



Investigating figulina pottery technology in the southern Po Plain through an integrated archaeometric approach

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ABSTRACT

Figulina pottery refers to a fine, light-coloured ceramic class commonly occurring in Neolithic assemblages of southern and central Italy and, on the opposite side of the Adriatic Sea, along the Dalmatian coast of Croatia. In northern Italy, *figulina* pottery occurs in limited quantities during the 5th millennium cal. BCE and seems to diverge from the local ceramic productions in terms of technological choices and firing procedures. In light of these technical considerations, past scholarly research hypothesised the existence of networks involving either the exchange of *figulina* vessels or dynamics of knowledge transmission between Neolithic communities bearing distinct pottery traditions. In this paper, *figulina* sherds from five mid-late Neolithic settlements located in the southern Po Plain area of northern Italy have been analysed through a multi-analytical archaeometric approach that comprises macroscopic fabric analysis, thin section petrography, X-Ray Powder Diffraction (XRPD) and portable X-Ray Fluorescence (p-XRF). The investigation was carried out with the scope of exploring the technological choices behind the rare *figulina* pots exceptionally retrieved at the Po Plain sites. Results shed light on the production technology and presumable provenance of the raw materials selected for *figulina* productions in the region, disclosing possible scenarios of technological transmissions while calling into question the ceramic production model currently hypothesised for Neolithic northern Italy.

1. Introduction and archaeological background

In archaeological literature, the term *figulina* refers to fine ceramic productions consistently displaying light-coloured surfaces, often found at Neolithic sites on both sides of the Adriatic Sea (Spataro, 2002, 2009; Teoh et al., 2014). In the southern Italian territory such painted, highly elaborate ceramics start to appear as early as the first half of the 6th millennium cal. BCE (Pessina and Tinè, 2018: 43). In 5th millennium cal. BCE southern Italy, *figulina* pots are one of the most recurring productions within the Serra D'Alto assemblages (Muntoni and Laviano, 2008). Along the mid Adriatic coast of Italy, *figulina* wares characterise early on both the Catignano (second half of the 6th-early 5th millennium cal. BCE) and Ripoli (5th millennium cal. BCE) archaeological

facies (Colombo and Boschian, 2009; Spataro, 2009). According to many scholars, the presence of such fine wares – often elaborately painted – represents a significant shift towards a more complex manufacturing sequence with improvements on paste preparation, forming, finishing and firing techniques when compared to the coarse ceramic productions (Malone, 2003: 287; Muntoni and Laviano, 2008: 126). The elaborateness displayed by the *figulina* ceramic shapes and their decorative patterns, as well as the significant technological advancement in achieving fine pastes and consistent homogeneous, light-coloured surfaces, has led to the identification of *figulina* pottery as one of the first specialised pottery productions, possibly involving groups of highly-trained craftspeople (Spataro, 2009, 2017).

On the eastern side of the Adriatic Sea, in central Dalmatian middle

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Neolithic villages, archaeometric analyses showed that locally-produced painted *figulina* pots are highly variable in composition despite sharing technological and formal similarities with their painted counterparts found in central and southern Italy (Teoh et al., 2014). The occurrence of *figulina* sherds outside of their core area has been recorded as far as south-eastern France and Malta, leading to hypothesise the existence of long-distance networks involving the exchange of these fine ceramic productions - or rather their content (Binder et al., 2018; Malone, 2003).

According to a recent review, the appearance of *figulina* wares north of the Italian Apennines can be traced back to the late 6th/early 5th millennium cal. BCE, when painted *figulina* sherds occur at various northern Italian sites, supposedly connecting the Po Plain either with the Catignano/early Ripoli ceramic traditions or with the Serra d'Alto nuclear area (Colombo, 2021: 456). In the context of the middle Neolithic¹ Po Plain, in an area where the Square-Mouthed Pottery culture with its scratched and incised coarser wares is predominant, *figulina* sherds amount to a lesser extent when compared to the central and southern Italian areas, yet their presence is recorded at a number of sites where a scenario of regional production has been previously hypothesised in light of the mineralogical or geochemical characteristics of the sherds analysed (Cannavò et al., 2014; Mannoni, 1988; Muntoni et al., 2019). Indeed, the appearance of *figulina* wares within Square-Mouthed Pottery assemblages is registered as early as the beginning of the 5th millennium BCE, for example at Rivalentella near Reggio Emilia, a site that yielded a copious amount of *figulina* sherds as well as a possible structure linked to its production (Colombo, 2021; Tirabassi, 1987, 2014). Nevertheless, similarly fine, light-coloured ceramics appear to be spanning for at least a millennium, with recent excavations in the Po Plain sporadically unearthing *figulina* specimens in contexts attributed to the late 5th millennium (Table 1), seemingly in accordance with the generalised decrease in *figulina* production at the Italian mid Adriatic sites during the late Ripoli phase (2nd half of the 5th millennium cal. BCE; Pessina and Radi, 2002).

Building on previous works on *figulina* wares aimed at determining their compositional characteristics, samples of *figulina* sherds retrieved in the Po Plain area were analysed through various archaeometric techniques. The main aim was to understand the technological choices at play in a region where these elaborate productions often represent only a small percentage of the total ceramic assemblages. Previous studies on *figulina* pottery have indeed suggested processes of clay fractioning through levigation to achieve such refined pastes (Spataro, 2009, 2017; Teoh et al., 2014). Moreover, the production sequence of *figulina* pottery is thought to require higher temperatures when compared to coarser productions, thus implying greater expertise in managing complex pyrotechnological processes (Muntoni and Laviano, 2008; Spataro, 2017; Teoh et al., 2014). In order to investigate the technology of the *figulina* pottery found in the Po Plain, a multi-analytical archaeometric approach was adopted. Novel specimens of *figulina* pottery from recently excavated mid-late Neolithic settlements were taken into consideration and analysed via thin section petrography, X-Ray Powder Diffraction (XRPD) and portable X-Ray Fluorescence (p-XRF) as a means to explore *figulina* pottery variability at a

regional scale as well as to investigate the transmission mechanisms contributing to the spread of such ceramic class over a vast geographic area. Results disclosed previously unknown facets of local production technology and shed further light on the possible provenance of the raw material utilised by the *figulina* makers in northern Italy.

2. The Po Plain mid-late Neolithic sites

Five sites located in the south-eastern Po Plain were selected for the purpose of this study (Fig. 1). The area is bounded by the Po River to the north and by the Apennines mountain chain to the south, and is marked from west to east by several streams flowing northward from the Apennines.

The drainage basins of the Apenninic rivers and streams in the studied region consist mainly of marine sedimentary successions, formed between the Cretaceous and the Pliocene-Pleistocene (Amorosi et al., 2002; Conti et al., 2020; Fig. 2). While to the west the geology is dominated by turbidites and mélanges of the Cretaceous-Eocene External Ligurian Domain and by the pre-evaporitic Epiligurian sedimentary succession, to the east of the Sillaro river the Miocene turbidites of the Marnoso-Arenacea formation prevail, with alternated sandstones and marls (Amorosi et al., 2002). The Messinian evaporitic Gessoso-Solfifera formation, consisting of gypsum and clays, outcrops in localised areas, stretching on a NW-SE direction (Benini et al., 2010; Conti et al., 2020). The Plio-Pleistocene marine succession, consisting of clays, marls and littoral sands (Benini et al., 2010; Conti et al., 2020), completes the geology of the area to the south of the analysed sites. The erosion of such variegated lithostratigraphic setting built a portion of the Po Plain characterized by low-angle coalescing fans dominated by fine-grained sediments with occasional bedded gravels (Benini et al., 2010).

The Late Quaternary alluvial fan sediments laid by the streams incorporate the Neolithic sites at varying depths of approximately 3 m to 1.40 m below the current topographic surface. The settlements of Ozzano dell'Emilia, Forlì-Via Navicella, Rimini-Igea Marina, Cesena-Via Masiera and Gatteo were partially investigated during development-led preventive excavations. The selected sites belong to the Emilia-Romagna region, an area that was specifically selected on account of being located during the middle Neolithic at the interface of the Square Mouthed Pottery (SMP) core area and the Ripoli archaeological *facies*, which is spread to the south-east along the mid Adriatic coast and is known for its trichrome-painted *figulina* productions (Colombo, 2021). During the late Neolithic, the western part of the Emilia Romagna region is deeply affected by the cultural influence of the Chassey culture starting approximately at 4300 cal. BCE (Maffi, 2014), partly overlapping with the last manifestations of the SMP culture in the area. On the other hand, during this time frame most of the coastal Romagna area appears to gravitate towards the mid Adriatic late Ripoli area as evidenced by generalised affinities in the material culture with the coeval sites of the Marche and Abruzzo regions (Bernabò Brea et al., 2017). Being particularly prone to multiple cultural inputs during the course of the Neolithic, the southern Po Plain is therefore particularly suitable to investigate the transmission mechanisms of *figulina* pottery technology from the middle Neolithic onwards, when multiple evidence of supposedly locally-produced *figulina* specimens consistently appear in the area (Colombo, 2021). Furthermore, at the above mentioned sites coarser wares tend to predominate the ceramic assemblages, with *figulina* sherds representing only a small fraction of the sherds retrieved. When compared to the coarse utilitarian wares characterising the ceramic productions at these sites, the *figulina* pottery represents therefore a significant technological shift.

Of the five sites analysed, three were radiocarbon dated (Ozzano dell'Emilia, Rimini-Igea Marina and Forlì-Via Navicella; Table 1), while no absolute dates have been obtained for the sites of Cesena-Via Masiera and Gatteo.

Ozzano dell'Emilia is the westernmost site considered and the only one that participates to the Square-Mouthed Pottery cultural tradition. A

¹ In this paper we follow the chronological sequencing proposed for central/northern Italy by Pessina and Tinè (2018), taking nevertheless into account the further specifications proposed for central Italy by Dolfini (2020). The early-middle Neolithic transitional period in the Po Plain is characterised by the appearance of the Square-Mouthed Pottery culture at about 5200 cal. BCE, partly overlapping with the most recent evidence of the Fiorano culture (5500–4800 cal. BCE). The Middle Neolithic period in the Po Plain area can therefore be dated from 5200 to 4500 cal. BCE. Late Neolithic: 4500–3800 cal. BCE. Final Neolithic: 3800–3600 cal. BCE (Dolfini, 2020). Further developments on the chrono-cultural sequencing of the Neolithic period with specific reference to the Emilia-Romagna region are summarised in Bernabò Brea et al. (2017).

Table 1

Radiocarbon dates obtained for the analysed Emilia Romagna sites. Calibrated with OxCal v4.4.4 Bronk Ramsey (2021); atmospheric data from Reimer et al. (2020).

