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Scientific investigation of pottery grinding bowls from the Archaic and Classical Eastern Mediterranean

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Summary Pottery mortaria, or grinding bowls, are found in most early cultures around the Mediterranean. As with most plain, utilitarian household pottery, archaeologists often believe them to be locally produced and of too little value to be objects of trade. In order to test this view and to distinguish production centres and technological traits, petrographic analyses of thin sections and measurements of elemental composition using scanning electron microscopy with energy dispersive X-ray spectrometry were carried out on examples from several sites. These included pieces from recent excavations in the East Greek city of Miletos (Turkey) as well as from Al Mina in Syria, Lachish in Judah (Israel) and the Greek trading post of Naukratis in Egypt, all in the British Museum's collections. In addition, several groups of reference material were analysed. Overall, 61 ceramic objects, mostly mortaria dating to the seventh–fifth century BC, were analysed. The results revealed that Cyprus was a major production centre for mortaria and that its products were widely traded in the Eastern Mediterranean, not only to the Levant but also to East Greece. The results also suggest further production centres, including locations in the Egyptian Nile Delta and at Miletos, and the use of different clay recipes in the production of the same shape.

INTRODUCTION

In the ancient Mediterranean world, plain, undecorated domestic pottery was ubiquitous in any household and makes up the majority of finds in most archaeological excavations. Usually presumed to be locally produced, slow to change in shape, and not subject to trade, it is, therefore, perceived to be of little scholarly interest. Only recently has its potential begun to be recognized; cooking pots in particular have become popular objects of research, being conceived of as markers of technological and social change, as indicators for ethnic or cultural association, but also as highly specialized commodities of trade [1–3]. An example of the latter are the carefully burnished cooking pots of Aigina, made from local volcanic clay and highly resistant to thermal shock, that were popular export items in the Greek Mediterranean over many centuries [4–7], and that were imitated closely by Classical Athenian potters. Examinations of this kind have been made possible by increasingly sophisticated methods to investigate pottery scientifically, as well as by the wider acceptance in Classical archaeology of these methods as effective complements to traditional archaeological and art-historical methods.

The study presented here applies such collaborative research to another functional item of ancient household pottery: the mortar, or mortarium. Mortaria are shallow open bowls, usually around 30 cm in diameter, sometimes made from stone, wood or metal, but mainly in pottery; they are found in most civilizations around the Mediterranean from the late eighth century BC until Roman times. Strong traces of abrasion (scratches, smoothing, and inclusions exposed or removed) indicate that they were used for grinding and mashing substances with the help of a wooden pestle, Figure 1. It is known from ancient texts and representations that the ground substances were primarily foodstuffs, which were processed into spicy sauces, cereal gruels and vegetable mashes; other materials could also be ground in mortaria, including medicinal mixtures or pigments [8].

The starting point for this investigation was the study of still-unpublished finds from recent excavations in the seventh–fifth-century BC levels of the East Greek city of Miletos (Figure 2) [9], which was an important political, economic and cultural centre within the Greek and wider Mediterranean world. Among the pottery excavated from the habitation quarter and sanctuaries was an exceptional

FIGURE 1. Greek terracotta figurine of a monkey using a mortarium and pestle, made in Corinth *c.*400 BC (British Museum GR 1903,0518.4)

variety of different types of mortaria, Figure 3. One type, present throughout the seventh and sixth centuries BC, which is represented by over 400 fragments that make up about one quarter of all mortaria from the site, stands out from the rest on account of its unusual yellow-buff colour. It is typically of truncated conical shape with a thickened, more or less oval rim, a slightly wavy/rippled outside and a smooth inside. Morphologically it resembles another group of Milesian mortaria in brown clay, but the closest parallels, for both shape and clay, seem to be mortaria from other sites in the Eastern Mediterranean region, and particularly from Cyprus and Palestine. They include examples in the British Museum's collections from the Greek trading posts of Naukratis in Egypt and Al Mina in Syria. For some of the pieces from Naukratis, neutron activation analysis (NAA) has recently suggested Cypriot as well as local production [8, 10]. Examples of this type (and of a related ring-footed type) from Palestine have also been identified in recent archaeometric studies as mostly Cypriot or North Syrian as well as possibly East Greek imports [11; pp. 198–200, 12; pp. 79–82, 13; pp. 19–20, 14; pp. 141–142, 15].

As a consequence, several questions emerged regarding the examples from Miletos:

- Are the flat-based mortaria local Milesian products or were they imported?
- Why does the type appear in so many places (was it

FIGURE 2. Locations of the sites discussed in the text

produced in one place, or made in several places in a similar manner)?

- Is there any indication that the specific function of mortaria (i.e. grinding) occasioned the use of special clay fabrics and pottery technology for this shape?

In order to answer these questions, typological studies of the shapes and visual examination of the clays alone were not sufficient. In particular, it was impossible to decide whether the yellow-buff clay of the Milesian mortaria, which seemed unusual for Miletos but was paralleled at other sites, was due to a single production centre exporting its wares or to the exploitation of local sources of buff clay in a variety of places especially for this particular shape. Progress could be made only by scientific analysis of the clay fabrics in question.

