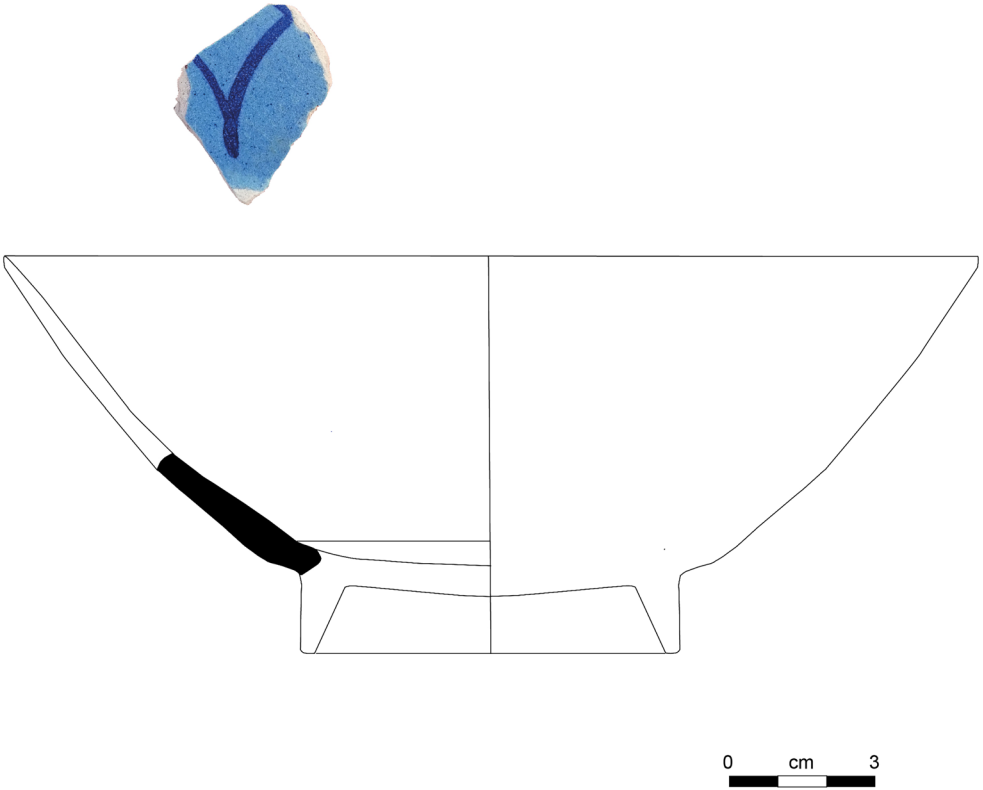


Fig. 3 Sample of protostonepaste discovered in Durres amphitheater

Western European area (excluding Islamic Spain). A few finds in the Ligurian-Genovese [26] and Venetian regions [27] confirm the role of these maritime cities in relations with the East. For us, the discovery of a fragment from Raqqa Ware in Salento [28] is very significant because of the privileged cultural, technological, and commercial connections with the area of *Dyrrachion* (Durrës).

Methods

The ceramic body underwent comprehensive analysis at the D.A.T.A.-U.D'A Analytical High-Tech Laboratory at the G. d'Annunzio University in Chieti, Italy. OPTECH optical microscopy was employed for the study of ceramics in thin sections. For investigating the chemical composition of the bulk matrix, glasses, and minerals, scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM–EDX) was utilised. Specifically, the backscattered electron microscope imaging mode (BSE) allowed distinguishing different phases based on their atomic number contrast.

Powder X-ray diffraction (XRD) analyses were conducted using the Bruker XRD D2 PHASER diffractometer. The XRD data acquisition parameters included Cu-K (1.540598 Å) radiation generated at 30 kV and 15 mA, exploring an interval between 5 and 70 2θ with 0.1 steps and a scan rate of 0.15/s. After obtaining the diffractogram, background subtraction and indexing of peaks, along with semi-quantitative analysis, were performed. The mineral identification process employed the Eva-Bruker software.

Total reflection X-ray fluorescence analysis was carried out using the TXRF Horizon (GNR) instrument to detect trace elements in the ceramic body composition. This analysis utilised Mo-K α excitation energy, operating at 40 kV and 15 mA. The TXRF method provides insights into the presence and concentration of trace elements in the ceramic sample with a microanalytical approach. The data acquired through the two analytical techniques has been processed. A mathematical calculation

was performed to obtain an accurate ratio of elements and precise data from the samples. The microanalytical method was also carried out on soil standards JG-3, GBW-07045, GBW-07405, and NIST to validate the analytical data on our sample.

Results

Petrology

The ceramic body has a fine-grained, hard, and light-coloured texture (Fig. 4). Its matrix is homogeneous, with low porosity and minimal vesiculation. The vesicles in the ceramic have amoeboid shapes and are small and irregularly distributed. The amoeboid shape suggests that the vesicles were filled with a virtual liquid that evaporated during firing, probably a resin binder [29, 30]. The primary components, which comprise about 20% of the volume, can be seen under an optical microscope and consist of K-feldspar, quartz, and frits. These components are sub-rounded or angular and align with the ceramic's edges. They range in size from 10 to 200 μm and have an unimodal distribution. Darker, large inclusions of frit fragments can also be seen, with a maximum length of 0.5 mm. The matrix texture varies from microcrystalline to aphanitic (cryptocrystalline and glassy) and can be examined using SEM–EDX.

Newly formed minerals form a framework that forms the solid structure of the ceramic body.