Site	Lab code	Dated material	Uncal. date	Cal. Date BCE (2 σ , rounded by 10)	$\delta^{13}\text{C}$	References
Rimini-Igea Marina, Ca' Giorgetti (RN), Stratigraphic Unit 7	LTL-13066A	Charcoal (unidentified)	6051 \pm 45	5210–4800 [5210–5180: 2.6 %; 5060–4830: 91.8 %; 4820–4800: 1.1 %]	–	Bernabò Brea et al., 2017
Rimini-Igea Marina, Ca' Giorgetti (RN), Stratigraphic Unit 22	LTL-13068A	Charcoal (unidentified)	6020 \pm 45	5030–4790	–	Bernabò Brea et al., 2017
Rimini-Igea Marina, Ca' Giorgetti (RN), Stratigraphic Unit 22	LTL-13070A	Charcoal (unidentified)	5890 \pm 45	4900–4610 [4900–4650: 93.7 %; 4640–4610: 1.8 %]	–	Bernabò Brea et al., 2017
Forlì, Via Navicella (FC), Stratigraphic Unit 1624	UGAMS-4256	Charcoal (unidentified)	5850 \pm 30	4800–4610	–	Bernabò Brea et al., 2017
Rimini-Igea Marina, Ca' Giorgetti (RN), Stratigraphic Unit 8	LTL-13067A	Charcoal (unidentified)	5800 \pm 45	4790–4540	–	Bernabò Brea et al., 2017
Rimini-Igea Marina, Ca' Giorgetti (RN), Stratigraphic Unit 42	LTL-13069A	Charcoal (unidentified)	5758 \pm 45	4720–4490	–	Bernabò Brea et al., 2017
Ozzano dell'Emilia, Via Tolara di Sotto (BO), Stratigraphic Unit 21	DSH10208_CS	Caryopsis (unidentified)	5728 \pm 59	4720–4440	–37 \pm 1 ‰	Tiezzi et al., 2023a
Ozzano dell'Emilia, Via Tolara di Sotto (BO), Stratigraphic Unit 53	RCMiB105	Caryopsis (unidentified)	5585 \pm 49	4540–4340 [4540–4520: 1.9 %; 4510–4340: 93.6 %]	–50 \pm 2 ‰	Tiezzi et al., 2023a
Ozzano dell'Emilia, Via Tolara di Sotto (BO), Stratigraphic Unit 53	RCMiB105b	Caryopsis (unidentified)	5462 \pm 44	4450–4170 [4450–4420: 2.9 %; 4400–4380: 0.7 %; 4370–4230: 90.3 %; 4190–4170: 1.5 %]	–59 \pm 6 ‰	Tiezzi et al., 2023a
Forlì, Via Navicella (FC), Stratigraphic Unit 2202	UGAMS-4255	<i>Quercus</i> seed	5410 \pm 30	4350–4170 [4350–4230: 89.7 %; 4200–4170: 5.8 %]	–	Bernabò Brea et al., 2017
Forlì, Via Navicella (FC), Stratigraphic Unit 1636	FTMC-MV65-1	<i>Bos</i> sp., vertebra (collagen)	5308 \pm 31	4250–4000 [4250–4040: 95.1 %; 4010–4000: 0.3 %]	–21.31 \pm 0.15 ‰	

later phase of occupation at the site, dated to the onset of the Late Neolithic, is characterised by the presence of ceramic elements seemingly influenced by the Chassey culture on the one hand and by the late Neolithic tradition as known on the Adriatic area of Romagna on the other (Tiezzi et al., 2023a). Conversely, the sites of Rimini-Igea Marina and Forlì-Via Navicella share most of their ceramic traits with the Adriatic late Ripoli pottery tradition, with stylistic elements that appear to be influenced by the southern Italian Diana ceramic *facies*, such as the characteristic spool and tubular handles. Radiocarbon dates obtained for the three sites considered enabled to date these contexts between the second quarter and the end of the 5th millennium cal. BCE (Table 1; Bernabò Brea et al., 2017; Tiezzi et al., 2023a). While at Ozzano dell'Emilia 22 *figulina* sherds were retrieved during the excavations, with *figulina* pottery accounting for approximately 5 % of the assemblage, at Rimini-Igea Marina 24 *figulina* and *figulina*-like sherds were unearthed (3.8 % of the assemblage). At the site of Forlì-Via Navicella, *figulina* pottery appears albeit in minor amounts (only 4 specimens, less than 1 % of the assemblage).

The sites of Gatteo and Cesena-Via Masiera, despite not having yielded C14 dates, can be ascribed to the late 5th-4th millennium cal. BCE on the basis of typological comparisons with coeval sites in northern and central Italy (Bernabò Brea et al., 2017; Steffè et al., 2017). The *figulina* pottery from Cesena-Via Masiera is therefore limited to few partially refitting sherds retrieved from a single context, i.e. the fill of a ditch that yielded materials ascribed to a generic late Neolithic occupation of the site. At the site of Gatteo, where evidence of final Neolithic and early Copper Age occupation is known (Steffè et al., 2017), a single pot consisting of a slightly coarser *figulina* paste was retrieved, serving as isolated evidence of the persistence of light-coloured, *figulina*-like fabrics even at the onset of the Copper Age. At both these sites, *figulina* pottery constitutes less than 1 % of the total ceramic assemblage.

With the aim of comparing the *figulina* productions found at the Po Plain sites to the Ripoli and southern Italian Serra d'Alto productions, as well as to analogous products retrieved in other geographical areas,

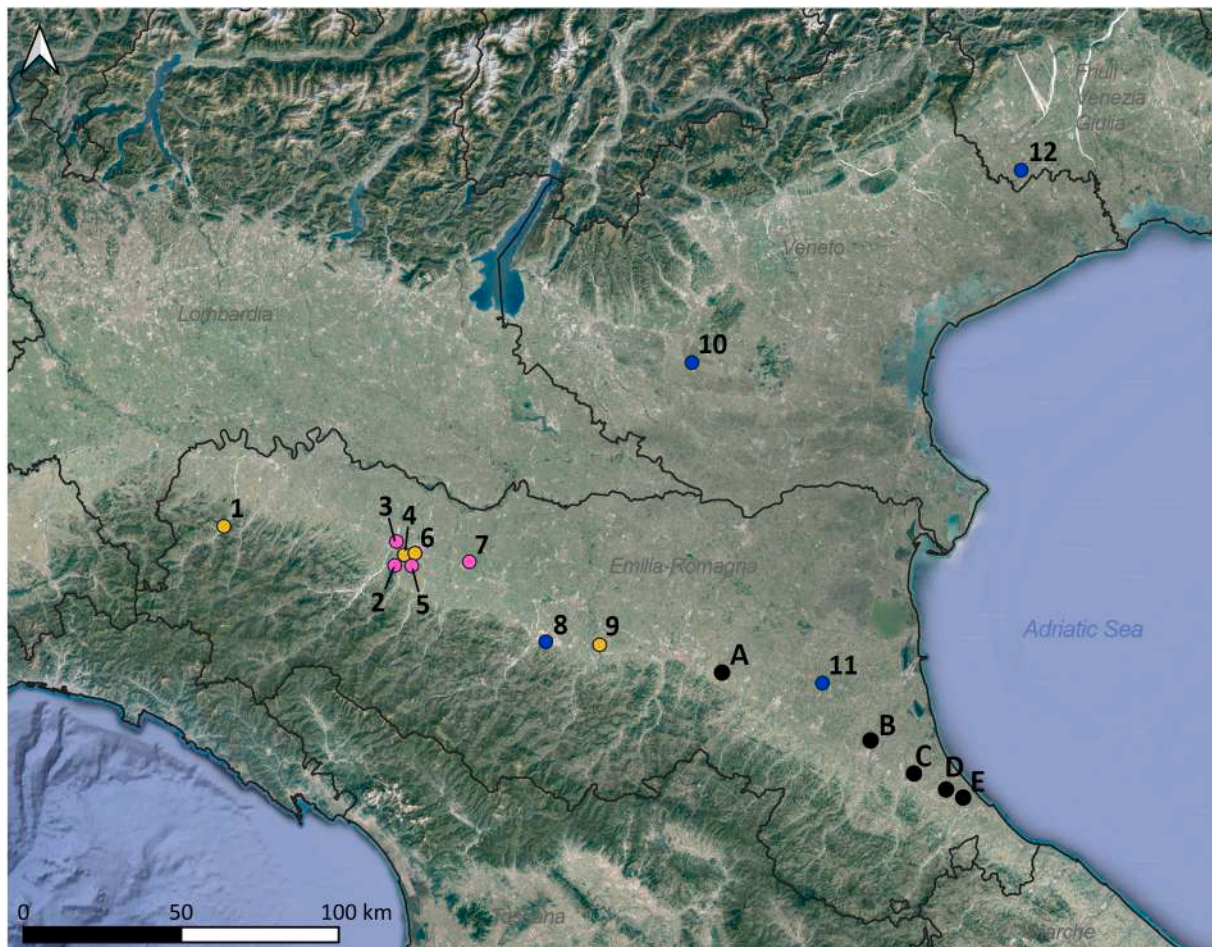
archaeometric data from previous research on Neolithic *figulina* wares were taken into account (Angeli et al., 2017; Binder et al., 2018; Canavò et al., 2014; Fabbri et al., 2013; Fermo et al., 2013; Laviano and Muntoni, 2007; Mannoni, 1988; Michelaki et al., 2015; Muntoni and Laviano, 2008; Muntoni et al., 2009, 2019; Pallecchi, 2019; Spataro, 2002, 2009, 2017; Teoh et al., 2014).

3. Materials and methods

Fifteen *figulina* sherds (Table 2) from Ozzano dell'Emilia, Rimini-Igea Marina, Forlì-Via Navicella, Cesena-Via Masiera and Gatteo were sampled for analysis (Fig. 3). The general scarcity of *figulina* sherds retrieved at the sites led to a limited number of samples being analysed. As a matter of fact, *figulina* sherds amount to less than 5 % of the total ceramic sherds retrieved at the aforementioned sites, with coarser, utilitarian wares in all cases representing the vast majority of the finds.

The ceramic samples were chosen on the basis of their macroscopic characteristics, particularly their light yellowish, light orangey or whitish colour observed on the sherd surface and on intentionally produced fresh breaks. Additionally, the absence or relatively low quantity of visible inclusions was considered. Another sampling criteria was the stratigraphic position of the potsherds. At Forlì and Gatteo all the few available sherds were sampled, while at Ozzano, Rimini-Igea Marina and Cesena, where slightly more numerous *figulina* sherds were retrieved, only sherds unearthed from distinct stratigraphic units were sampled as a way to minimise the risk of analysing multiple fragments belonging to a single ceramic shape. In fact, given the high level of fragmentation of the ceramic assemblages, only in very few cases the original shape of the vessels was identified upon search of refitting sherds (Table 2; Fig. 3). The majority of the sampled specimens are plain and undecorated, with the exception of one sherd from the site of Ozzano that displays traces of a reddish coating on the external surface (OZZ-11; Fig. 3).

The ceramic pastes were first analysed macroscopically with the aid



- Sites analysed in the present study
 - A: Ozzano dell'Emilia, Via Tolara di Sotto
 - B: Forlì, Via Navicella
 - C: Cesena, Via Masiera
 - D: Gatteo, Via Erboisa
 - E: Rimini-Igea Marina, Ca' Giorgetti
- Other figulina-bearing sites with published compositional analyses
 - Early Neolithic
 - Middle Neolithic
 - Mid-late Neolithic

Fig. 1. Map of northern Italy displaying the sites analysed in the paper and other sites with published compositional data on Neolithic figulina wares. 1: Travo S. Andrea (Muntoni et al., 2019); 2: Collecchio (Cannavò et al., 2014); 3: Pontetaro (Muntoni et al., 2019); 4: Vicofertile (Cannavò et al., 2014); 5: Gaione (Cannavò et al., 2014; Muntoni et al., 2019); 6: Parma Via Guidorossi (Cannavò et al., 2014; Muntoni et al., 2019); 7: Razza di Campegine (Cannavò et al., 2014); 8: Fiorano Modenese (Spataro, 2002); 9: Spilamberto (Spataro, 2009); 10: Santa Giustina (Fermo et al., 2013); 11: Lugo di Romagna (Pallecchi, 2019); 12: Fagnigola (Spataro, 2002).

of a handheld digital microscope (Dino-Lite Premier AM7013MZT4). The macroscopic analysis focussed on the type, frequency, maximum size and sorting of the inclusions and the characteristics of the ceramic matrices such as colour, hardness, porosity.

As an established analytical technique enabling to characterise ceramic technology as well as provenance, thin section ceramic petrography through polarising microscopy was performed on all the samples. Thin sections were analysed with a petrographic microscope (Leica DM 2500P) equipped with a digital camera for the acquisition of photomicrographs. Given the visible differences among the samples analysed in terms of inclusion type, size and distribution, a qualitative approach was adopted. Samples were grouped first in petrographic fabrics or petrofabrics and then described following the criteria established by Quinn (2022).