METHODS AND SAMPLING

Samples of 52 mortaria, mostly dating to the seventh–fifth century BC, were selected for petrographic analysis from five sites located along the eastern Mediterranean coastline, Figure 2: Miletos; the city of Xanthos in Lycia; the Greek trading post of Naukratis in the Egyptian Nile Delta; Al Mina, the Greek/Phoenician trading post and port of the neo-Hittite kingdom of Unqi in Syria; and the Judean city of Lachish, Figures 3 and 4. Sampling encompassed mortaria with a wide range of stylistic and typological features and fabrics, but particular emphasis was placed on the group of flat-based mortaria in buff clay.

In addition to mortaria, samples were taken from other objects for which the place of manufacture can be

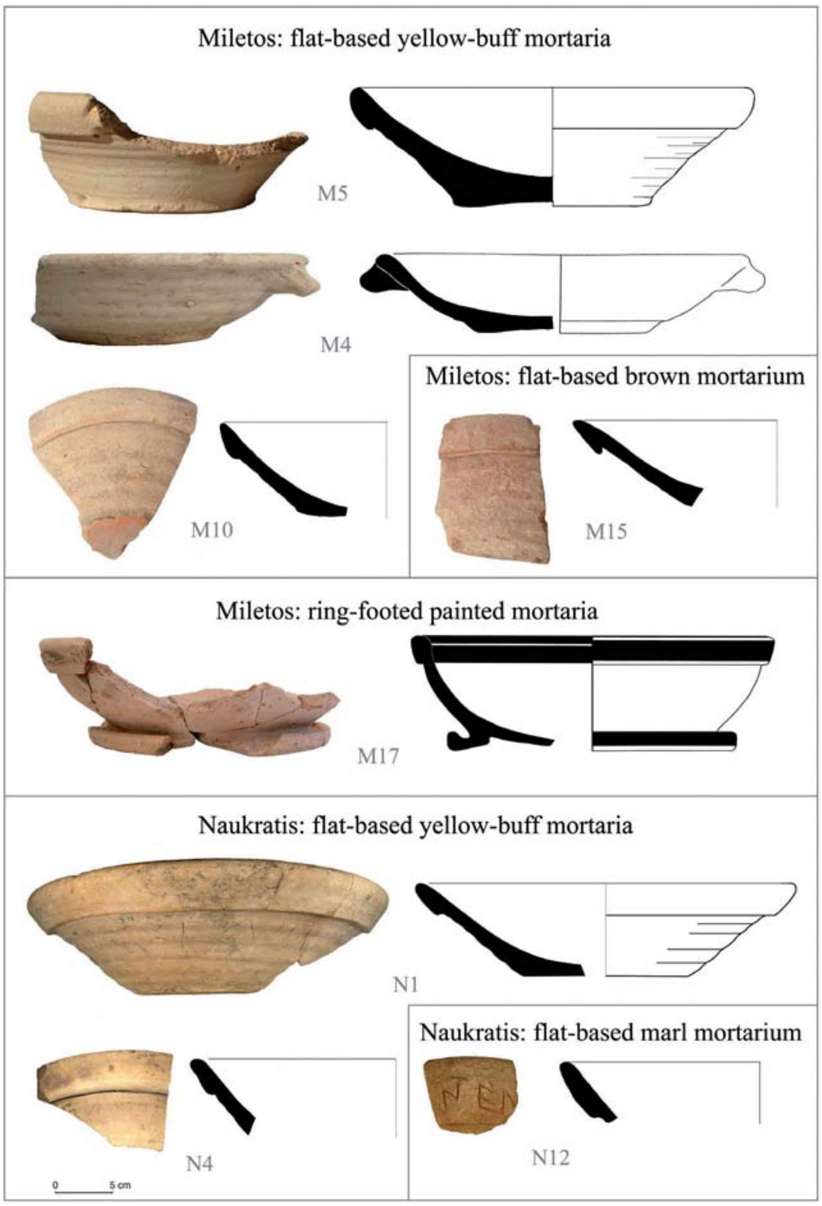

FIGURE 3. Photographs and profile drawings of mortaria from Miletos and Naukratis: M5 (Miletos K92.958.1); M4 (Miletos K86.32.20); M10 (Miletos K91.306.3); M15 (Miletos K86.201.3); M17 (Miletos Z04.9.13); N1 (Naukratis, British Museum GR 1886,0401.80); N4 (Naukratis, British Museum GR 1886,0401.81); and N12 (Naukratis, British Museum GR 1910,0222.15)