Residual or accessory minerals in the pottery include <1% volume of sphene, apatite, xenotime, REE-hydroxyl pyromorphite, and an Sb-Fe phase. Neogenesis mineral phases, analysed using SEM–EDX and XRPD, consist of tridymite (~10% volume, averaging 20–25 μm in size), leucite (2.3% volume, ranging from approximately 15–20 μm), kalsilite (13% volume, forming laths up to 200 μm long), clinopyroxenes (37% volume, with a size range of about 10–25 μm), melilite *s.l.* (16% volume, ranging from approximately 15–20 μm), and wollastonite (8% volume, with a prismatic shape and a size of about 60 μm) (Fig. 5). Accessory phases are smaller than



Fig. 4 a Reflection optical microscope image of the polished ceramic fragment displays the glaze surfaces in green-ocean and blue-sky colours. Insets **b** and **c** provide detailed views of the external glaze (**b**) and groundmass containing frits, inclusions and amoeboid vesicles (**c**)

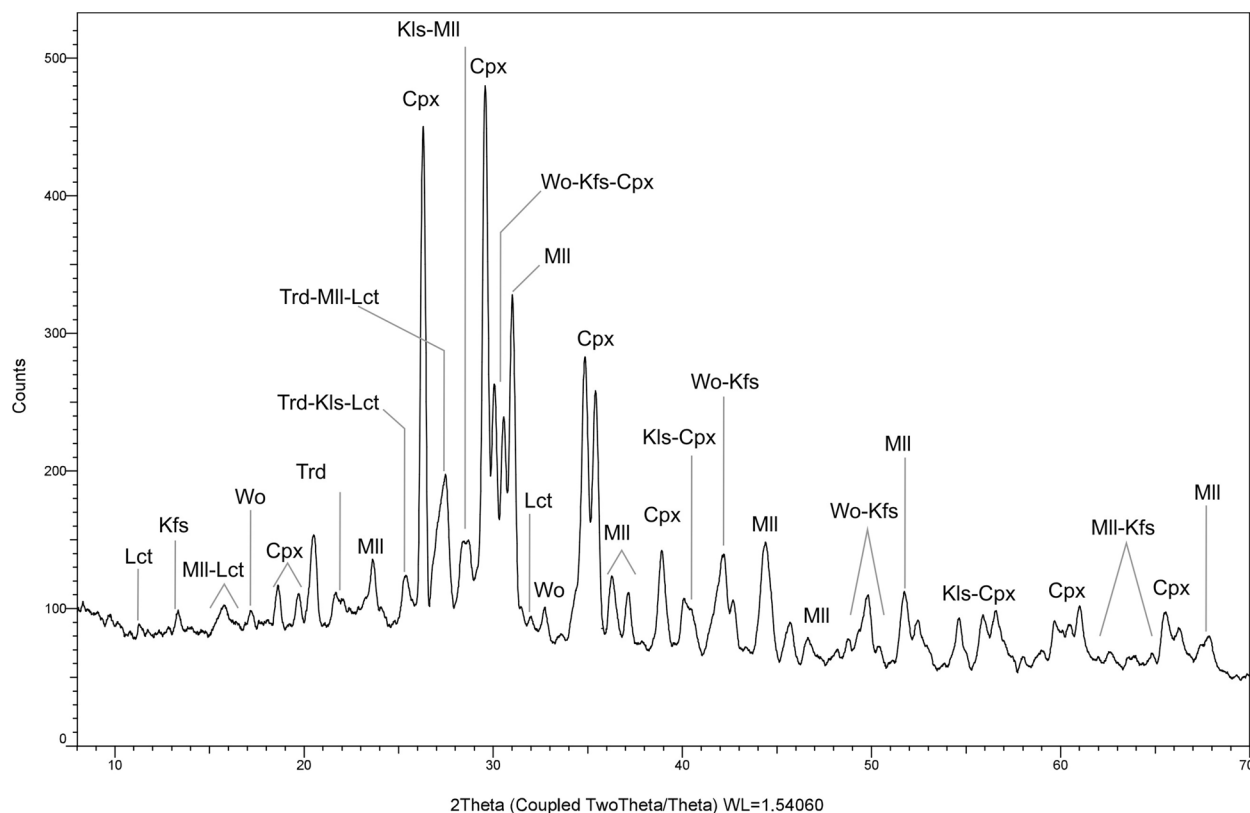


Fig. 5 XRPD interpreted spectrum of body pottery. List of mineral abbreviations: *Cpx*-clinopyroxene; *Lct*-leucite; *Kfs*-k-feldspar; *Kls*-kalsilite; *MII*-melilite; *Trd*-tridymite; *Wo*-wollastonite

50 μm . In contrast, the unidentified SbFe phase measures 200 μm .

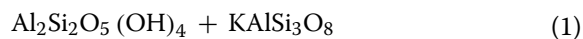
The plastic primary mass consisted of talc, kaolinite, albite, calcite, and an organic binder like a resin. These components undergo chemical reactions during firing, resulting in the formation of new minerals and glass. K-feldspar, quartz, and frits function as flux and secondary elements in the plastic matrix. This original recipe helped chemical reactions that led to the formation of new minerals and glass. Additionally, glazing was applied to supply hardness, impermeability, and a shiny appearance to the ceramic body.

Glaze (Fig. 6) is extensively discussed in the paper by [14] and contains cerussite, cassiterite, quartz, K-feldspar, As, and Co used as pigments and P as a glaze modifying agent.

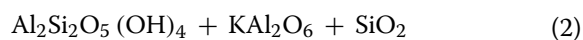
Mineralogy

The initial recipe typically includes K-feldspar, quartz, albite, and accessory phases. Some of these minerals are metastable and transform into higher-temperature phases during firing (Additional file 1: Figure S1a–f). Neogenetic minerals form by incorporating kaolinite,

talc, and calcite, including kalsilite, wollastonite, akermanite, and kushiroite. The following reactions occur:



(kaolinite + K-feldspar)

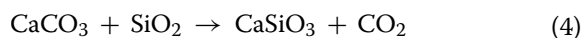


(kaolinite + leucite + quartz)



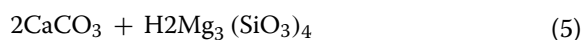
(kalsilite + quartz + sillimanite + water).

Calcite and quartz are combined to form wollastonite and carbon dioxide at a temperature of 1200 °C:



(calcite + quartz \rightarrow wollastonite + carbon dioxide).