Semi-quantitative frequency labels were utilised to describe the frequency of inclusions following Quinn (2022: 108). Moreover, for each type of inclusion identified the maximum size and the estimated average

size was recorded. Lastly, the overall grain size distribution of the inclusions was taken into account with the purpose of identifying diagnostic features linked to paste preparation processes via sieving or elutriation, which normally result in changes in the frequency of the inclusions and their overall grain size distribution (Eramo, 2020; Quinn, 2022: 214-216).

Ceramic petrography was coupled with X-Ray Diffraction on the powdered samples (XRPD). The XRPD technique was performed with the aim of characterising the mineralogy of the sherds and thus identifying neoformation minerals linked to the firing process (Gliozzo, 2020). Slips and post-depositional layers were removed from the surfaces and breaks of the sherds using a low-speed drill prior to grinding; each ceramic body scraped of the external layers was then ground in an agate mortar with an agate pestle. The analysis was performed with a Bruker D8 advance equipped with with a Cu-sealed tube (40 kV/20 mA), a Göbel mirror optics, a 0.2 mm divergence slit, a fixed knife edge to suppress air scatter and a VANTEC 1-detector. The crystalline phases

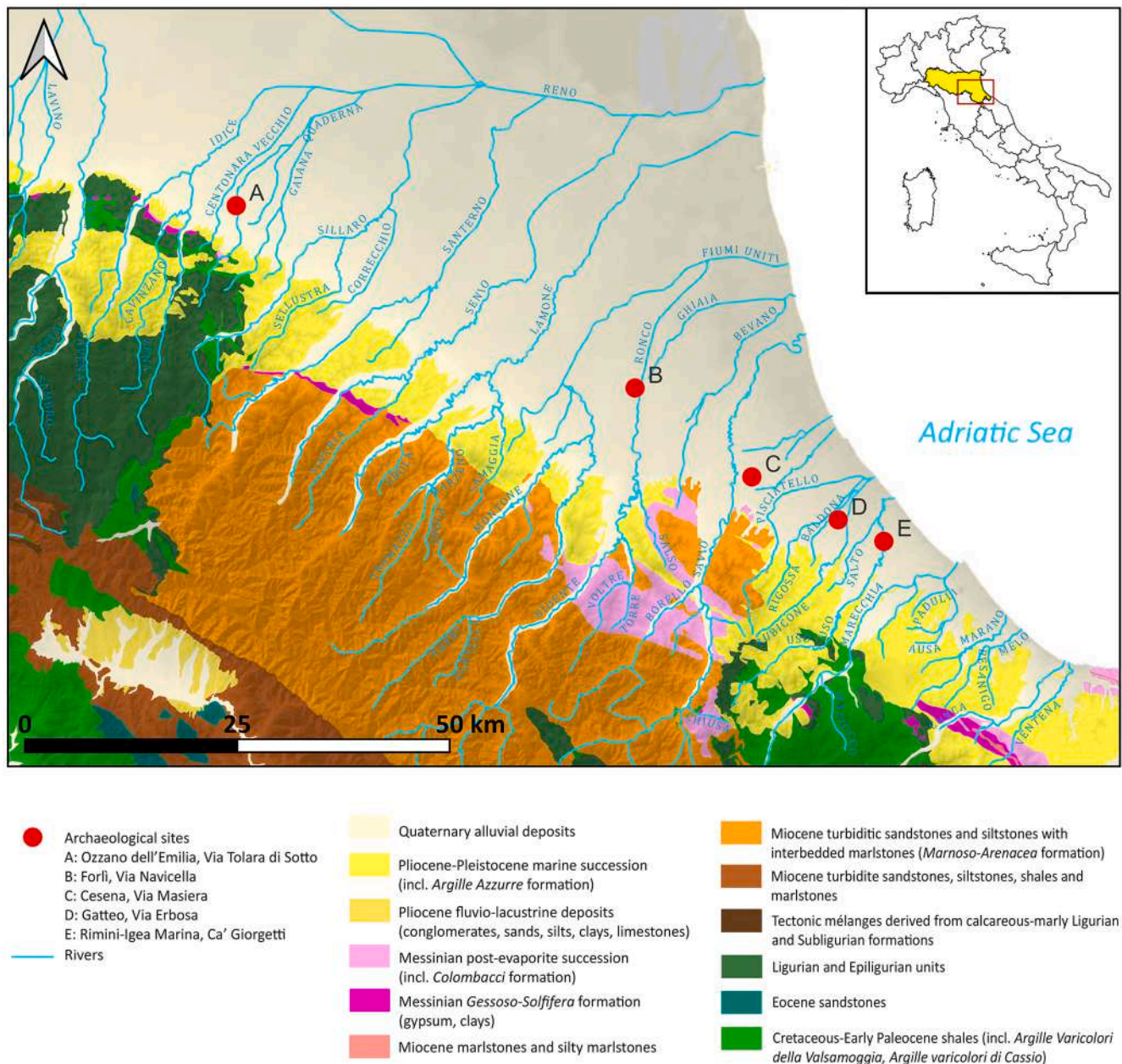


Fig. 2. Simplified geological map of the analysed area with the sites location (vectorial data from Conti et al., 2020; Digital Elevation Model from Tarquini et al., 2007).

were identified using the pdf data from the 2006 International Centre for Diffraction Data-Joint Committee of Powder Diffraction Standards (ICDD-JCPDS).

Portable X-Ray Fluorescence (p-XRF) was carried out on all 15 samples using a Niton XL3t with an external calibration specifically adjusted for the study of ceramics, developed at the University of Frankfurt am Main (Helfert et al., 2011). The advantage of this method is that it is non-destructive, fast and cost-efficient. However, only a small spot on the sample is analysed, which may not be representative of the composition of the whole specimen. This can be especially problematic for samples lacking a homogenous matrix. In order to minimise potential inaccuracies, three different points in the cross-section of each fragment were measured, and their average was calculated. The results of the p-XRF analysis for major and minor elements were normalised to 100 % in their oxide form calculated by stoichiometry.

4. Results

4.1. Macroscopic fabric analysis

The macroscopic analysis of the sherds enabled us to identify two macroscopic fabrics: *figulina* (samples OZN-1, OZN-6, OZN-9, OZN-11, OZN-13, OZN-15, NAV-4, NAV-17, IGE-1, IGE-2, IGE-11, MAS-4; Fig. 4A-D) and coarse *figulina* (samples NAV-18, NAV-19, GAT-1; Fig. 4E-F). The former defines a very fine fabric, with very light cream or orange/yellow-coloured surfaces and fractures. The matrix is generally homogeneous with very few or no visible inclusion to the naked eye, while surfaces are powdery to the touch. The samples generally display a high porosity. Most sampled sherds are plain and undecorated. Only one sample from Ozzano displays a reddish coating on the external surface and dark core (OZN-11; Fig. 4D).

Coarse figulina is characterised by very light-coloured surfaces and

Table 2

List of analysed *figulina* and coarse *figulina* samples with the corresponding identified formal types and macroscopic fabric.

Sherd ID code	Site	Context/ Stratigraphic Unit n.	Chronology	Type	Macroscopic fabric
OZN-1	Ozzano dell'Emilia, Via Tolara di Sotto	64 (weakly anthropic layer at the base of the stratigraphy)	Middle Neolithic	n.a., wall sherd	<i>Figulina</i>
OZN-6	Ozzano dell'Emilia, Via Tolara di Sotto	30 (gravelly layer in correspondence of Structure A)	Middle Neolithic	n.a., wall sherd	<i>Figulina</i>
OZN-9	Ozzano dell'Emilia, Via Tolara di Sotto	138 (fill of foundation trench of Structure A)	Late Neolithic	n.a., wall sherd	<i>Figulina</i>
OZN-11	Ozzano dell'Emilia, Via Tolara di Sotto	48 (fill of pit, uncertain phase)	Mid-late Neolithic	n.a., wall sherd	<i>Figulina</i>
OZN-13	Ozzano dell'Emilia, Via Tolara di Sotto	21 (spread of ceramic sherds near combustion structure/oven C)	Middle Neolithic	Flask with three handles, wall sherd	<i>Figulina</i>
OZN-15	Ozzano dell'Emilia, Via Tolara di Sotto	29 (later frequentation layer)	Late Neolithic	n.a., wall sherd	<i>Figulina</i>
NAV-4	Forlì, Via Navicella	1622 (fill of pit)	Late Neolithic	n.a., wall sherd	<i>Figulina</i>
NAV-17	Forlì, Via Navicella	2200 (Neolithic soil)	Late Neolithic	n.a., wall sherd	<i>Figulina</i>
NAV-18	Forlì, Via Navicella	2200 (Neolithic soil)	Late Neolithic	Carinated bowl, rim sherd	Coarse <i>figulina</i>
NAV-19	Forlì, Via Navicella	2200 (Neolithic soil)	Late Neolithic	Cup or bowl, rim sherd	Coarse <i>figulina</i>
IGE-1	Rimini-Igea Marina, Ca' Giorgetti	7 (fill of narrow ditch)	Mid-late Neolithic	n.a., wall sherd	<i>Figulina</i>
IGE-2	Rimini-Igea Marina, Ca' Giorgetti	3 (Neolithic soil)	Mid-late Neolithic	n.a., wall sherd	<i>Figulina</i>
IGE-11	Rimini-Igea Marina, Ca' Giorgetti	22 (fill of large, irregular pit)	Mid-late Neolithic	n.a., wall sherd	<i>Figulina</i>
MAS-4	Cesena, Via Masiera	75/76 (fill of ditch)	Late Neolithic	n.a., wall sherd	<i>Figulina</i>
GAT-1	Gatteo, Via Erbosca	204 (fill of pit)	Final Neolithic -Early Copper Age	Carinated cup, rim sherd	Coarse <i>figulina</i>

fractures and a rather homogeneous or slightly inhomogeneous matrix. However, it contains visible inclusions ranging in size from fine to very coarse sand as defined on the Udden-Wentworth grain-size scale (Fig. 4E-F).

4.2. Ceramic petrography

Thin section analysis of the six samples from Ozzano dell'Emilia enabled us to distinguish three distinct petrographic fabrics:

-Clay mixing (figulina samples OZN-1, OZN-9; Fig. 5A). This group is characterised by a slightly calcareous, inhomogeneous matrix with microstructural variations in colour and optical density within the clay body. The moderately sorted inclusions are predominantly in the range of coarse silt and very fine sand, with larger inclusions in the range of medium sand. The grain size distribution of the inclusions is unimodal. Mono- and polycrystalline quartz with undulose extinction, likely derived from metamorphic rocks, is the prevailing mineral inclusion. Microfossils are rarely present and are mainly represented by planktonic foraminifera belonging to the Globigerinidae family. Given the inhomogeneity of the matrix and the presence of frequent sub-spherical, darker clay lumps and rare swirls and lenses (*sensu* Ho and Quinn, 2021) displaying diffuse or clear to merging boundaries and occasionally tapering tails, it is highly likely that this fabric derives from the deliberate mixing of a calcareous and a non calcareous, iron-rich clay. The prevalence of clay bodies such as lumps and lenses over other plastic features like swirls and streaks might result from the incorporation of a dry source of clay within a moist base clay (Ho and Quinn, 2021: 8). It is unclear whether the original base clays were processed through fractionation before mixing. Only sample OZN-1 is optically active. This characteristic could be linked to a lower firing temperature below the 800° C threshold. Post-depositional voids-infilling calcite is registered in both samples.