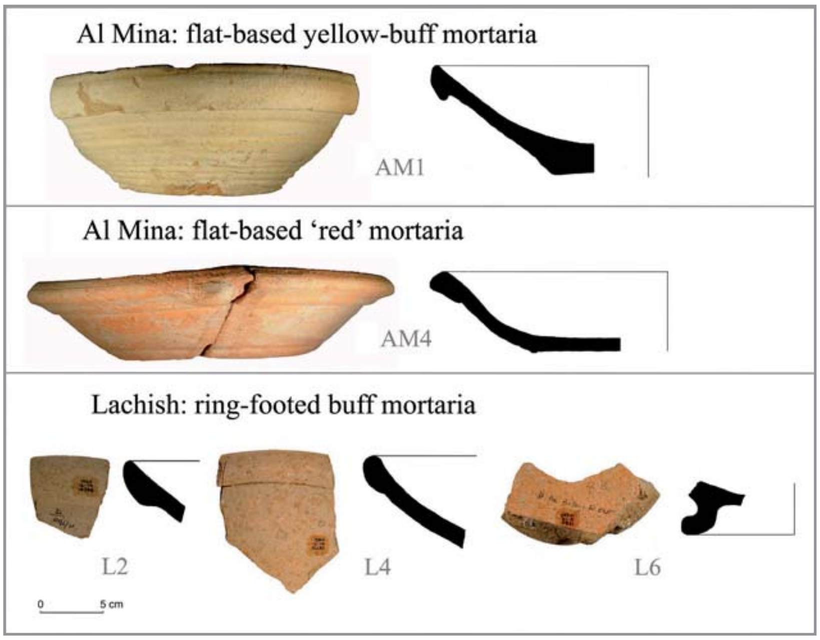

FIGURE 4. Photographs and profile drawings of mortaria from Al Mina and Lachish: AM1 (Al Mina, British Museum ME 1995,1223.2); AM4 (Al Mina, British Museum ME 1995,1223.1); L2 (Lachish, British Museum ME 1980,1214.10348); L4 (Lachish, British Museum ME 1980,1214.10281); and L6 (Lachish, British Museum ME 1980,1214.10283)

inferred on archaeological grounds so as to establish reference groups for Cypriot and Milesian clays. Samples were taken from a typical Cypriot basket-handled amphora and three Cypriot terracotta figurines found at Miletos, from a likely Cypriot basket-handled amphora from Lachish, and from three locally produced cooking pots and a pithos-like vessel from Miletos. Extensive analyses of Milesian pottery were moreover available in the form of Seifert's study of Milesian amphorae by X-ray diffraction, X-ray fluorescence and optical microscopy [16].

These samples were analysed using two complementary techniques: petrographic analysis of thin sections (61 samples) and scanning electron microscopy (SEM) used in combination with energy dispersive spectrometry X-ray analysis (EDX; 28 samples), Table 1. Both techniques are necessary to identify the differences and similarities among samples in terms of quantitative and qualitative composition. Petrographic analysis of ceramic thin sections can be used to identify mineral inclusions, which are then compared to the geological setting of the study area with the aim of locating potential sources of clay and other raw materials, and thus the most likely centre of production for each fabric. Elemental analysis allows the identification of the elemental composition of the fabrics, in particular the matrix, which is mainly composed of clay minerals that are too fine to be studied in thin section with the polarized light microscope.

Elemental analysis was carried out using a Hitachi S-3700 SEM in combination with an Oxford Instruments INCA EDX analyser. Five bulk analyses were conducted for each sample at a magnification of 90× on an area of *c.*1.4 × 1.0 mm that included matrix and temper. The results for 11 elements (Na, Mg, Al, Si, P, K, Ca, Ti, Mn, Fe, Zn) were quantified, converted into oxide percentages (oxygen by stoichiometry) and normalized. The five analyses for each sample were averaged, which was reasonable as the results did not show significant differences.

Principal component analysis (PCA) was used to interpret the EDX results and to help in the identification of chemical groups based on the concentration of the oxides. The PCA analysis was performed using the Microsoft Excel plug-in *Biplot 1.1* [17], with column data centred and standardized. Only the first two components were extracted. The inclusion or omission of particular samples and elements, as well as the choice of which components to extract, strongly affects the resulting scatter plots and their interpretation is inherently subjective. Nevertheless, chemically similar samples will cluster in the same region of each scatter plot, reflecting the abundance of various elements in the samples and allowing the petrographic grouping to be compared to a clustering based on elemental composition.

This contribution does not present all the data and results from this study, but instead focuses on the research methodology and the results that relate to the flat-based, buff mortaria from Miletos and elsewhere, helping to place them within the framework of patterns of production, technology transfer and trade in the Eastern Mediterranean.

RESULTS AND DISCUSSION

Petrographic analysis

Among the 61 samples from five sites that were studied, 31 clay fabrics were identified. The greatest variety of clay fabrics was found in the assemblage from Miletos, from which 33

TABLE 1. Compositional data derived from EDX analyses. The results are the mean of five bulk analyses carried out on each sample with standard deviation reported in parentheses; the detection limit was 0.1–0.3% and the reproducibility 1–2%