Similarly, calcite and talc are combined to form akermanite and enstatite + carbon dioxide water at a temperature of 1280 °C:



(calcite + talc)

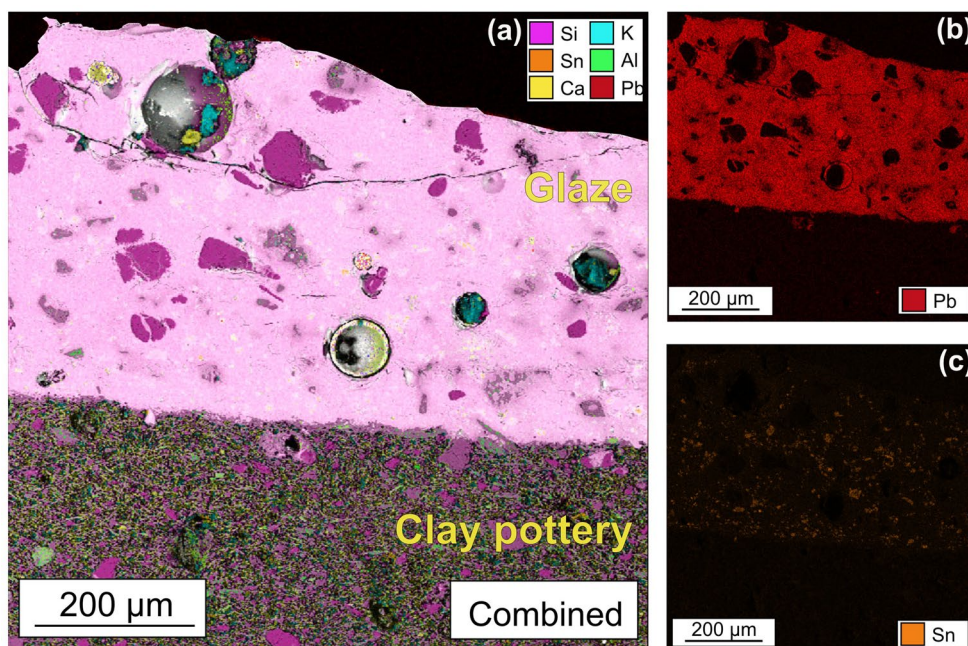
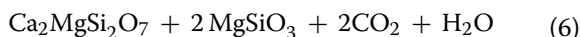
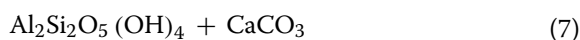


Fig. 6 BSE-EDS combined map of the glaze-body contact (a). Inset (b) and inset (c) show Pb and Sn concentration, respectively

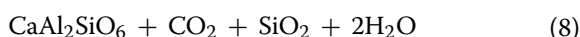


(akermanite + enstatite + carbon dioxide + water).

Kushiroite forms finally at a temperature up to 1300 °C:



(kaolinite + calcite)



(kushiroite + carbon dioxide + tridymite + water).

Notably, most reactions do not necessitate crystallisation from the melt through sub-solidus transformation [31–34] (Additional files 2 and 3).

The mineral phases that exhibit significant stability during firing are melilite and clinopyroxene. Additional information about the mineral phases is in Additional file 10.

Frits and mesostatic glass

Frits compositions vary from silicate lead glass to lead-bearing silicate-alkaline glass without Sn and seem to form three groups (Fig. 7 and Additional file 4: Table S1).

The partial melting temperature and glass formation depend on the chemical composition of the ceramic mixture and the type of flux. Mesostatic glass forms an enclave in a framework of new crystallised phases. These enclaves are close systems in the framework that form the solid structure of the ceramic body, preventing

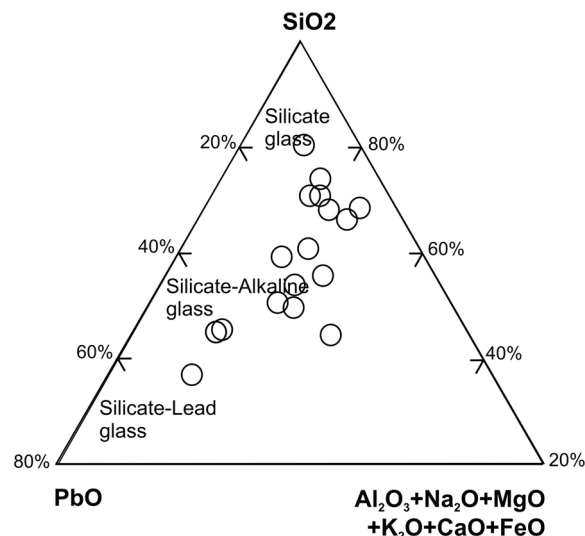


Fig. 7 Modified diagram of Tite et al. [35]. Circles plot the position of frits compositions in the sample

plasticisation and deformation of the body itself. During quenching, the presence of glass becomes a binder that gives the ceramic body greater strength and a porcelain-like appearance. Different glass compositions suggest some equilibrium with co-crystallising mineral phases (Fig. 8a, b and Additional file 5: Table S2).

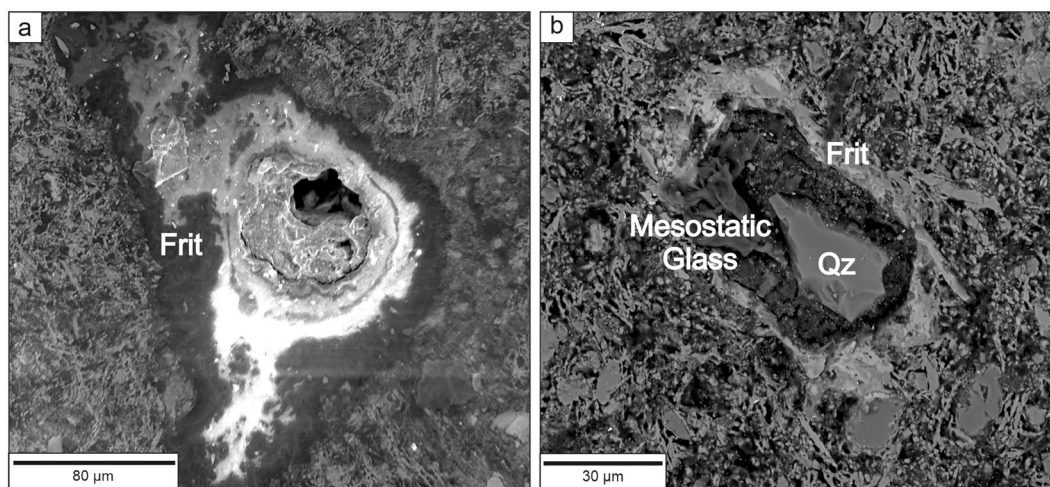


Fig. 8 **a** Fragment of frit showing an empty vug in the centre surrounded by glass and intermediate Pb-rich reaction plus a further glassy rim; **b** Detail of frit showing residual quartz surrounded by mesostatic glass and external reaction rich in Pb