-Calcareous, quartz-microfossils-shells (figulina samples OZN-6, OZN-13, OZN-15; Fig. 5B). This group is characterised by a calcareous and slightly inhomogeneous matrix with moderately to well sorted inclusions predominantly ranging in size from coarse silt to fine sand, with very few larger inclusions in the range of medium sand. The grain size distribution of the inclusions is unimodal. Mineral inclusions include micritic calcite, quartz, muscovite mica and feldspars (plagioclase and microcline). Microfossils such as planktonic foraminifera, namely of the Globigerinidae and Globorotaliidae families, are frequent. Coarser biogenic inclusions such as gastropods and bivalve shells are also common. Sample OZN-6 differs from the others in that the microfossils and shells are completely decayed and occur as vesicles or elongated voids. Overall, the use of a fossiliferous and shell-rich calcareous clay can be suggested for this fabric. Due to the packing, sorting and size of the inclusions there is not enough evidence of deliberate clay fractionation processes. The slightly inhomogeneous matrix comprises TCFs with clear to diffuse boundaries that can be either interpreted as naturally occurring clay pellets or can indicate an incomplete hydration and homogenisation of the base clay. Optical activity of the matrix varies from very low to absent, thus suggesting a relatively high firing temperature, close to or just above the 800° C threshold. An even higher firing temperature can be inferred for sample OZN-6, where the calcium carbonate foraminifera tests appear to be completely decayed. Post-depositional voids-infilling micritic calcite is registered in sample OZN-15.

-Quartz-muscovite-calcite (figulina sample OZN-11; Fig. 5C). Sample characterised by a non calcareous, iron-rich matrix with few moderately sorted discrete inclusions predominantly in the range of silt and more rarely very fine sand. The maximum grain size registered is in the range of fine sand. The inclusions display a unimodal grain size distribution. Mono- and polycrystalline quartz with undulose extinction is the prevailing mineral inclusion, followed by muscovite and sparitic calcite. The prevalence of the matrix over the inclusions (the latter estimated to

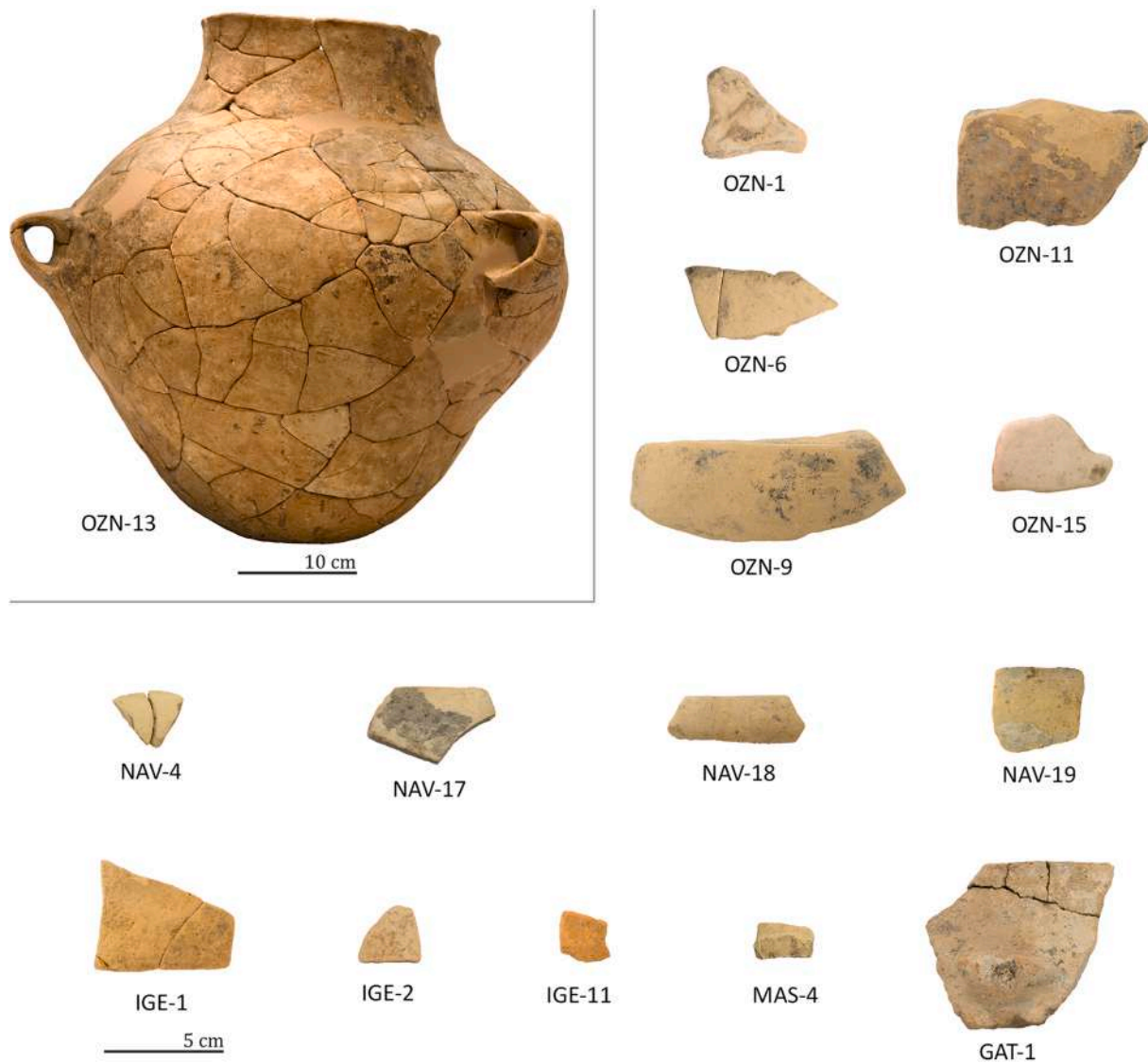


Fig. 3. Photos of the sampled ceramics. Samples from Ozzano dell'Emilia-Via Tolara di Sotto: OZN-1, OZN-6, OZN-9, OZN-11, OZN-13, OZN-15. Samples from Forlì-Via Navicella: NAV-4, NAV-17, NAV-18, NAV-19. Samples from Rimini-Igea Marina, Ca' Giorgetti: IGE-1, IGE-2, IGE-11. Sample from Cesena-Via Masiera: MAS-4. Sample from Gatteo: GAT-1. All images courtesy of the *Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Bologna e le province di Modena, Reggio Emilia e Ferrara* and the *Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Ravenna, Forlì-Cesena e Rimini*.

occur with approximately 5 % frequency) as well as the unimodal skewed distribution of the inclusions' grain sizes might be an indication that the fabric was obtained by refining a non calcareous clay containing quartz and carbonatic rock fragments, either through sieving or elutriation (Eramo, 2020; Quinn, 2022: 214-216: 12). The matrix is optically active, thus suggesting a firing temperature below the 800° C threshold. The dark core exhibited by this specimen is likely an indication of short firing time at low temperatures with insufficient oxygen penetration, rather than signalling the presence of organic matter within the clay body (Quinn, 2022: 274). A thin layer of post-depositional micritic calcite can be observed at the margins of the sherd.

The analysis of the four samples from Forlì-Via Navicella, highlighted the presence of three petrographic fabrics:

-*Calcareous, quartz-muscovite-biotite (figulina* samples NAV-4, NAV-17). This group displays a calcareous and relatively homogeneous matrix with moderately to well sorted silt-sized inclusions, with a maximum grain size in the range of fine sand. The grain size distribution of the inclusions is unimodal. Common inclusions are mono- and polycrystalline quartz, muscovite and biotite mica. Rare multi-chambered voids observable in the clay matrix might be due to decayed

microfossils (e.g. planktonic foraminifera). While the unimodal skewed distribution of the inclusions' grain sizes could hint at refining processes of the base clay, there is not enough evidence for clay fractioning due to the relatively high packing of the inclusions. The matrix is optically inactive, suggesting a relatively high firing temperature above the 800° C threshold.

-*Calcareous, fossiliferous polymict sand* (coarse *figulina* sample NAV-18; Fig. 5D). This petrographic fabric is characterised by a calcareous and relatively homogeneous matrix. It contains moderately sorted aplastic inclusions ranging in size from coarse silt to fine sand. The grain size distribution of the inclusions is unimodal. The inclusions display a heterogeneous composition, with frequent fragments of sedimentary and metamorphic rock fragments. Quartz, micritic calcite, muscovite, biotite, chert and sparitic calcite are the most common mineral inclusions. Fossilised shells and microfossils are particularly abundant. Among the bioclasts recognised are bivalves, echinoids (e.g. *Brissopsis ottmangensis*), planktonic foraminifera of the Globigerinidae family (including *Orbulina* sp.), benthic foraminifera and calcareous algae. The degree of roundness and the heterogeneity of the sand-sized inclusions is likely an indication that the original sediment underwent a certain

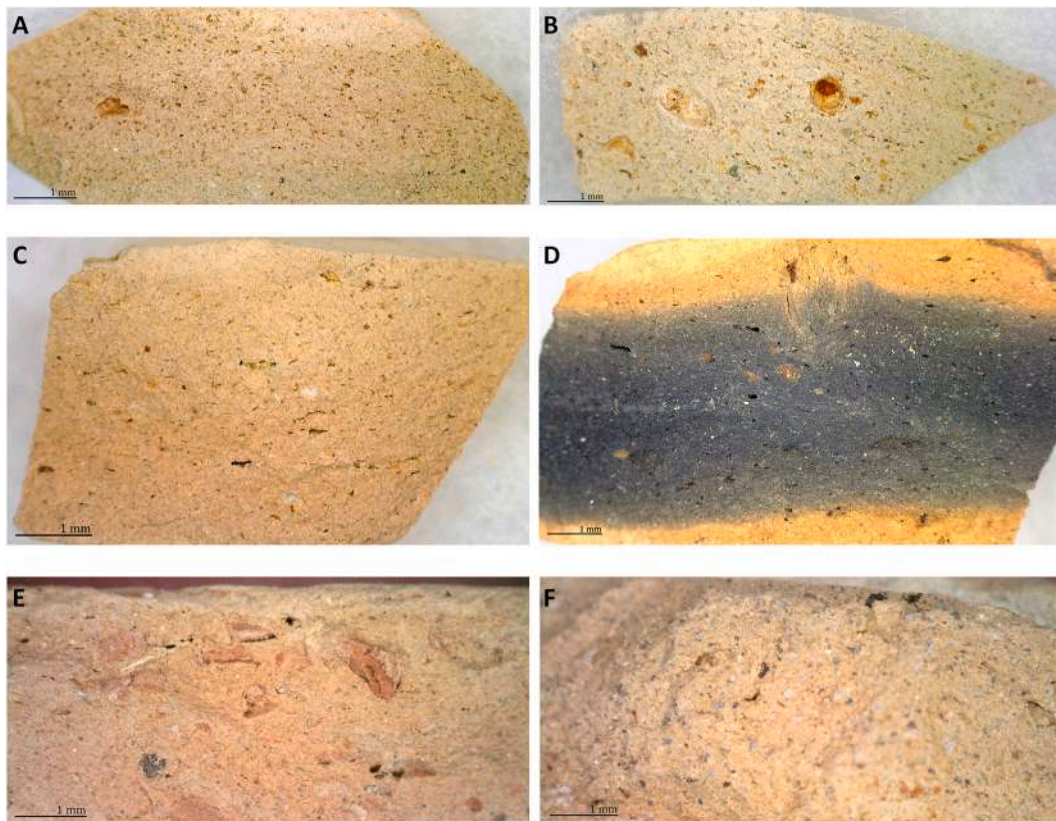


Fig. 4. Images of the ceramic bodies in fresh fracture captured with a digital microscope (Dino-Lite Premier AM7013MZT4). A-D: “*figulina*” macroscopic fabric, samples NAV-17 (A), MAS-4 (B), IGE-2 (C), OZN-11 (D). In fresh break, only OZN-11 displays a dark core. E-F: “*coarse figulina*” macroscopic fabric, samples NAV-19 (E) and NAV-18 (F). All images courtesy of the *Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Bologna e le province di Modena, Reggio Emilia e Ferrara* and the *Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Ravenna, Forlì-Cesena e Rimini*.

degree of transportation. This probably indicates the use of a secondary calcareous clay source rich in microfossils. Specifically, the presence of ‘polymict’, rounded sand-sized inclusions might point to the use of a fluvial sediment. The matrix displays low optical activity, suggesting a firing temperature below the 800° C threshold.