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO
Al Mina										
AM1	1.20 (0.10)	6.87 (0.53)	13.36 (0.51)	52.87 (2.08)	0.17 (0.11)	2.44 (0.28)	16.07 (1.06)	0.68 (0.12)	0.04 (0.08)	6.20 (0.36)
AM3	1.40 (0.12)	5.59 (0.22)	12.63 (0.42)	52.75 (1.28)	0.32 (0.06)	2.35 (0.18)	18.03 (1.01)	0.67 (0.08)	0.11 (0.06)	6.23 (0.23)
AM4	1.65 (0.09)	7.32 (0.20)	15.56 (0.24)	59.67 (0.38)	0.15 (0.08)	3.21 (0.22)	5.03 (0.40)	0.78 (0.09)	0.11 (0.06)	6.53 (0.16)
Miletos										
M3	1.31 (0.17)	6.63 (0.27)	13.36 (0.22)	52.28 (0.53)	0.13 (0.13)	1.93 (0.28)	17.10 (0.78)	0.74 (0.17)	0.13 (0.07)	6.48 (0.21)
M4	1.14 (0.16)	5.70 (0.28)	14.14 (0.49)	52.29 (1.15)	0.25 (0.08)	1.40 (0.11)	17.48 (1.11)	0.75 (0.11)	0.10 (0.08)	6.74 (0.20)
M14	1.89 (0.12)	2.08 (0.19)	15.75 (0.99)	66.74 (2.11)	0.44 (0.23)	4.29 (0.30)	4.52 (0.59)	0.57 (0.14)	0.04 (0.04)	3.71 (0.30)
M16	3.18 (0.27)	3.33 (0.44)	16.06 (0.93)	61.95 (2.68)	0.34 (0.06)	2.43 (0.63)	7.62 (1.02)	0.59 (0.09)	0.06 (0.04)	4.42 (0.61)
M17	1.59 (0.36)	5.09 (1.17)	15.27 (2.75)	59.44 (7.09)	0.30 (0.15)	1.81 (0.44)	8.45 (1.90)	0.78 (0.20)	0.09 (0.05)	7.17 (3.36)
M25	2.09 (0.09)	3.61 (0.14)	13.16 (0.38)	54.69 (0.15)	0.30 (0.04)	1.04 (0.10)	19.84 (0.53)	0.59 (0.12)	0.09 (0.03)	4.55 (0.05)
M26	1.96 (0.36)	2.58 (0.31)	20.95 (0.55)	61.68 (1.04)	0.30 (0.17)	3.50 (0.43)	1.22 (0.30)	0.91 (0.12)	0.05 (0.02)	6.75 (0.29)
M27	0.83 (0.21)	0.93 (0.28)	13.89 (3.46)	77.22 (5.67)	0.22 (0.20)	1.97 (0.44)	0.38 (0.15)	0.43 (0.15)	0.02 (0.02)	4.08 (1.15)
M28	1.99 (0.24)	1.74 (0.39)	19.63 (0.44)	65.30 (1.72)	0.03 (0.07)	1.96 (0.14)	3.17 (0.42)	0.69 (0.09)	0.08 (0.04)	5.38 (0.83)
M29	0.87 (0.12)	1.89 (0.26)	16.51 (0.92)	68.08 (2.38)	0.26 (0.05)	2.50 (0.29)	4.02 (0.88)	0.73 (0.05)	0.12 (0.02)	5.03 (0.30)
M30	1.40 (0.16)	5.47 (0.28)	13.67 (0.19)	56.36 (0.70)	0.18 (0.09)	2.05 (0.28)	13.69 (0.45)	0.69 (0.12)	0.13 (0.03)	6.25 (0.35)
M31	1.14 (0.14)	5.84 (0.28)	13.37 (0.58)	52.96 (1.79)	0.24 (0.16)	1.44 (0.14)	17.46 (1.67)	0.72 (0.08)	0.17 (0.13)	6.61 (0.14)
M32	0.70 (0.21)	7.14 (0.21)	15.98 (0.23)	52.81 (0.19)	0.27 (0.09)	1.50 (0.20)	12.33 (0.39)	0.78 (0.05)	0.21 (0.09)	8.16 (0.31)
M33	1.25 (0.12)	6.46 (0.24)	13.29 (0.66)	51.25 (1.03)	0.20 (0.09)	1.43 (0.20)	18.92 (0.53)	0.63 (0.07)	0.17 (0.06)	6.45 (0.09)
Naukratis										
N1	1.96 (0.19)	5.67 (0.36)	12.52 (0.47)	49.93 (0.81)	0.23 (0.10)	1.84 (0.08)	20.58 (1.05)	0.63 (0.11)	0.40 (0.08)	6.33 (0.21)
N4	1.54 (0.21)	6.19 (0.32)	13.30 (0.27)	51.50 (1.27)	0.26 (0.12)	1.91 (0.15)	17.62 (0.56)	0.69 (0.06)	0.13 (0.05)	6.85 (0.31)
N10	1.55 (0.09)	4.37 (0.46)	17.75 (0.67)	54.80 (0.85)	0.20 (0.16)	1.63 (0.05)	12.88 (0.27)	0.74 (0.13)	0.10 (0.07)	6.01 (0.82)
N12	1.60 (0.14)	2.82 (0.07)	12.50 (0.14)	54.39 (0.90)	1.10 (0.15)	1.53 (0.07)	18.24 (1.03)	1.22 (0.10)	0.13 (0.12)	6.46 (0.33)
N13	1.88 (0.11)	2.92 (0.16)	13.23 (0.54)	60.80 (1.43)	0.94 (0.18)	1.97 (0.22)	9.91 (0.78)	1.44 (0.23)	0.14 (0.08)	6.79 (0.05)
N14	3.95 (0.15)	6.71 (0.20)	11.08 (0.64)	53.38 (1.96)	0.81 (0.36)	1.83 (0.13)	17.54 (2.70)	0.54 (0.07)	0.29 (0.04)	3.65 (0.12)
N15	0.85 (0.11)	5.53 (1.86)	15.89 (1.11)	56.04 (2.60)	0.21 (0.20)	2.78 (0.07)	11.07 (1.29)	0.71 (0.09)	0.13 (0.04)	6.88 (1.68)
Xanthos										
X1	1.45 (0.04)	5.44 (0.11)	12.92 (0.31)	52.90 (1.28)	0.26 (0.06)	1.78 (0.10)	18.07 (0.88)	0.64 (0.07)	0.16 (0.05)	6.33 (0.23)
Lachish										
L2	1.32 (1.02)	4.29 (1.67)	13.89 (6.89)	51.65 (2.07)	0.16 (0.12)	1.83 (0.75)	21.96 (4.28)	0.52 (0.24)	0.15 (0.10)	4.27 (1.62)
L4	0.67 (0.05)	7.41 (0.37)	16.02 (0.29)	48.79 (0.92)	0.31 (0.07)	3.20 (0.13)	17.75 (1.30)	0.75 (0.04)	0.02 (0.05)	5.04 (1.42)
L7	1.25 (0.12)	4.96 (0.68)	12.80 (0.55)	54.48 (1.44)	0.34 (0.09)	2.60 (0.31)	17.03 (0.82)	0.69 (0.12)	0.12 (0.03)	5.71 (0.32)

sherds were analysed. These included samples that can be assumed to have been produced locally (Archaic cooking pots and a pithos storage jar), samples that were almost certainly imported to the site from Cyprus (Archaic terracotta figurines and an amphora), and the mortaria, Figure 3.