Chemistry

The ceramic body has a composition SiO_2 47.3 wt.%, TiO_2 0.19 wt.%, Al_2O_3 16.8 wt.%, $\text{FeO}_{\text{total}}$ 4.96 wt.%, MnO 0.07 wt.%, MgO 3.60 wt.%, CaO 15.1 wt.%, Na_2O 2.74 wt.%, K_2O 2.78 wt.%, P_2O_5 2.27 wt.%, PbO 1.21 wt.%, SnO_2 0.21 wt.%, SO_3 1.40 wt.%, Cl 0.06 at.%. Trace elements are Co 285 ppm, As 305 ppm, Cu 644 ppm, Ni 790 ppm, Cr 206 ppm and Sr 170 ppm. The standards composition analysis is in Additional file 6: Table S3.

The contribution of a mafic component (talc) is confirmed by high Cr and Ni content. As and Co indicate traces of cobaltite that are already well documented in the pottery glaze [14].

Four basic types of pottery and their provenience have been compared with the sample under study using chemical criteria, according to Mason [25] and Tite [13] (Fig. 9a, c and d), and normative calculation (CIPW) (Fig. 9b): stonepaste, clayware, porcelains, and protostonepaste. Normative analyses approximate the original ingredients of quartz, alkali-feldspars, and clay-mixture, represented by the sum of the neogenic minerals after clay minerals recombination in stable forms at the range of firing temperatures. Figure 9b shows a triangular diagram that displays the different normative compositions of our sample ceramic [7, 25, 36]. The average normative compositions of the different types and the relative chemical and physical characteristics are displayed in Additional file 7: Table S4.

In terms of chemical characteristics, Additional file 7: Table S4 shows that porcelains have the highest aluminium saturation index, reflecting the higher Al_2O_3 content in the average chemical composition of porcelains (21.4 wt.%) due to the large amount of kaolinite in the original

recipe of porcelains. The alkalinity index is variable and reflects the Na_2O , K_2O , and Al_2O_3 content in the pottery. Stonepaste has the lowest alkalinity index (1.01), while porcelains have the highest (3.9). Al_2O_3 , Na_2O , and K_2O represent mainly kaolinite and alkali-feldspars adding. The other elements are primarily found in clay, marl, and steatite (talc). Regarding physical properties like density and viscosity, our sample is very similar to protostonepaste. The calculated density of protostonepastes (2.92 g/cm^3) is the same as the sample under study (2.91 g/cm^3). Our sample (0.184) has an extremely low viscosity (0.184 dry and 0.175 wet), like protostonepaste (0.407 dry and 0.374 wet) (Additional files 8 and 9).

Regarding temperature, our sample has a T of 1257°C , calculated based on the crystallisation temperature of the mineral assemblage at the equilibrium of quenching. The temperature seems high but still comparable with those of [9].

Table 1 shows that stonepaste has the highest amount of normative quartz compared to other ceramic types. Clayware has a similar normative content regarding alkali feldspar and clay minerals; their sum is major to normative quartz. Porcelains have a similar normative composition in terms of quartz and alkali feldspar as clayware. At the same time, the content of clay minerals is lower. Protostonepastes have a different normative composition with a much higher content of clay minerals (around 71 wt.% normative).

In contrast, the value of quartz normative and alkali feldspar is lower and around 10–15 wt.%. In this respect, our sample has a normative composition of 10 wt.% alkali feldspars and 60 wt.% clay minerals. No normative quartz is present as our ceramic is undersaturated