-*Grog* (coarse *figulina* sample NAV-19; Fig. 5E). This fabric displays a slightly calcareous matrix with a bimodal grain size distribution of the inclusions. The finer fraction is in the range of coarse silt to medium sand containing predominantly quartz and mica inclusions, while the coarse fraction is characterised by the prevalence of grog, mostly obtained from a fabric with similar composition or slightly coarser than the analysed sample. Grog inclusions range in size from medium sand up to granules and are characterised by high to neutral density and sharp to clear boundaries (*sensu* Whitbread, 1986). They are discordant with the rest of the fabric and often display shrinkage voids. The matrix displays very low to absent optical activity, suggesting a relatively high firing temperature, approximately close to the 800° C threshold. It has a slightly inhomogeneous appearance that is likely due to the use of a naturally variegated clay. Post-depositional calcite is commonly observed on the surface of the sherd and infilling the voids within the ceramic body.

The three samples from Rimini-Igea Marina belong to a single petrofabric:

-*Calcareous, quartz-muscovite-microfossils* (*figulina* samples IGE-1, IGE-2, IGE-11; Fig. 5F). Characterised by a calcareous matrix with moderately to well sorted silt-sized inclusions, with a maximum grain size in the range of fine sand. The inclusions display a unimodal grain size distribution. Mono- and polycrystalline quartz with undulose extinction and muscovite mica represent the main mineral inclusions. Poorly preserved microfossils, likely planktonic foraminifera, are common. The prevalence of the matrix over the inclusions (the latter

estimated to occur with approximately 10–15 % frequency) as well as the unimodal skewed distribution of the inclusions’ grain sizes indicates that the fabric was probably obtained by refining a calcareous clay containing quartz inclusions, muscovite and microfossils, likely through fractioning processes via sieving or elutriation (Eramo, 2020; Quinn, 2022: 214-216: 12). The matrix is optically inactive, suggesting a relatively high firing temperature above the 800° C threshold. Post-depositional voids-infilling micritic calcite is registered in all samples.

The sample from Cesena, Via Masiera is characterised as following:

-*Calcareous, quartz-microfossils-muscovite* (*figulina* sample MAS-4; Fig. 5G). The sample displays a calcareous, homogeneous matrix containing moderately sorted silt-sized inclusions, with a maximum grain size in the range of fine sand. Quartz, muscovite, biotite and opaque minerals are the main mineral inclusions. Planktonic microfossils of the Globigerinidae family are common but generally poorly preserved. While the unimodal skewed distribution of the inclusions’ grain sizes could hint at refining processes of the base clay, there is not enough evidence for clay fractioning due to the relatively high packing of the inclusions. The matrix is optically inactive, suggesting a relatively high firing temperature above the 800° C threshold. A thin layer of post-depositional micritic calcite can sporadically be observed at the edges of the sample.

The sample from Gatteo, Via Erbosa is characterised as following:

-*Grog* (coarse *figulina* sample GAT-1; Fig. 5H). This fabric is characterised by the addition of grog inclusions to a slightly calcareous, inhomogeneous base clay. The grain size distribution of the inclusions is polymodal, with the fine fraction containing mainly quartz and muscovite, while the medium and coarse fraction are characterised by crushed grog fragments ranging in size from fine sand up to very coarse sand. Grog inclusions have heterogeneous compositions and often derive

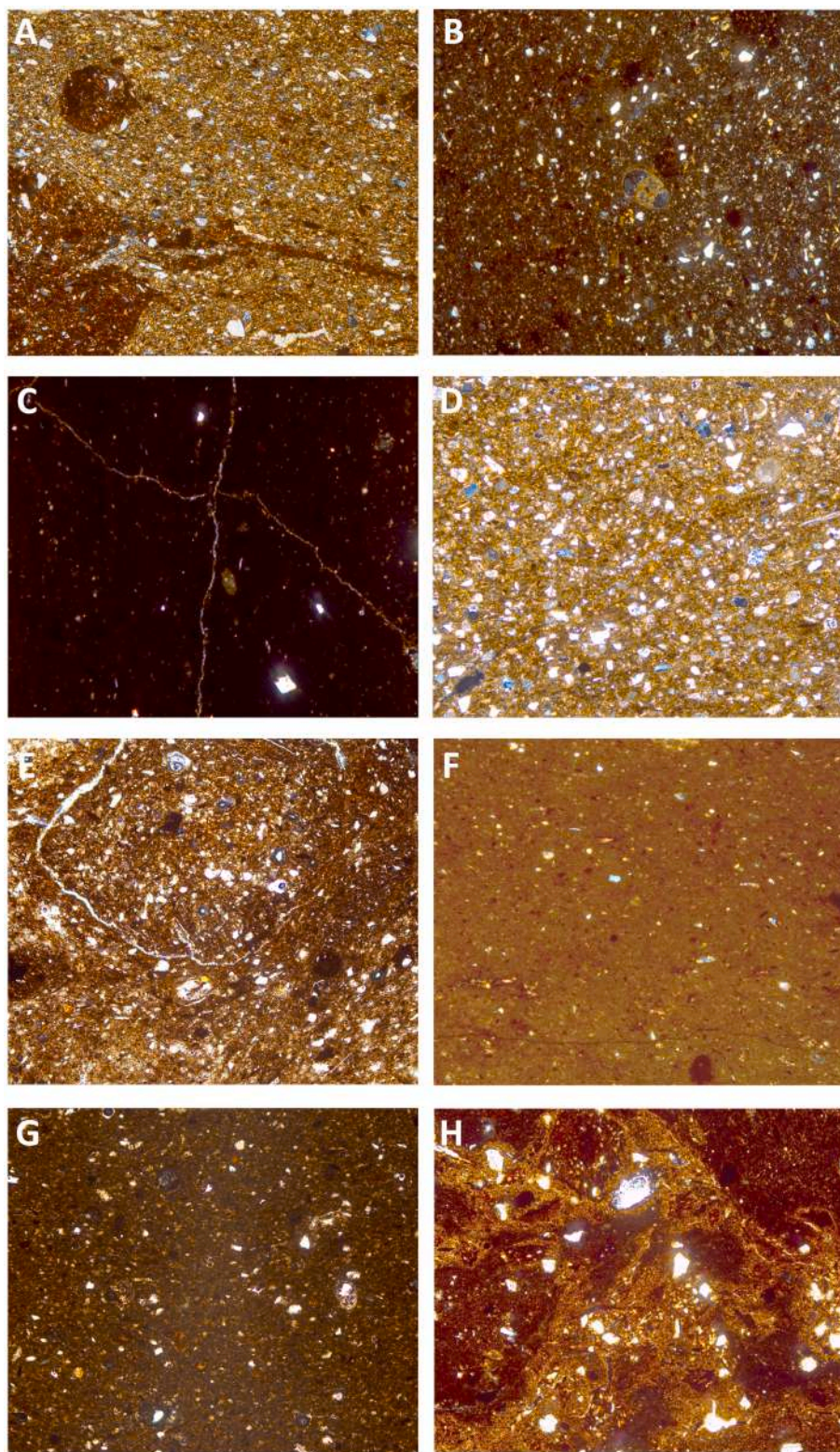


Fig. 5. Photomicrographs of selected samples representative of the main *figulina* and coarse *figulina* petrographic fabrics retrieved at each site. From the site of Ozzano dell'Emilia: Clay mixing, sample OZN-1, XPL (A); Calcareous, quartz-microfossils-shells, sample OZN-13, XPL (B); Quartz-muscovite-calcite, sample OZN-11, XPL (C). From the site of Forlì, Via Navicella: Calcareous, fossiliferous polymict sand, sample NAV-18, XPL (D); Grog, sample NAV-19, PPL. From the site of Rimini-Igea Marina, Ca' Giorgetti: Calcareous, quartz-muscovite-microfossils, sample IGE-1, XPL (F); from Cesena, Via Masiera: Calcareous, quartz-microfossils-muscovite, sample MAS-4, PPL (G); from Gatteo: Grog, sample GAT-1, PPL (H). Width of field in all photomicrographs is 3 mm.

from coarser fabrics. They are characterised by high to neutral density and sharp to clear boundaries; they are generally discordant with the rest of the fabric and at times display shrinkage voids or relic surfaces. Second generation grog (Quinn, 2022: 71) has been sporadically observed. The clay matrix is characterised by darker and lighter streaks and lenses with diffuse to merging boundaries. These are likely resulting from the use of a naturally variegated base clay, as there is not enough evidence of clay mixing. Low optical activity of the matrix is indicative of firing temperatures below the 800° C threshold. Post-depositional voids-infilling micritic calcite is present.

A detailed description of each petrographic fabric with photomicrographs is provided as [supplementary material \(Supplementary Data 1\)](#).

4.3. XRPD

Ceramic petrography was paired with X-Ray Powder Diffraction for the identification of the clay minerals and the estimate of firing temperatures. In carbonatic clays (as defined in Gliozzo, 2020), calcite starts decomposing at approximately 600° C, releasing CO₂ and forming CaO that reacts with the clay minerals to form new mineral phases such as diopside and wollastonite starting from 800° C-900° C (Gliozzo, 2020; Maritan et al., 2006).

XRPD analysis disclosed a moderate degree of variability among the analysed *figulina* and coarse *figulina* petrofabrics (Supplementary Data 2). The main phases detected were quartz, illite/muscovite, calcite, diopside and feldspar. A summary of the mineralogical phases identified in each sample is proposed in Table 3.

The main calcite peak at $d = 3.04 \text{ \AA}$ ($2\theta = 29.41^\circ$) has been identified in 12 sherds, with variations in intensity among the samples. Sharp peaks signalling the presence of well-crystalline calcite have been registered in samples OZN-1, OZN-11 and NAV-18, in contrast to the e.g. weak/broad main peaks of diopside at $d = 2.99 \text{ \AA}$ ($2\theta = 29.91^\circ$), which points to crystalline sizes below the μm -range. These samples also show sparitic calcite occurring as discrete mineral inclusions in thin section. Samples OZN-6, OZN-9, OZN-13, OZN-15, NAV-4, NAV-19, IGE-1, IGE-11 and GAT-1, on the other hand, show weak or very weak, broad calcite signals, denoting the persistence of micro-crystalline calcite within the clay matrix.

Only samples MAS-4, IGE-2 and NAV-17 show no calcite signal, while the main diopside peak is present in all the three samples, denoting firing temperatures above 800° C. In addition, newly-formed diopside has been identified in various samples still containing calcite (OZN-6; OZN-9; OZN-13; OZN-15; NAV-4; NAV-19; IGE-1; IGE-11). The coexistence of both mineral phases could be explained on account of short firing time or excessive amounts of calcite causing an incomplete reaction between CaO and the clay minerals (Fabbri et al., 2014).

Table 3

Mineralogical phases identified via XRPD; sharp peaks are indicative of the presence of well-crystalline phases, while broad peaks are attributable to the crystal sizes below the μm -range of mineral phases occurring within the ceramic micromass.

Sample ID	Illite/muscovite	Quartz	Calcite	Diopside	Feldspars	Petrofabric
OZN-1	X (weak/broad)	X (very sharp)	X (sharp)		X (weak/broad)	Clay mixing
OZN-6	X (weak/broad)	X (very sharp)	X (very weak/broad)	X (weak/broad)	X (weak/broad)	Calcareous, quartz-microfossils-shells
OZN-9	X (weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Clay mixing
OZN-11	X (weak/broad)	X (very sharp)	X (sharp)		X (weak/broad)	Quartz-muscovite-calcite
OZN-13	X (weak/broad)	X (very sharp)	X (weak/broad)	X (very weak/broad)	X (weak/broad)	Calcareous, quartz-microfossils-shells
OZN-15	X (weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Calcareous, quartz-microfossils-shells
NAV-4	X (very weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Calcareous, quartz-muscovite-biotite
NAV-17	X (very weak/broad)	X (very sharp)		X (weak/broad)	X (sharp)	Calcareous, quartz-muscovite-biotite
NAV-18	X (weak/broad)	X (sharp)	X (sharp)		X (weak/broad)	Calcareous, fossiliferous polymict sand
NAV-19	X (weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Grog
IGE-1	X (weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Calcareous, quartz-muscovite-microfossils
IGE-2	X (very weak/broad)	X (very sharp)		X (weak/broad)	X (weak/broad)	Calcareous, quartz-muscovite-microfossils
IGE-11	X (weak/broad)	X (very sharp)	X (weak/broad)	X (weak/broad)	X (weak/broad)	Calcareous, quartz-muscovite-microfossils
MAS-4		X (very sharp)		X (weak/broad)	X (weak/broad)	Calcareous, quartz-microfossils-muscovite
GAT-1	X (weak/broad)	X (very sharp)	X (weak/broad)		X (weak/broad)	Grog

Indeed, the original chemical composition of the ceramics may account for the generally weak or absent diopside peaks, as insufficient quantities of magnesium within the clay body may have hindered the formation of such mineral phase (see also Table 4).