Two of the cooking pots have very micaceous pastes, rich in coarse sub-angular schist fragments, biotite and muscovite (Figures 5a and 6), whereas a third cooking pot is rich in micas and amphibole. All three cooking pots contain as temper sand rich in coarse minerals and rock fragments from either metamorphic or volcanic formations and were low-fired; the lack of vitrified pastes indicates that the firing temperature never exceeded 850°C [18; p. 431]. This specific choice of non-calcareous clays tempered with metamorphic, volcanic rock fragments might have been for thermal shock resistance purposes, since this recipe had been known in Europe since Neolithic times [7]. The fabric is consistent with the geological setting of Miletos, with volcanic tuff around the site and outcrops of gneiss, mica-schist, dolerite, basalt and amphibolite about 10 km north east and less than 20 km north west of the site [19; Figure 5.1].

The three Cypriot terracotta figurines showed two different fabric types: one is vitrified and very fine-grained, with some fine quartz, occasional calcareous fragments, some iron oxides, small quantities of chert, igneous inclusions, serpentine and pyroxene; the second is fossiliferous and coarser. The geology of Cyprus is highly distinctive and varied, with the Troodos ophiolite complex (Pre-Campanian) in the centre, the Pentadaktylos succession in the north, the Circum Troodos sedimentary succession in the north east and south, and the Mamonia complex in the south [20]. Although the inclusions in the figurines are very fine, it is possible that they come from the Troodos outcrops, which are rich in ophiolite and volcanic sediments (basalt, dolerite, and lava) and radiolarian shales [21]. The fabric of the basket-handled amphora, derived from mafic bedrock, is similar to that of the Cypriot figurines.

Most of the Archaic flat-based buff mortaria from Miletos (Figure 3; M4, M5 and M10) are made from two fabric types, each with vitrified and very fine pastes that are much finer than the other mortaria types. One group is micritic and vitrified, with scarce inclusions, mainly of very fine quartz, muscovite mica, occasional metamorphic