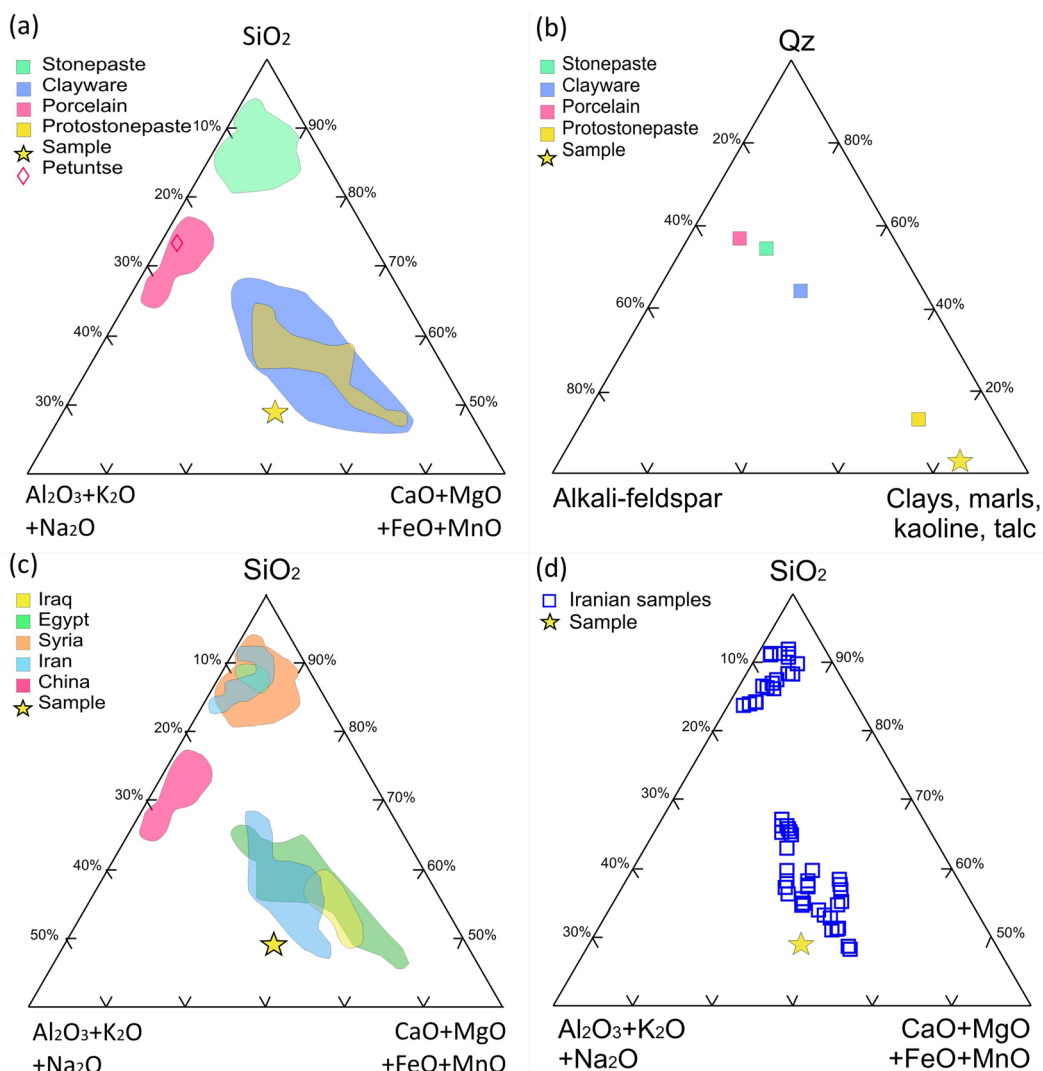


Fig. 9 **a** Triangular diagram showing the conventional pottery composition with the plot of Iranian Islamic pottery; **b** Average normative composition of the studied ceramic types; **c** Triangular diagram showing the ceramic body composition from different areas of Iraq, Egypt, Syria, Iran and China; **d** Iranian ceramic composition. Data are from [7, 25, 36–40]

Table 1 Summary of normative key of distinction for the four ceramic classes under examination and our sample

Type	Optical reconnaissance	Normative key
Stonepaste	High presence of crushed glass	Qz > Alk-feld + clay minerals
Earthenware	Clay	Alk-feld = clay minerals / Alk-feld + Clay minerals > Qz
Protostonepaste	Low presence of glass crushed	Clay minerals > Qz + Alk-feld
Porcelains	White, vitrified, translucent, and resonant	Alk-feld > Clay minerals / Alk-feld + Clay minerals < Qz

The normative key is based on the different proportions of quartz, alkali feldspars, and clay minerals

in SiO_2 . From a normative point of view, therefore, it is a protostonepaste.

Glaze composition

SEM–EDS and Total XRF analysed the glaze of the ceramic fragment [14]. The glaze, featuring a green ocean with a blue-sky decoration, contains As–Co and Pb–Sn–Si compounds and phosphorous. A chemistry-based glaze classification identifies it as alkaline-lead SnO_2 -opacified. Uncommon compounds, textural contexts, and compositional domains provide insights into production techniques. At the same time, identified phases help constrain firing temperatures to 720 °C and 900 °C. Furthermore, it is known that during the twelfth century, decorations with dark blue cobalt on a stonepaste ceramic body, known as the minai technique, were associated with an 'inglaze' technique. However, our observations show this is an 'overglaze' technique, indicating that the body is not necessarily a stonepaste.

Discussion

A glassy matrix, frits, inferred high firing temperature and ameboid vesicles initially filled with a virtual organic compound, like a resin, burning during firing suggest that the studied pottery falls into the stonepaste category. There is textual evidence of Jowhari Nishaburi (592 AH/ca. 1195 AD), which indicates the use of gum tragacanth mixed with other stone paste ingredients. However, the ceramic body's chemistry resembles clayware and protostonepaste compositions (Fig. 9a). This discrepancy is attributed to the Fe and Ca content, shifting the ceramic body composition towards clayware.

Normative calculations and physical property assessments align more closely with protostonepaste (Fig. 9b) despite the ceramic exhibiting a distinct mafic character with SiO_2 undersaturation and mineralogical richness in foids. When plotting the average composition of the ceramic body on the SiO_2 vs $\text{Al}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O}$ vs. $\text{CaO} + \text{FeO} + \text{MgO} + \text{MnO}$ diagram, it consistently falls close to Iranian-origin ceramic pottery belonging to the clayware and protostonepaste group (Fig. 9c and d).

We propose that the raw materials used for the plastic mass were chosen to imitate porcelain. It is well-known that the introduction of stonepastes aimed to mimic Chinese porcelain [3, 7, 9, 13, 36, 41]. The basic recipe remains similar to porcelain but with the addition of 60% talc. Protostonepaste predates stonepaste in the Islamic world and has a chemical composition similar to clayware. However, original raw materials are different and are characterised by a combination of kaolinite, calcite and talc. This blend explains the white colour, accompanied by elevated levels of Ca–Mg–Fe–Ti. However, Iranian stonepaste uses residual

clays from dolomitic limestones instead of kaolinite. In proto-stone paste, the potential addition of talc is suggested by the presence of mafic minerals. Calcite plus talc reaction justifies the presence of akermanite and enstatite, uncommon minerals in other ceramic types.

The felsic component was obtained by crushing a kaolinised leucogranite composed of approximately 1/3 quartz, 1/3 orthoclase, and 1/3 albite, with a minor component of kaolinite. The presence of sphene and xenotime further confirms the leucogranite origin. The mafic component, represented by talc, is derived from talc schist incorporated into the ceramic. Leucogranites originate from *Qamsar* and *Ghohrud*, approximately 30 km south of *Kashan* [42]. The talc mafic component is sourced from ophiolites in Central Iran, northwest of *Kashan* [43]. The use of talc and calcite in the Iranian area is primarily documented in the Medieval period, with calcite and talc minerals in the *Qamsar* region near *Kashan* [44]. The presence of talc justifies the high Mg content in the ceramic body. However, it cannot be derived from marls in the *Kashan* area, which have Mg and Fe about 5%, respectively. In our opinion, talc remains the best candidate for the presence of Mg as the area's geology is characterised by ophiolites, which also justifies the high Cr and Ni content in the body.

Furthermore, this hypothesis does not exclude the presence of kaolin, which is one of the most widespread clay minerals in the rocks and which justifies the presence of Al. Eventually, both talc and kaolinite are mined in the area near *Kashan*. The closest mine for *Kashan* kaolinite is *Châle Ghâr* mines in *Veshnaveh*, *Aran* and *Bidgol* County, *Isfahan* Province, *Iran*; for *Kashan* talc, there are two very near mine in the area of *Marzaki* Province; the first one in the *Markazal* mine, *Mahallat* County, and the second one is *Mighan Playa*, *Arak* County.