However, it is also worth noting that the calcite signal in some samples containing diopside could also be linked to the presence of post-depositional calcite incorporated within the ceramic body during burial and still visible in thin section, for example in samples OZN-9, OZN-15, NAV-4, NAV-19, IGE-1, IGE-11.

Illite/muscovite signal is still present in most of the samples analysed at $d = 10.02 \text{ \AA}$ ($2\theta = 8.82^\circ$), excluding the sherd from Cesena-Via Masiera (MAS-4). The latter also displays a main peak of diopside with high intensity. The absence of the illite peak in this case could be an indication of higher firing temperatures. Indeed, illite can start its decomposition process at various temperatures, however this mineral phase is normally not recorded above the threshold of 900° C in carbonate-rich ceramics (Amicone et al., 2023; Trindade et al., 2009). Therefore, a firing temperature between 900 and 1100° C can be suggested for this specimen, considering that diopside tends to disappear above the 1100° C threshold (Gliozzo, 2020).

Conversely, few diffractograms of specimens not containing diopside can be indicative of firing temperatures below 800° C: namely, two of the sherds belonging to the coarse *figulina* macroscopic fabrics (NAV-18 and GAT-1), the only sample of the *Quartz-muscovite-calcite* fabric (OZN-11) and one specimen of the clay-mixing petrofabric (OZN-1). All these samples also display an optically active or slightly active matrix in thin section, which points to a not completely amorphous matrix.

4.4. P-XRF

The small dataset with up to five samples per site makes any interpretation challenging. However, some general remarks regarding the chemical composition when compared to the petrofabric groups can be made. For example, the CaO content varies significantly among the fabrics analysed, but some of the lowest values for calcium have been recorded for the grog-tempered coarse *figulina* fabrics (NAV-19; GAT-1; Fig. 6A-B). The *Quartz-muscovite-calcite* fabric (sample OZN-11), despite the sporadic presence of coarse calcite inclusions, has a surprisingly small amount of CaO, meaning that the clay paste for all the three above mentioned samples can be classified as non-carbonatic clayey raw material (following Gliozzo, 2020).

For the samples retrieved at Ozzano dell'Emilia there is no series of elements that provide a clear indication for distinguishing sub-groups, however, most major, minor and trace element show a considerable variability which could be an indication of the use of clays derived from a wider range of sources. Taking into account the effects of clay processing, such as the mixing of distinct raw materials in the *Clay mixing*

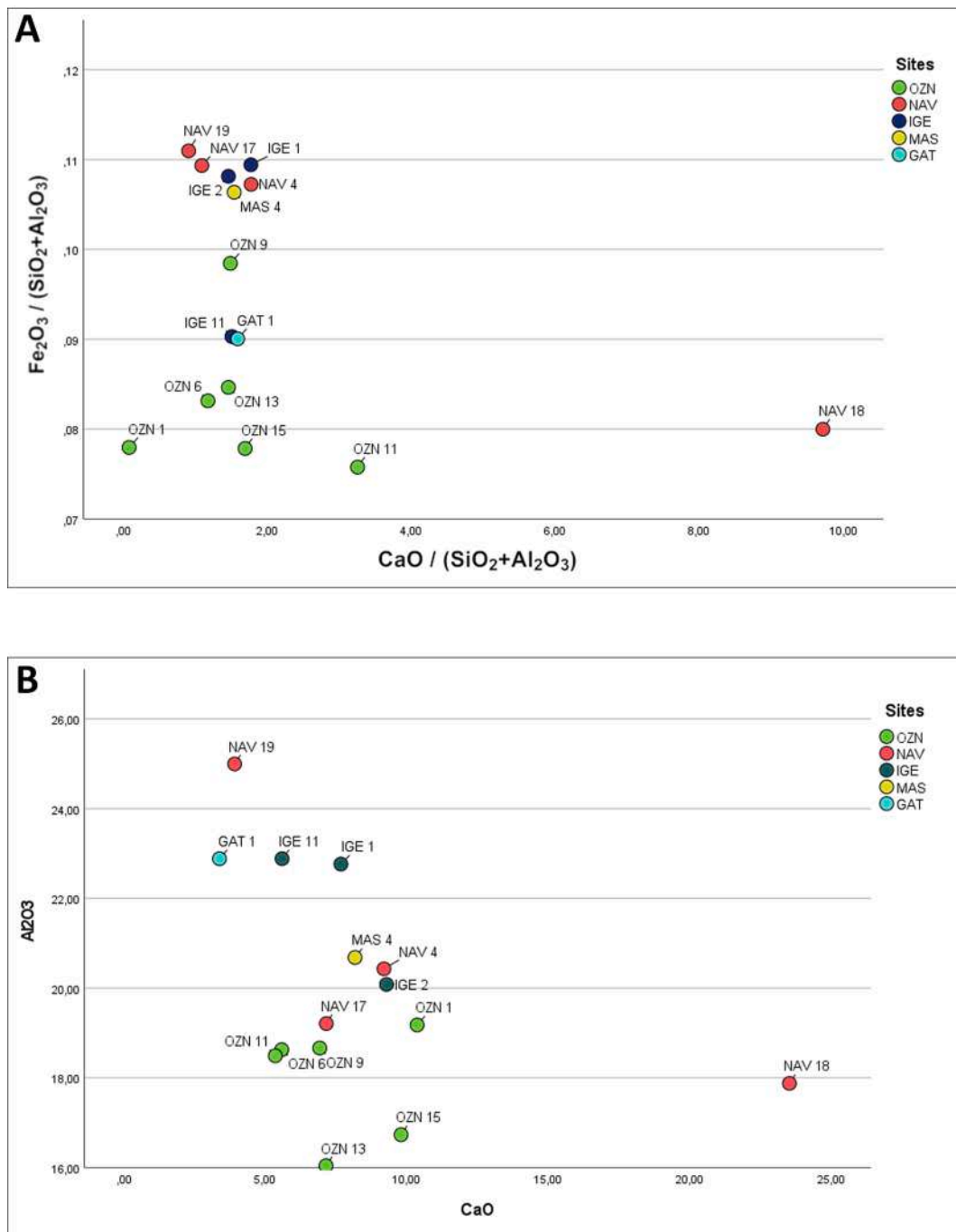


Fig. 6. Biplot of $\text{Fe}_2\text{O}_3/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ versus $\text{CaO}/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ (A) and Al_2O_3 versus CaO (B).

group (OZN-1, OZN-9), the chemical variability among the samples grouped in this particular petrofabric can be explained by variations in the ratio of the base clays used, likely bearing distinct geochemical signatures.

Most likely made from the same raw material are the two couples OZN-13 and OZN-15, belonging to the *Calcareous, quartz-microfossils-shells* group, while the third specimen belonging to this group (OZN-6) displays slight differences in major elemental composition that can likely be explained in terms of natural internal variations within the clay source used. Significant internal variations in the CaO content within each petrographic group should also take into account the effects of post-depositional calcite incorporated in voids during burial. As a matter of fact, the precipitated calcite detected in OZN-15 may explain the higher CaO level registered in this specimen when compared to OZN-13

and OZN-6.

As to the samples from Forlì-Via Navicella, NAV-18 is clearly an outlier due to the high amount of CaO likely deriving from both the matrix and the coarse fraction, but also for a variety of deviating trace elements when compared to the rest of the samples from this site (e.g. lower vanadium and chrome as well as elevated levels of strontium and barium; Table 5). The grog-tempered NAV-19 specimen, with its elevated aluminium and low calcium (Fig. 6B) is very likely made from a different type of clay, as are the two samples NAV-4 and NAV-17, who in contrast are similar enough to originate from the same raw material.

For the three samples found at Rimini-Igea Marina, it is very likely that the clay raw material used for IGE-1 and IGE-2 was the same, with IGE-11 being similar in most elements, but varying in the lower manganese and calcium contents as well as elevated phosphorus.

Table 4

Major and minor elemental composition in wt% of the samples measured via p-XRF. Analysis normalized to 100%.

SAMPLE	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	P ₂ O ₅
OZN-1	58,27	0,84	19,18	6,04	0,04	2,09	10,36	2,37	0,81
OZN-6	60,94	0,85	18,63	6,62	0,09	4,67	5,58	1,64	0,98
OZN-9	57,44	1,20	18,66	7,49	0,09	4,56	6,92	2,76	0,87
OZN-11	64,23	0,75	18,49	6,27	0,09	1,57	5,35	2,43	0,83
OZN-13	61,69	0,81	16,04	6,58	0,05	4,82	7,15	2,05	0,82
OZN-15	58,51	0,94	16,73	5,86	0,06	5,72	9,80	1,78	0,62
NAV-4	52,19	1,27	20,43	7,79	0,06	5,08	9,19	2,08	1,93
NAV-17	54,43	1,18	19,21	8,05	0,10	6,47	7,16	2,49	0,91
NAV-18	47,99	0,64	17,88	5,27	0,08	2,34	23,52	2,17	0,12
NAV-19	53,89	1,07	25,00	8,75	0,07	4,22	3,92	2,44	0,65
IGE-1	53,47	1,14	22,76	8,34	0,11	4,23	7,67	1,96	0,31
IGE-2	52,91	1,08	20,08	7,89	0,14	6,26	9,28	2,03	0,32
IGE-11	56,78	1,26	22,88	7,19	0,05	3,62	5,59	1,83	0,78
MAS-4	53,89	1,05	20,68	7,93	0,09	5,21	8,17	1,94	1,04
GAT-1	57,37	1,19	22,88	7,23	0,08	2,04	3,38	2,05	3,77

Table 5

Trace elements in ppm measured via p-XRF.

SAMPLE	S	V	Cr	Ni	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th
OZN-1	260	119	154	43	13	96	6	97	307	28	150	16	297	26	14
OZN-6	115	124	294	69	29	94	5	55	211	31	167	14	377	23	13
OZN-9	199	152	235	74	36	111	10	84	367	35	159	19	769	31	21
OZN-11	30	184	276	75	24	157	9	100	251	30	153	17	664	36	18
OZN-13	0	130	176	71	27	120	11	106	333	29	135	18	753	25	17
OZN-15	68	125	326	70	3	136	4	63	354	46	172	15	288	27	17
NAV-4	416	156	374	49	18	63	10	47	190	41	188	19	201	21	18
NAV-17	262	170	361	47	21	73	8	68	177	61	194	19	127	10	19
NAV-18	392	84	151	59	18	80	9	80	349	32	116	12	380	20	10
NAV-19	382	141	329	70	21	123	10	88	158	48	155	20	226	33	19
IGE-1	171	182	302	49	20	77	19	61	149	40	150	20	153	33	17
IGE-2	94	169	300	70	21	87	10	53	218	39	162	19	253	29	18
IGE-11	187	111	373	48	26	110	11	50	169	34	169	20	153	34	17
MAS-4	150	147	378	60	21	103	8	54	153	50	172	20	86	23	20
GAT-1	479	144	220	56	19	125	21	74	1371	35	178	17	418	27	15

5. Discussion

5.1. Investigating the production technology of the *figulina* wares in the southern Po Plain

The analysis of the 15 *figulina* and coarse *figulina* samples (Table 6.) revealed the employment of a variety of raw materials specifically selected, processed and fired following a procedure that greatly differentiates this ceramic class from the low-fired utilitarian coarse wares found at the Po Plain Neolithic sites. As a matter of fact, when

considering the Square-Mouthed Pottery tradition of the southern Po Plain, one of the main tempering strategies for coarse, utilitarian productions seems to be the incorporation of crushed sparitic calcite to calcareous and non-calcareous clays (Muntoni et al., 2019), a technological trait that has been recorded in many coarse specimens retrieved at the site of Ozzano. In the Romagna area, preliminary results of the petrographic analysis of coarse samples from the sites of Forlì-Via Navicella, Gatteo, Cesena-Via Masiera and Rimini-Igea Marina revealed the predominance of tempered fabrics containing crushed grog fragments and/or other types of rocks (Tiezzi et al., 2023b). Furthermore,

Table 6

Technological traits associated to each petrographic fabric.