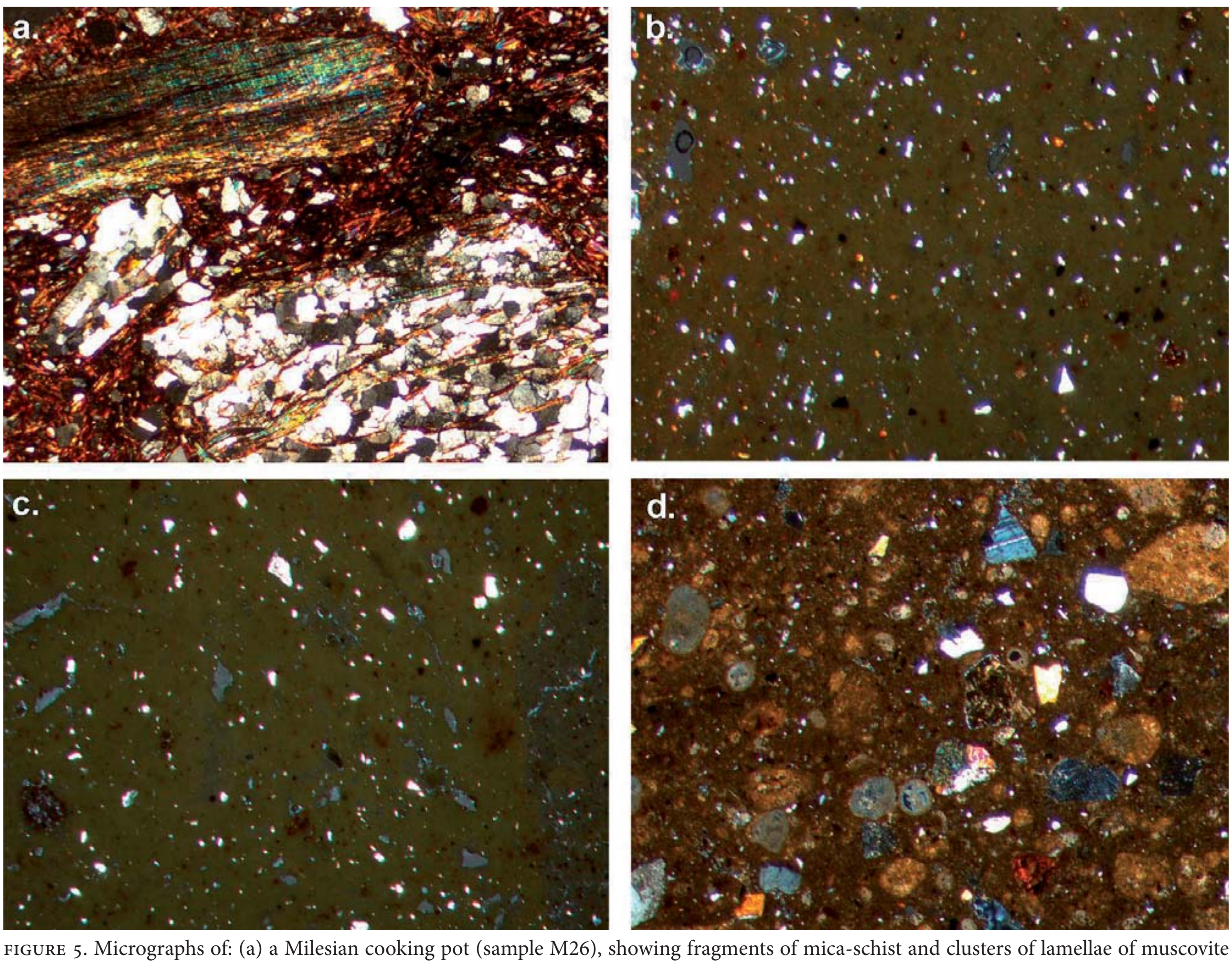

FIGURE 5. Micrographs of: (a) a Milesian cooking pot (sample M26), showing fragments of mica-schist and clusters of lamellae of muscovite mica; (b) a flat-based buff mortarium (sample M3) from Miletos; (c) a flat-based buff mortarium from Naukratis (sample N7); and (d) a sample (L2) of a ring-footed buff mortarium from Lachish. In each case, the width of the image is 3.5 mm

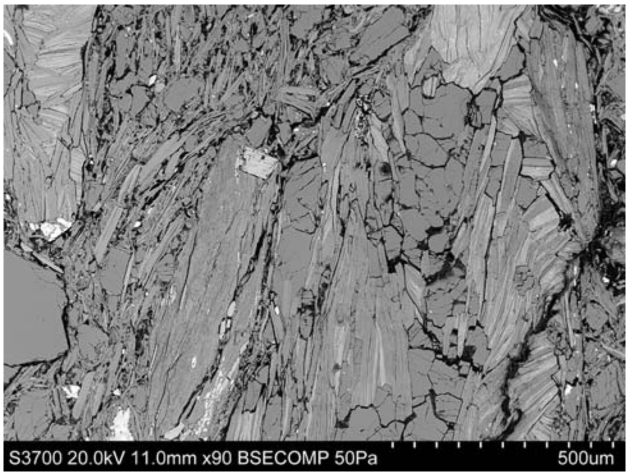

FIGURE 6. SEM image (90×) of a sample of a Milesian cooking pot (M26), showing large mica-schist fragments and clusters of muscovite mica

rock fragments or chert and, very rarely, tiny fragments of serpentine, Figure 5b. The second contains more abundant fine rounded microcrystalline calcareous fragments, very occasional microfossils and coarser mineral grains. They are petrographically similar to the Cypriot terracotta figurines, and even though formations similar to the Troodos outcrops occur elsewhere in the Greek/Eastern Mediterranean region, a Cypriot origin for the Milesian flat-based buff mortaria is quite possible. One further sample could also come from Cyprus (as it is very rich in radiolarian chert and flint) but it was produced with a very different recipe, in which flint was probably deliberately added to the clay.

The fabrics of the Archaic painted mortaria from Miletos (Figure 3; M17) are much coarser than the flat-based buff mortaria. Their fabric is slightly calcareous and micaceous, with fine and well-sorted sub-angular quartz, some coarse rounded microcrystalline micritic fragments, muscovite and occasional biotite micas, rare opaque minerals, some rounded mudstone and abundant sub-angular to sub-rounded coarse fragments of metamorphic quartz-rich rock. In contrast to the flat-based buff mortaria, which do not contain added inclusions, they were probably tempered with metamorphic sand rich in mica-schist that was also added to the Milesian cooking pot fabric, and which is abundant around Miletos.

Two other mortaria (M15 and M16) were made from clay originating from the same medium-grade metamorphic environment, but (as the inclusions are smaller and less angular) from sources located farther from the original outcrop. A flat-based mortarium (Figure 3; M15) looks much like the buff mortaria in shape, but it differs from them in being made of brown clay. It belongs to a large group of such flat-based brown mortaria that sometimes feature a thin white coating.

Several other less common mortarium shapes have fabrics similar to the cooking pots and to the painted mortaria. An example is M16, a Hellenistic spouted mortarium, the fabric of which is very similar in visual appearance to locally produced Bronze Age pottery at Miletos. Petrographic examination shows that it is isotropic, slightly micritic and micaceous, with abundant poorly sorted quartz, muscovite, plagioclase and occasional biotite, and a few igneous inclusions (most probably basalt). Similar clay from a metamorphic environment was also used to produce Milesian amphorae in the Archaic period [16; p. 36 and Figure 16].

Finally, the coarse fabric of sample M14 (a flat-based mortarium) is micritic, micaceous and isotropic, with abundant coarse and poorly sorted quartz, some muscovite, plagioclase, and a little chert and pyroxene. Although the paste is burnt and its matrix cannot easily be described, it is unlike the paste of the flat-based buff mortaria, and does not contain rock fragments comparable to those in the fabrics of the cooking pots and painted mortaria such as M17.