Considering the average chemical composition of kaolinised leucogranites and talc schist of chemical composition and applying the lever rule, a ratio of 6:4 for talc schist to leucogranite is obtained.

Talc was initially employed as a flux, and after firing, it, along with kaolinite, provided strength while reducing deformation during high-temperature firing [29]. Kaolinite does not melt during firing and, together with the neogenesis minerals, contributes to the rigid framework of the pottery. Talc, calcite, and kaolinite account for the high Mg content. The action of flux on quartz and alkali feldspars produces two main effects: the formation of glass that forms isolated plaques with different compositions depending on the phases with which it is in equilibrium and the formation of neogenesis minerals connected by kaolinite, resulting in a rigid framework [32–34, 45–47].

This partial vitrification process confers specific physical characteristics typical of porcelain.

From a historical-archaeological perspective, existing evidence demonstrates contact between Durrës and the eastern Mediterranean area dating back to the early Middle Ages [48–50]. The archaeological investigations in the southern sector of the Durrës amphitheater and the archaeometric analyses conducted on the pottery in this study confirm the continuation of these contacts up to the twelfth century. The presence of this pottery is added to other ceramics from the Byzantine–Eastern area such as fine sgraffito ware, measles ware, which confirm the *Dyrrachion's* role as a connection between East and West, even in the medieval period. This is especially true in the twelfth century when the city was at the centre of Byzantine policies in the area and benefited from the presence of Venetian and Amalfitan trading neighbourhoods and warehouses [21, 23, 51].

Archaeological evidence from Durres reveals a single fragment of fritware from the southern wall of city with origins traced back to Syria, dating to the thirteenth–fourteenth century [52]. In contrast, the sherd find from our excavation and analysed in this study can confidently be classified as protostonepaste, representing the sole specimen definitively identified within the Durres context. Another pottery sherd from the same amphitheater stratigraphy, preliminarily classified as protostonepaste, has also been discovered. Although ongoing analyses are underway for this fragment, its morphological characteristics align with a lustre-painted dish from *Kashan*, dating approximately between 1100 and 1125 [25]. This additional finding further supports the presence and distribution of this transitional pottery style in Durres.

Conclusions

1. The analysis of the ceramic body reveals textural and mineralogical characteristics that exhibit similarities with specific components typical of stonepaste. However, the overall chemical composition closely resembles clayware, though not an exact match. From a normative perspective, our sample aligns closely with protostonepaste, a ceramic type that remains poorly known and studied. Visually and based on physical properties and normative calculation, our sample closely resembles protostonepaste.
2. The presence of mineralogical and compositional peculiarities confidently suggests an Iranian origin, likely associated with production in the *Kashan* area, possibly in the *Qamsar* region, during the twelfth century. The geological characteristics of this area justify the utilisation of minerals derived from leu-

cogranite in the ceramic body, along with adding a mafic component, such as talc, enabling the production of high-temperature ceramic products while preventing plastic deformation. The presence of arsenic and cobalt in the glaze further supports this origin.

3. The discovery of Islamic glazed pottery in Durrës during the twelfth century confirms the city's significant role. The town played a crucial part in facilitating contact between the East and the West, with this finding further attesting to the active presence of Venice in the city. The extensive network of city contacts in the twelfth century suggests its involvement in productive activities.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40494-024-01200-w>.

Additional file 1: Figure S1. SEM images. (a) General view of the matrix showing inclusions of various minerals of neogenesis immersed in darker mesostatic glass plus a fragment of frits (in the lower left corner); (b) Rutile fragment with inclusion of REE-rich hydroxylpyromorphite; (c) Detail of the neogenesis mineral in the matrix showing melilite s.l. and residual k-feldspar; (d) Laths of kalsilite; (e) Leucite at contact with glass in the matrix; (f) Clinopyroxene immersed in a glassy matrix. List of mineral abbreviations: Cpx- clinopyroxene; Hpm – hydroxylpyromorphite; Lct-leucite; Kfs – k-feldspar; Kls -kalsilite; Mll- melilite; Qz- quartz; Rt- rutile.

Additional file 2: Figure S2. BSE-EDS map of a mineral fragment of antimoniite showing a Fe-rich core surrounded by an exsolved rim rich in Sb.

Additional file 3: Figure S3. Mesostatic glass composition (cross) in the triangular diagram $\text{SiO}_2\text{—Al}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O} - \text{CaO} + \text{MgO} + \text{FeO}$. The diagram shows the evolution of mesostatic glass composition compared with the matrix's neogenesis mineral composition (circles). List of mineral abbreviations: Di – diopside; En – enstatite; Ess – esseneite; Kus – kushiroite; Mel – melilite.

Additional file 4: Table S1. Frits compositions.

Additional file 5: Table S2. Glasses compositions. Mg# is the atomic ratio of $100 \times \text{Mg}/(\text{Mg} + \text{Fe}^{2+})$; alkali content is the sum of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ and alkalinity index is $\text{Al} = \text{Al} - (\text{K} + \text{Na})$.

Additional file 6: Table S3. Synoptic table association of ceramic types, macroscopic composition and normative key as composite classification tools

Additional file 7: Table S4. Summarises the normative key of distinction for the four ceramic classes under examination and our sample. The normative key is based on the different proportions of quartz, alkali feldspars, and clay minerals

Additional file 8: Table S5. Melilite group minerals chemical compositions.

Additional file 9: Table S6. Clinopyroxene group minerals chemical compositions.

Additional file 10. Mineralogy.

Acknowledgements

The fieldwork for this study was supported and co-funding by the Archaeological Institute of Tirana (Albania), the University of Chieti (Italy), and the Italian Ministry of Foreign Affairs-MAECI and endorsed by the Ministry of Culture (Albania). The funding organisations did not influence the study design, data collection and analysis, publication decision, or manuscript preparation.

Author contributions

Conceptualisation CC, FF, MGP, FS, SA; method FF, MGP; validation EM, investigation CC, FF, MGP, FS, SA; funding CC, FS, SA; resources CC, SA, EM; instrumental resources GR, FS; data curation CC, FF, MGP; original draft preparation CC, FF, MGP, FS, SA; writing review GR; editing CC, FF, MGP, EM, GR, FS, SA; figures curation CC, FF, MGP; supervision EM, FS, SA. All authors read and approved the final manuscript.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Declarations**Competing interests**

The authors declare no competing interests.