Petrofabric	Sample(s) n.	Fractioning	Clay mixing	Tempering	Est. firing temperature
Clay mixing	OZN-1, OZN-9	Uncertain	Yes, likely in a moist-dry state	No evidence	800° C-900° C (sample OZN-9); below 800° C (sample OZN-1)
Calcareous, quartz-microfossils-shells	OZN-6, OZN-13, OZN-15	No evidence	No evidence	No evidence	800° C-900° C
Quartz-muscovite-calcite	OZN-11	Yes	No evidence	No evidence	below 800° C
Calcareous, quartz-muscovite-biotite	NAV-4, NAV-17	Uncertain	No evidence	No evidence	800° C-900° C
Calcareous, fossiliferous polymict sand Grog	NAV-18 NAV-19, GAT-1	No evidence No evidence	No evidence Unlikely	No evidence Yes	below 800° C 800° C-900° C (sample NAV-19); below 800° C (sample GAT-1)
Calcareous, quartz-muscovite-microfossils	IGE-1, IGE-2, IGE-11	Yes	No evidence	No evidence	800° C-900° C
Calcareous, quartz-microfossils-muscovite	MAS-4	Uncertain	No evidence	No evidence	900° C-1100° C

the coarse sherds analysed are optically active in thin section, suggesting firing at low temperatures, below the 800° C threshold. By contrast, *figulina* potters generally opted for carbonatic raw materials, which were processed if deemed necessary through various techniques such as clay mixing or fractioning. The latter process was likely aimed at achieving a refined, inclusion-free paste, while clay mixing might have been employed to improve the properties of the paste in terms of workability or firing behaviour, and/or to achieve the desired colour (Eramo, 2020: 164). The correction of the clay paste through tempering, a practice documented at these sites for many coarse utilitarian wares, has only been identified so far for the grog-tempered coarse *figulina* specimens found at Forlì and Gatteo (samples NAV-19 and GAT-1).

Results obtained from the samples retrieved at Ozzano dell'Emilia disclosed three distinct ways of producing *figulina* wares (Table 6.). Two petrographic groups (*clay mixing* and *calcareous-quartz-microfossils-shells*) are characterised by the deliberate use of clay with a relatively calcareous matrix. In the case of the *clay mixing* group (samples OZN-1, OZN-9), the paste was corrected by adding a clay from a different source. The additional clay used to correct the paste has a ferruginous matrix, however it is extremely difficult to observe noticeable differences in terms of aplastic inclusions. The observation of microstructural inhomogeneities within the micromass in both samples pertaining to this petrofabric, consisting in darker clay lumps and, more rarely, swirls and lenses displaying diffuse or clear to merging boundaries and occasionally tapering tails led to the identification of clay mixing practices through the incorporation of a dry source of clay within a moist base clay (Ho and Quinn, 2021).

For both the *clay mixing* (OZN-1, OZN-9) and *calcareous-quartz-microfossils-shells* fabrics (OZN-6, OZN-13, OZN-15), no fractioning process seems to have been employed to further refine the base clay used, although fractioning of one or both raw materials cannot be conclusively ruled out in the case of the *clay mixing* group as the compositional and textural characteristics of the two base clays cannot be discerned in a suitable manner.

Most of the samples belonging to these groups still display illite/muscovite peaks as well as diopside and calcite peaks, with the exception of sample OZN-1 that does not contain diopside and displays an optically active matrix in thin section, suggesting a firing temperature below 800° C. For the remaining samples (OZN-9; OZN-6, OZN-13, OZN-15) a firing temperature in the range of 800° C-900° C can be inferred, given the presence of both newly formed diopside and the illite/muscovite peak. The occurrence of the calcite signal in most of the samples, including those bearing diopside, could be due to the presence of post-depositional voids-infilling calcite or may signify an incomplete reaction of the carbonate minerals with the phyllosilicates due to short firing time.

The last sample retrieved at Ozzano (OZN-11) displays marked differences in compositional and textural characteristics. It shows a non-calcareous, iron-rich matrix with few inclusions, namely quartz, muscovite and sparitic calcite. Its characteristics in thin section suggest that the fabric was obtained by refining the base clay, either through sieving or elutriation, as suggested by a clay-rich matrix with sparse silt and very fine sand-sized inclusions with a unimodal skewed grain size distribution. Macroscopically, this is the only sherd from Ozzano that is characterised by traces of a reddish coating on the external surfaces, possibly a poorly preserved clayey slip (Fig. 3). The dark core visible in thin section could be a consequence of insufficient penetration of oxygen in the ceramic body during rapid firing (Quinn, 2022: 274). The relative diffractogram still displays the illite and calcite signals, while diopside is absent, thus suggesting firing temperatures below the 800° C threshold.

The *figulina* petrofabrics from Cesena and Rimini-Igea Marina show rather similar compositional characteristics. The generalised use of calcareous base clays, rich in quartz, mica and planktonic microfossils can be observed at both sites. At Rimini-Igea Marina (IGE-1, IGE-2, IGE-11) the base clay was likely refined, while there is not enough evidence of such practice at Cesena (MAS-4). Consequently, the specimen from

Cesena in thin section displays a higher frequency of inclusions (30 % at Cesena vs 10 % to 15 % at Rimini-Igea Marina), as well as more frequent biotite and microfossils. Firing temperatures can be estimated to be in the range of 800-900° C for the Rimini-Igea Marina samples, while temperatures between 900° C-1100° C were reached at Cesena as evidenced by the presence of diopside and the absence of illite.

At Forlì, the samples belonging to the macroscopic *figulina* fabric can be grouped into a single fabric (*calcareous, quartz-muscovite-biotite*: samples NAV-4 and NAV-17) with relatively similar mineralogical composition to the *figulina* found at Rimini-Igea Marina and Cesena. However, microfossils (likely planktonic foraminifera) are only sporadically appearing as relics within well rounded or multi-chambered shaped voids. For this group there is not enough evidence to suggest fractioning processes aimed at refining the base clay. Corresponding diffractograms display neo-formation fine crystalline diopside coupled with illite/muscovite identified by XPRD, implying firing temperatures in the range of 800-900° C.

Sample NAV-18 has been macroscopically classified as coarse *figulina*, and its compositional patterning in thin section suggest that it was probably obtained from a fluvial clay source with abundant sand-sized inclusions. Firing temperatures below 800° C can be inferred from the presence of calcite and the absence of newly-formed minerals.

The coarse *figulina* samples NAV-19 and GAT-1 are characterised by a slightly calcareous, relatively inhomogeneous matrix tempered with grog. The intentional addition of grog is one of the recurring tempering strategies at both these sites, particularly for coarser fabrics, suggesting that coarse *figulina* was obtained by adopting the same clay processing procedure typical of other ceramic classes (Tiezzi et al., 2023b). The recycling of old pottery to be incorporated in the paste could have had functional reasons, as grog is known to improve the mechanical and thermal properties of ceramics (Koutouvakis et al., 2021; Rice, 1987: 229). In the southern Po Plain evidence of grog tempering are known since the early Neolithic (Pallecchi, 2019) and continue in later periods (Cannavò et al., 2017), suggesting that this tempering choice might as well be narrowed down to dynamics of cultural transmission coupled with the lack of easily accessible suitable raw material due to geological constraints.

Overall, the craftspeople involved in *figulina* production in the southern Po Plain used different strategies to manipulate the clay in order to obtain a suitable paste for *figulina* production. Our results seem to corroborate similarities in the raw material processing strategies adopted by Neolithic *figulina* makers that seemingly extend over cultural borders. For example, intentional mixing of different clay sources has been suggested in previous research on southern Italian *figulina* ("buff ware") found at Penitenzeria in the Calabria region (Michelaki et al., 2015). Fractioning processes, namely through levigation, have also been proposed as befitting refining process for samples retrieved on both sides of the Adriatic Sea from the early Neolithic onwards (La Marca et al., 2017; Spataro, 2009, 2017; Teoh et al., 2014). Highly carbonatic, microfossil-bearing clays were also employed for the Southern Italian Serra d'Alto *figulina* production, in many cases without undergoing any further processing via elutriation (Muntoni et al., 2009). However, the Serra d'Alto painted productions were systematically fired at higher temperatures in the range of approximately 850-1050° C as indicated by the absence of clay minerals and by the presence of newly-formed phases in the diffractograms (Muntoni and Laviano, 2008: 131), thus implying extensive expertise in achieving and maintaining such a high temperature range in consistently oxidising conditions.

At a regional level, compositional similarities can be observed with the *figulina* sherds retrieved at the Square-Mouthed-Pottery site of Spilamberto near Modena (Spataro, 2009). The composition of the Spilamberto samples, consisting of a vitrified and micaceous matrix with fine quartz, iron oxides and opaque mineral inclusions, is generally in line with the *figulina* samples from the Romagna area. Fabrics with abundant microfossils have also been observed at Spilamberto (Spataro, 2009). In addition, analyses on the "S. Martino" small vessels retrieved

at various Emilia Romagna sites have identified fabrics with prevalence of the matrix and few silt-sized inclusions, mainly quartz, mica and iron oxides. However, the latter group of finds were likely fired at temperatures below 800° C due to the absence of newly-formed mineral phases (Cannavò et al., 2014). Calcareous raw materials characterised by mineral inclusions such as quartz, muscovite and iron oxides were employed to obtain *figulina* wares at the sites of Gaione and Travo S. Andrea, while specimen rich in foraminifera are abundant at the site of Pontetaro (Muntoni et al., 2019), confirming that the *figulina* potters in the region were capable of exploiting a wide variety of raw materials.

5.2. Observations on provenance of the raw materials

As to the possible provenance of the raw material, the Neogene clay formations outcropping in the region may represent a compatible source of clay for most samples characterised by a calcareous matrix with more or less common occurrence of planktonic foraminifera (OZN-6, OZN-13, OZN-15; IGE-1, IGE-2, IGE-11; MAS-4; maybe NAV-4 and NAV-17). It is worth noting that the Plio-Pleistocene clays of the “Argille Azzurre” formation outcrop within 10–15 km of all studied sites (Fig. 2). Previous geochemical and mineralogical characterisations conducted on the “Argille Azzurre” formation in the Emilia Romagna region have revealed that these clays have high illite content and can be classified as clays, marly clays or clayey marls according to their carbonate content (Dondi et al., 1999). Internal variations within the formation (reported in Benini et al., 2009, 2010), when coupled with the deliberate alteration of the raw material through clay processing, might explain most of the differences registered between the aforementioned fabrics from a mineralogical and chemical point of view. From a biostratigraphic viewpoint, the “Argille Azzurre” are characterised by the presence of species such as *Globorotalia margaritae*, *Globorotalia aemiliana* and *Globigerina cariacensis*, as well as gastropods and bivalves (Benini et al., 2009; Benini et al., 2010; also denominated “Argille e marne di Riolo Terme” in Antolini et al., 2001). Significantly, a specimen of *Globorotalia* has been

identified in sample OZN-15 (Fig. 7D), in association with *Globigerinidae* (e.g. Fig. 7C). While most of the microfossils and carbonate-rich *figulina* samples could potentially be obtained from such clayey outcrops, the use of clayey sediments of alluvial origin located in direct proximity of the sites cannot be conclusively ruled out without further geological sampling.