The flat-based buff mortarium from Xanthos has a fine and silty paste with calcareous pellets and very small amounts of chert, muscovite and pyroxene. This composition shows some similarities with those of the Cypriot terracotta figurines and the basket-handled amphora found at Miletos.

Of the 15 mortaria analysed from Naukratis, nine Archaic flat-based buff mortaria (some of which had been identified as Cypriot imports by neutron activation analysis (NAA): Figure 3; N1 and N4) have a very fine micritic fabric, extremely similar to the vitrified type from Miletos and also that from Al Mina (see below), with some fine quartz, and occasional igneous inclusions and chert, Figure 5c.

Previous work on the Nile clay and mixed Nile/marl clay pastes from New Kingdom pottery produced at Amarna and Memphis shows the presence of limestone, some plant remains, mica, feldspars and microfossil inclusions [22]. These minerals and inclusions do not seem to match the flat-based yellow-buff mortaria found at Naukratis, reinforcing the suggestion that these mortaria were imported.

In contrast, a mortarium of the same shape but made of a browner clay (Figure 3; N12) that had been identified by NAA as of Egyptian manufacture [10; p. 70], and a post-Archaic mortarium of a different shape, show fabrics that are more ferruginous and contain many angular iron-rich inclusions and coarse pyroxene fragments. Since the site of Naukratis is located in the Nile Delta on alluvial deposits that are transported by the river over long distances [23, 24; p. 165 and Figure 9.2], these minerals could have come via the Nile from a number of places, and their absence in the pottery from Memphis and Amarna does not exclude the possibility of mortaria production at Naukratis.

The three Archaic flat-based buff mortaria from Al Mina (Figure 4; AM1) are microscopically similar to those belonging to the same type from Miletos and Naukratis, with a very fine micritic and vitrified paste, occasional inclusions of chert, radiolarian chert, plagioclase, fine muscovite and pyroxene, and a small number of fine serpentine and felsic rock fragments. In contrast, two flat-based mortaria of a different morphological type typically made of a reddish clay (Figure 4; AM4) show two different fabrics: one is non-micritic and very micaceous with red clay fragments; the other is blackened by burning, very micritic, with abundant quartz, iron oxides, calcareous fragments, and a little chert. It is difficult to suggest a provenance for this type of fabric because these minerals are common to many different geological environments. The site of Al Mina lies near the northern Syrian border, at the estuary of the Orontes River and the surrounding area has greenstone, metamorphic and volcanic rocks in a geology that is very similar to that on the island of Cyprus. Serpentine outcrops are present in this northern region of Syria [25], making it difficult to distinguish Cypriot imports from locally or regionally produced pottery using petrographic analyses.

Of the six ring-footed mortaria from Lachish in Israel, all of which date to the Persian period (fifth–fourth century BC), five (of which two are illustrated in Figure 4; L2 and L6) are made from a clay fabric which is fossiliferous, micritic, rich in microfossils and calcareous fragments, with some serpentine and basalt inclusions, Figure 5d. The sixth sample (from the mortarium illustrated in Figure 4; L4) is rich in dolomitic sand.

These results seem to match Master's petrographic description of two mortaria from the site of Ashkelon [14; pp. 110 and 113], which mentions fossiliferous and calcareous fabrics with peridotite (in stages of serpentinization) and basalt fragments. Master suggests that this group ('category 9') might come from the Cypriot Troodos formation [14; p. 134]. Indeed, local production seems very unlikely, as serpentine is not present in the outcrops surrounding the Tell, even though Lachish is located in a fossiliferous and calcareous setting [26; p. 2569 and Figures 36.34 and 36.35, 27]. On the other hand, a quarry for dolomitic sand in the outcrops east of Lachish in the Judean Mountains around Jerusalem, appears to be the source for the clay of the sixth mortarium; this material was exploited for pottery manufacture in the Middle Bronze Age [28; pp. 263–264]. On the basis of the regional geology, it is possible to suggest a distant source for five of the six ring-footed mortaria studied, and possibly a regional production site for the sixth.

The fabric of the amphora from Lachish is different to those of the mortaria: it is a mixture of non-micritic and micritic clays with a much lower percentage of micritic fragments, serpentine and igneous inclusions, and a higher percentage of muscovite and chert. This suggests that the five mortaria not produced locally and the amphora might come from a similar geological background, although the potters exploited two different clay sources and techniques.

EDX analyses

In total, 14 samples from Miletos were analysed by EDX in the SEM. Initially, each of the five bulk analyses per sample was considered separately in PCA, Figure 7 and Table 1. Figure 7 shows that the bulk analyses from different sherds are very similar, which indicates that most samples have a homogeneous paste, suggesting that their clays were fine and well mixed; only the painted mortarium M17, which is coarser than the other specimens, shows some 'outliers'.

To the left of Figure 7 lies a cluster that includes all the cooking pots and the pithos (M26–M29) that are assumed to be locally produced. The clustering of the samples is of interest because the cooking pots were subdivided into three fabrics by petrographic examination, and the pithos was attributed to a fourth with shale as opposed to mica-schists, amphibole and dolerite. However, the EDX results suggest that their overall elemental composition is similar, rich in aluminium, potassium and silicon and low in calcium and magnesium (Table 1), reinforcing the impression (based on typology as well as petrographic examination) that these samples are of local production.