Received: 28 October 2023 Accepted: 27 February 2024

Published online: 08 March 2024

References

- Milanesi M. Ceramic classes in medieval archaeology, between terminologies, archaeometry and technology, in: *Atti della X giornata di Archeometria della Ceramica*, Roma, 2006, Edipuglia, Bari, 2009, pp. 47–55.
- Watson O. *Ceramics from Islamic lands*. London: Thames & Hudson Ltd; 2004.
- Mason RB, Tite MS. The beginnings of Islamic stone paste technology. *Archaeometry*. 1994;36:77–91. <https://doi.org/10.1111/j.1475-4754.1994.tb01066.x>.
- Mason RB. New looks at old pots: results of recent multidisciplinary studies of glazed ceramics from the Islamic world. *Muqarnas*. 1995;12:1–10. <https://doi.org/10.2307/1523219>.
- Mason RB. Criteria for the petrographic characterisation of stonepaste ceramics. *Archaeometry*. 1995B;37(2):307–21. <https://doi.org/10.1111/j.1475-4754.1995.tb00745.x>.
- Tonghini C. A new Islamic pottery phase in Syria: tell Shahin. *Levant*. 1995;27(1):197–207. <https://doi.org/10.1179/lev.1995.27.1.197>.
- Tonghini C. *Qal'at Ja'bar Pottery – a study of a Syrian fortified site of the late 11th–14th centuries*. Oxford: The Council for British Research in the Levant, Oxford University Press; 1998.
- Tonghini C. Glazed pottery of Egypt and Syria in the 11th and 12th centuries: status of studies and development of research. In: Schvoerer M, Ney C, Peduto P, editors. *Décor de lustre métallique et céramique glaçurée*. Bari: Edipuglia; 2005. p. 21–30.
- Tite M, Wolf S, Mason RB. The technological development of stonepaste ceramics from the Islamic Middle East. *J Archaeol Sci*. 2010;38(3):570–80. <https://doi.org/10.1016/j.jas.2010.10.011>.
- Watson O. *Fritware: Fatimid Egypt or Saljuq Iran?* In: Barrucand M, editor. *L'Égypte Fatimide; son art et son histoire*. Paris: Université de Paris-Sorbonne; 1999. p. 299–310.
- Ma Y, Li Z, Zhang L, Wu J, Xiong Y, Vahdati A, Zhang J. A scientific study of late Islamic blue-white stonepaste wares of Iran. *Archaeometry*. 2022;64(5):1110–23. <https://doi.org/10.1111/arc.12765>.
- Matin M. A Medieval stonepaste ceramic production site in Moshkin Tepe, Iran: ceramics, waster, and manufacturing equipment. *BIPS*. 2022. <https://doi.org/10.1080/05786967.2022.2080580>.
- Tite MS. Ceramic production, provenance and use – a review. *Archaeometry*. 2008;50:216–31.
- Perna MG, Falcone F, Casolino C, Antonelli S, Metalla E, Rosatelli G, Stoppa F. (unpublished results). *Analysing the Glaze of a Medieval Ceramic Fragment from the Durrës Amphitheater in Albania*.
- Gascoigne A, Bridgman R. Pottery from Jām: a mediaeval ceramic corpus from Afghanistan. *Environ Sci*. 2010;48:107–51. <https://doi.org/10.1080/05786967.2010.11864776>.
- McPhillips S. Continuity and innovation in Syrian Artisanal traditions of the 9th to 13th ceramic evidence from the Syrian French Citadel of Damascus Excavations. *BEO*. 2012;61:447–73.
- Mason RB, Tite MS, Paynter S, Salter C. Advances in polychrome ceramics in the Islamic World of the 12th century AD. *Archaeometry*. 2001;43(2):191–209. <https://doi.org/10.1111/1475-4754.00014>.
- Priestman SMN. Opaque Glazed Wares: the definition, dating and distribution of a key Iraqi ceramic export in the Abbasid period. *BIPS*. 2011;49:89–113.
- Falcone F, Cinosi A, Siverio G, Rosatelli G. New methodological XRF approach for powder microanalysis. *International Conference on Total Reflection XRay Fluorescence Analysis and Related Methods*, oral presentation, 05–08/09/2023, Clausthal Zellerfeld, Germany.
- Antonelli S, Metalla E, Casolino C, Moderato, Pallotta I. Results of the archaeological excavation in the Amphitheatre of Durrës (2018–2019). *Candavia*. 2020;8:359–77.
- Santoro S, Hoti A, Sassi B. The amphitheater of Durrës. *Studies and excavations 2004–2005*. *Annuario della Scuola Archeologica di Atene e delle Missioni Italiane in Oriente LXXXIII s.III 5 t.II 2005*; 717–806.
- Santoro S, Hoti A, Sassi B. The amphitheater of Durrës. *Studies and excavations 2006–2007*. *Annuario della Scuola Archeologica di Atene e delle Missioni Italiane in Oriente LXXXIII s.III 9 t.II 2009*; 1253–1278.
- Casolino C, Antonelli A, Metalla E. Transformations in Durrës amphitheater in medieval times: living and productive spaces, *Temporis Signa XVIII* (in press, 2023).
- Antonelli S, Metalla E, Casolino C. Results of the archaeological excavation in the Amphitheatre of Durrës (2021–2022), *Candavia 10* (in press, 2023).
- Mason RB. Shine like the sun – Lustre-painted and associated pottery from the medieval Middle East. Toronto: Royal Ontario Museum; 2004.
- Benente F. Imported ceramics from the Mediterranean between the 10th and 14th centuries. Updates and summary data for Liguria. In: Gelichi S, Baldassarri M, editors. *Pensare/Classificare. Studi e ricerche sulla ceramica medievale per Graziella Berti*. Firenze: All'Insegna del Giglio; 2010. p. 53–70.
- Gelichi S, Negrelli C, Ferri M, Cadamuro S, Cianciosi A, Grandi E. Importing, producing and consuming in the Venetian lagoon from the 4th to the 12th century Amphorae, glass and ceramics. In: Gelichi S, Negrelli C, editors. *Adriatico Alto Medioevale (VI–XI secolo)*. Venezia: Scambi, porti, produzioni, Edizioni Ca' Foscari; 2017. p. 23–113.
- Caprino P. Circulation of pottery in Lecce between the 12th and 13th centuries. Islamic and Byzantine tableware glazed productions. In: Arthur P, Leo Imperiale M, editors. *VII Congresso Nazionale di Archeologia Medioevale, Lecce, 9–12 Settembre*. Firenze: All'Insegna del Giglio; 2015. p. 251–6.
- Gualtieri S. Ceramic raw material: how to establish the technological suitability of a raw material. *Archaeol Anthropol Sci*. 2020;12(8):183. <https://doi.org/10.1007/s12520-020-01135-w>.
- Gradmann R. Analysis of historical Islamic glazes and the development of a substitution [PhD thesis], Institute of Geography and Geology Department of Geodynamics and Geomaterial Research, Julius Maximilian University Würzburg, Germany. 2016. <https://opus.bibliothek.uni-wuerzburg.de>.
- Aramaki S, Roy R. Revised phase diagram for the system SiO₂-Al₂O₃. *J Am Ceram Soc*. 1962;45:229–42.
- Allegretta I, Eramo G, Pinto D, Hein A. The effect of mineralogy, microstructure and firing temperature on the effective thermal conductivity of traditional hot processing ceramics. *Appl Clay Sci*. 2017;135:260–70. <https://doi.org/10.1016/j.clay.2016.10.001>.
- Tite MS, Kilikoglou V, Vekinis G. Strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice. *Archaeometry*. 2001;43:301–24.
- Kilikoglou V, Vekinis G, Maniatis Y, Day PM. Mechanical performance of quartz-tempered ceramics: Part I. Strength and toughness. *Archaeometry*. 1998;40:261–79.
- Tite MS, Freestone I, Mason R, Molera J, Vendrell-Saz M, Wood N. Lead glazes in antiquity- methods of production and reasons for use. *Archaeometry*. 1998;40(2):241–60. <https://doi.org/10.1111/j.1475-4754.1998.tb00836.x>.
- Röhrs S, Dumazet A, Kuntz K, Franke U. Bodies and glazes of architectural ceramics from the ilkhanid period at Takht-e Soleyman (North-Western Iran). *Minerals*. 2022;12:158. <https://doi.org/10.3390/min12020158>.