Sample OZN-11, characterised by a non calcareous, iron-rich matrix with quartz and sparitic calcite inclusions seems to have been obtained from a different geological source containing carbonatic rock fragments and quartz.

On the other hand, the polymict composition of the sand-sized fraction in sample NAV-18 could point to the use of a riverine clay. Microfossils identified in this specimen include *Orbulina* sp. (Fig. 7B) and a likely specimen of the echinoid *Brissopsis ottanangensis* (Fig. 7A; compare with Kroh and Nebelsick, 2010, Fig. 6h). For this sample, the most likely source of raw material could be the alluvial fan sequence produced by the Ronco-Bidente river, whose upper valley cuts the Miocene “Marnoso-Arenacea” formation as well as the Plio-Pleistocene clay outcrops of the “Argille Azzurre” to the south of Forlì (Fig. 2).

The variety of raw materials utilised may be a reflection on the one hand of multiple production locales with access to different sources of suitable clay; on the other hand, variations in raw material acquisition and processing practices might also be due to chronological factors, i.e. changes in the *chaîne opératoire* over the *longue durée* that may have occurred at each site. However, given the current state of the research, there is not enough evidence to suggest that the *figulina* pottery retrieved at the investigated Po Plain sites was part of a long-distance trade network of prestige commodities as previous research suggested (Malone, 2003). The calcareous, fossiliferous raw materials were likely obtained within the region, where outcrops of microfossil-bearing clays and marly clays are known. Furthermore, variations in microfossils content among the petrographic fabrics analysed could be partly linked to levigation or settling processes, as the biogenic material could have deposited with the coarse silt fraction during fractioning processes via

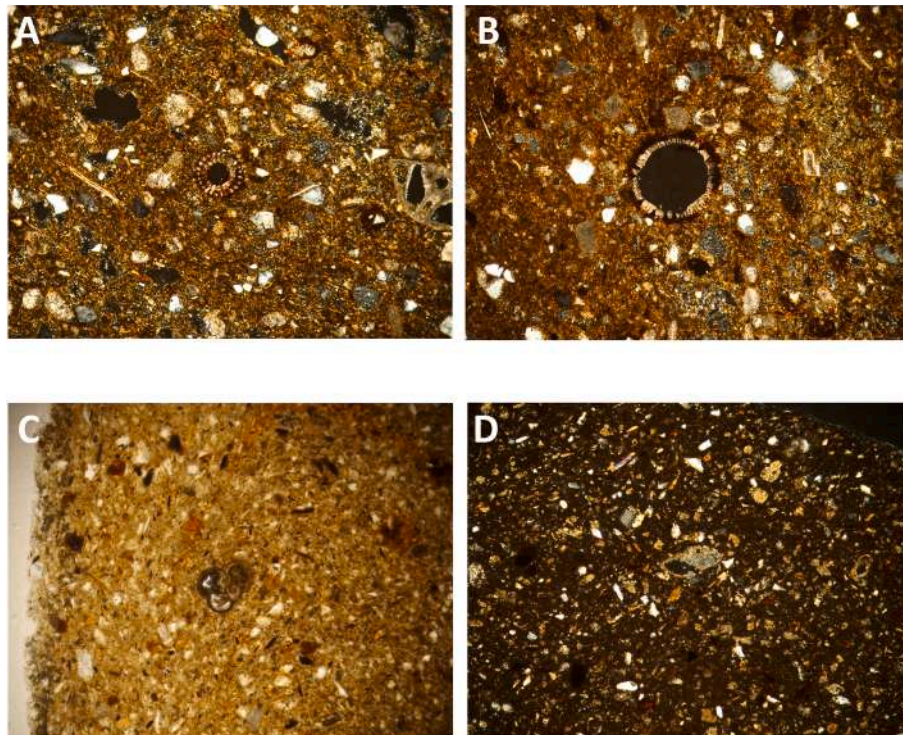


Fig. 7. Photomicrographs of microfossils-bearing petrofabrics with identified taxa. A: NAV-18, cross-section of spatangoid echinoid spine, possibly *Brissopsis ottanangensis* (centre), XPL. B: NAV-18, *Orbulina* sp. (centre), XPL. C: OZN-13, *Globigerinidae* specimen (centre), PPL. D: OZN-15, *Globorotalia* sp. (centre), XPL. Width of field in all photomicrographs is 2 mm.

elutriation (Eramo, 2020). Nonetheless, further geological sampling will be needed in the future in order to locate outcrops of suitable raw material within reasonable distances of the sites.

5.3. *Figulina* production: The cultural and social implications of a long-lasting, widespread manufacturing tradition

The presence of sporadic *figulina* sherds at early Neolithic sites to the north of the Apennines (i.e. Lugo di Romagna, Fiorano Modenese, Fagnigola: Fig. 1) testifies of an early appearance of the *figulina* phenomenon in northern Italy, with technological choices largely resembling the mid-late Neolithic *figulina* productions here analysed (Pallecchi, 2019; Spataro, 2002). Undoubtedly when comparing the technological data available from early and mid-late Neolithic *figulina*-bearing assemblages, the manufacturing process of this ceramic class seems to share a handful of constant technological traits that endure for more than a millennium.

First, the potters had to select specific clays that often differed from the raw material used for everyday, coarser wares. Clays relatively rich in carbonate content may have been accurately selected for the purpose of obtaining light-coloured surfaces for ceramic products. Then, the raw material was processed if deemed necessary, through clay mixing or fractioning. At the Po Plain sites here analysed, the acquisition and processing of the clay material is the stage at which most variations in the *figulina* chaîne opératoire occur, both at the intra-site level and from a sub-regional perspective.

Further skills were then needed in order to shape the pots. The potters had to be able to achieve very thin walls, ranging from 4 to 9 mm in thickness, and possibly complex shapes, similarly to the three-handled flask retrieved at Ozzano dell'Emilia (Fig. 3, OZN-13; average wall thickness 8 mm). The elaborately painted decorations typical of the southern and central Italian assemblages rarely appear at the mid-late Neolithic northern Italian sites, where ceramic surfaces tend to be plain (Colombo, 2021).

The final step was firing, a process that required expertise in order to maintain constant oxidising conditions and adequate soaking time at temperatures often exceeding 800° C. At present very little information is available on the firing structures where the *figulina* pottery could have been fired. In the region there is no reliable evidence of kilns for *figulina* production, apart from a structure consisting of two interconnected pits containing a large quantity of *figulina* sherds unearthed at Rivalentella (Tirabassi, 1987). Furthermore, there is no consensus among researchers on whether kilns are actually required to successfully fire such products, as opposed to pit firing (Muntoni and Laviano, 2008; Spataro, 2017; Teoh et al., 2014).

Overall, the special skill required to successfully produce *figulina* pots led many scholars to believe that such complex productions may signal an incipient stage of specialisation in pottery manufacture (Laviano and Muntoni, 2007), presumably requiring full-time, highly specialised potters with specific training (Spataro, 2017). The “household production” model (Van der Leeuw, 1977) may therefore not represent a suitable interpretative framework for this resource and time-consuming craft that entailed mastering complex pyrotechnology.

Finally, the question on how *figulina* technology spread in such a vast geographic area still remains largely unsolved. To date, *figulina*-bearing northern Italian assemblages remain mostly unstudied from an archaeometric point of view, with too little compositional data on northern Italian *figulina* wares to properly address the issue of its origin and spread in relation to its central and southern Italian counterparts. Nevertheless, the expertise needed to produce *figulina* pottery, as evidenced by the recurring choice of raw materials with specific characteristics, by time-consuming clay processing strategies and complex firing procedures, appears to be well distant from the local technical traditions at the Po Plain sites. In fact, when considering the five sites here analysed, the local pottery making tradition include mainly low-fired, coarse utilitarian wares. These were obtained by tempering the

locally available non-calcareous clays with the addition of crushed calcite in the case of Ozzano dell'Emilia, grog in the case of Forlì and Gatteo, as well as other rock fragments (Tiezzi et al., 2023b). Even so, the *figulina* pottery found at the Po Plain sites displays significant features that seem to be peculiar of this area, for example regarding the adoption of certain ceramic shapes that fall outside the typical peninsular *figulina* productions, the most notable example being the three handled flask unearthed at Ozzano dell'Emilia (Fig. 3: OZN-13). Another noteworthy characteristic seems to be the generalised lack of painted decoration, with one single exception (Fig. 3: OZN-11). In the hypothetical scenario that *figulina* pottery was indeed produced by few capable individuals within the northern Italian Neolithic communities as a local imitation of the elaborately painted central and southern Italian *figulina* wares, it can reasonably be argued that successfully producing *figulina* pottery heavily relied on a common technological background, shared by Neolithic potters pertaining to different cultural traditions over a wide geographic area. This observation expands to the north of Italy the interpretative framework proposed by Muntoni and Laviano (2008) on the circulation of the *figulina* technological model, originally hypothesised for the southern Italian middle Neolithic communities of Puglia and Calabria. Arguably, the technical know-how needed in *figulina* making entailed some extent of cultural contacts, resulting in the exchange of knowledge related to *figulina* technology between different communities of practice across the whole Italian Peninsula. At the current state of the research, however, the issue of the complex dynamics of knowledge transmission behind the spread of the *figulina* technological model remains a topic to be addressed by future investigations. In this scenario, the compositional variations as well as the recurring technological patterns within the *figulina* ceramic class recorded at the mid-late Neolithic sites of the southern Po Plain represent a prime example of a complex, multi-faceted production technology that unquestionably needs further research.

6. Conclusions

The multi-analytical study of fifteen *figulina* samples retrieved from five Neolithic sites located in the south-eastern Po Plain within the Emilia Romagna region of Italy highlighted a certain degree of variability in raw material acquisition and paste preparation strategies even within a relatively limited geographic area.

Complementary results from thin section ceramic petrography, X-Ray Powder Diffraction and portable X-Ray Fluorescence suggest a well-defined operational sequence denoting high expertise of the potters in (i) choosing a range of clayey raw materials with specific physicochemical characteristics from accessible clay outcrops in the surrounding areas, (ii) when necessary, processing the clay to obtain the desired properties for a highly refined final product, and (iii) controlling relatively high firing temperatures (mostly exceeding 800° C) and uniform oxidising conditions. Despite the generalised lack of attested pyrotechnological structures, the availability of fossiliferous, carbonatic and illite-rich raw materials within the region - in many instances within few km of the sites - reinforces the idea of a local or sub-regional production. Moreover, local production within the sites is certain for the coarse *figulina* wares that share many technological traits with the locally-produced coarser wares (e.g. grog tempering).

Given the overall scarcity of the *figulina* pottery in these contexts and the obvious technological gap with the coarser wares prevailing in the mid-late Neolithic traditions of the Po Plain, this highly elaborate ceramic class can therefore represent a category of objects with a specific intrinsic value that was widely recognised within the communities that used it. Shaping and successfully firing a *figulina* vessel represented a conspicuous investment in terms of training, time and resources. As a matter of fact, the skills needed to master *figulina* pottery production were likely to fall outside the scope of the “household production” model (Van der Leeuw, 1977). This consideration poses further questions regarding the makers of *figulina* pottery and their social role within the

Neolithic communities of the southern Po Plain, as well as hinting at complex and large-scale dynamics of technological transmission across Neolithic communities bearing distinct pottery traditions.

CRedit authorship contribution statement

Valeria Tiezzi: Conceptualization, Formal analysis, Investigation, Writing – review & editing, Writing – original draft, Visualization. **Silvia Amicone:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Lars Heinze:** Methodology, Formal analysis (p-XRF), Writing – review & editing. **Monica Miari:** Investigation, Resources, Writing – review & editing. **Nicoletta Volante:** Writing – review & editing, Supervision. **Christoph Berthold:** Methodology, Resources, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

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