37. Cheng HS, Zhang ZQ, Xia HN, Jiang JC, Yang FJ. Non-destructive analysis and appraisal of ancient Chinese porcelain by PIXE. *Nucl Instrum Methods Phys Res.* 2002;190:488–91. [https://doi.org/10.1016/S0168-583X\(01\)01280-0](https://doi.org/10.1016/S0168-583X(01)01280-0).
38. Leung PL, Stokes MJ, Tiemei C, Dashu Q. A study of ancient Chinese porcelain wares of the Song-Yuan dynasties from Cizhou and Ding kilns with energy dispersive X-Ray fluorescence. *Archaeometry.* 2000;42(1):129–40. <https://doi.org/10.1111/j.1475-4754.2000.tb00871.x>.
39. Tao S, Zhu Y, Liu S, Dong J, Yuan Y, Li Q. Morphology and structure characteristics of the rare black-glazed porcelains excavated from the Jian Kiln site of song dynasty. *Cryst.* 2023;13(4):632. <https://doi.org/10.3390/cryst13040632>.
40. Juan W, Leung PL, Jiazhi L. A study of the composition of chinese blue and white porcelain. *Stud Conserv.* 2007;52(3):188–98.
41. Tite M, Wood N. The technological relationship between Islamic and Chinese glazed ceramics prior to the 16th century AD. In: *China-Mediterranean Sea Routes and Exchange of Ceramics prior to 16th century Taoci* 4 (2005) 31–39.
42. Etedali Z, Ayati F, Ahankoub M. Geochemistry of tourmaline in granitoids and metamorphic rocks of Qohroud-Qamsar, Kashan, Central Iran. *Petrol J.* 2022. <https://doi.org/10.22108/IJP.2022.131425.1257>.
43. Moghadam HS, Stern RJ. Late Cretaceous forearc ophiolites of Iran. *Isl Arc.* 2011;20(1):1–4.
44. Allan JW. Abu’L- Qasim’s treatise on ceramics. *Iran.* 1973;11:111–20.
45. Allegretta I, Eramo G, Pinto D, Hein A. The effect of temperature on the thermal conductivity of traditional ceramics: nature, percentage and granulometry. *Thermochim Acta.* 2014;581:100–9.
46. Eramo G. Ceramic technology: how to recognise ceramic processing. *Archaeol Anthropol Sci.* 2020. <https://doi.org/10.1007/s12520-020-01132-z>.
47. Hein A, Müller NS, Day PM, Kilikoglou V. Thermal conductivity of archaeological ceramics: the effect of inclusions, porosity and firing temperature. *Thermochim Acta.* 2008;480:35–42.
48. Neri E. The mosaics of Durrës amphitheatre: an assessment using technical observations. *AnTard.* 2017;25:353–74.
49. Neri E, Gratuze B, Schibille N. Dating the mosaics of the Durres amphitheatre through interdisciplinary analysis. *J Cult Herit.* 2017;28:27–36. <https://doi.org/10.1016/j.culher.2017.05.003>.
50. Boschetti C, Leonelli C. Crafts inside the Amphitheater: an Interdisciplinary Analysis of Medieval Glass-working at Durrës, Albania. In: Cavalieri M, Boschetti C, editors. *MVLTA PER ÆQVORA. Il polisemico significato della moderna ricerca archeologica. Omaggio a Sara Santoro.* Louvain: Louvain University Press; 2018. p. 963–81.
51. Shehi E. Nje Histori e shkurtër e Durrësit [A brief story of Durres]. Durres: Botimet Jozef; 2021.
52. Vroom J. Pottery finds from a ‘cess-pit’ at the southern wall in Durrës, central Albania. In: Böhlendorf-Arslan B, Uysal AO, Witte-Orr J, editors. *Çanak. Late antique and medieval pottery and tiles in mediterranean archaeological contexts.* Instambul: Ege Yayınları; 2007. p. 319–34.

Publisher’s Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.