The flat-based yellow-buff mortaria (M3 and M4) cluster with the Cypriot basket-handled amphora (M30) and the Cypriot terracotta figurines (M31–M33) on the right side of Figure 7. They have similar elemental composition, with high percentages of magnesium and calcium. The Hellenistic spouted mortarium (M16) and a burnt flat-based mortarium (M14) – possibly a kiln waster – seem to be local, because they cluster well with the cooking pots. The coarse-tempered painted mortarium (M17) does not fit either cluster, even though it contains mica-schist that is typical of the local geology.

Elemental analysis also suggests a similarity with the Cypriot figurines for the mortarium from Xanthos (X1), Figure 8. From the mineralogical and elemental results it would seem that the flat-based yellow-buff mortaria found in Ionia and Lycia were imported from Cyprus, while a version of this type made in brown clay, painted mortaria, cooking pots and the pithos-like vessel (M14, M16 and M26–M29) were produced locally by Milesian potters.

The elemental composition of the seven mortaria from the Greek trading post of Naukratis in Egypt analysed by EDX (pink in Figure 8) reflects the grouping identified by optical microscopy reasonably well. The flat-based yellow-buff mortaria (N1, N4) have high positive PC1 values, as do the other objects thought to have been made in Cyprus. NAA had already suggested that many Archaic flat-based mortaria from Naukratis are Cypriot imports [10; p. 70], a conclusion supported by this study. Although petrographically different, the flat-based mortarium (N10) and Corinthian 'tile fabric' mortarium (N15) [8; p. 33 and Figure 10] have similar PC2 values that are both more negative than that for the Egyptian marl mortarium (N12), which is a contemporary local version of the flat-based type that Mommsen *et al*. have already attributed to Egyptian manufacture using NAA [10; p. 70]. This Egyptian marl mortarium is fairly similar to a mortarium of different and later type (N13), with which it shares high PC2 values and a comparable petrography, suggesting that the manufacture of mortaria in the region persisted into later, post-Archaic periods.

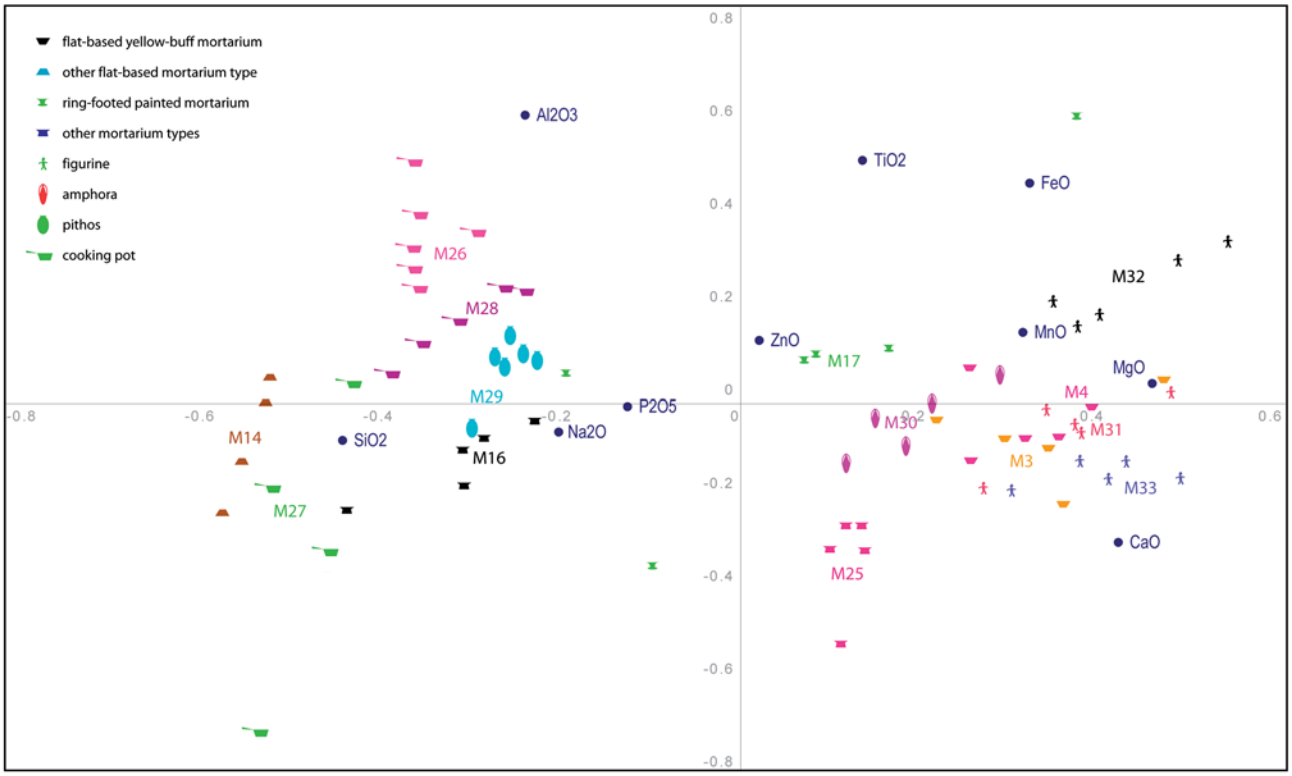

FIGURE 7. Principal component analysis of EDX results from samples found at Miletos, first and second components (PC1, horizontal axis, 39% variance; PC2, vertical axis, 16% variance). Each symbol represents one of the five bulk analyses for each sample. Different colours represent the different samples and the symbol shape indicates typology

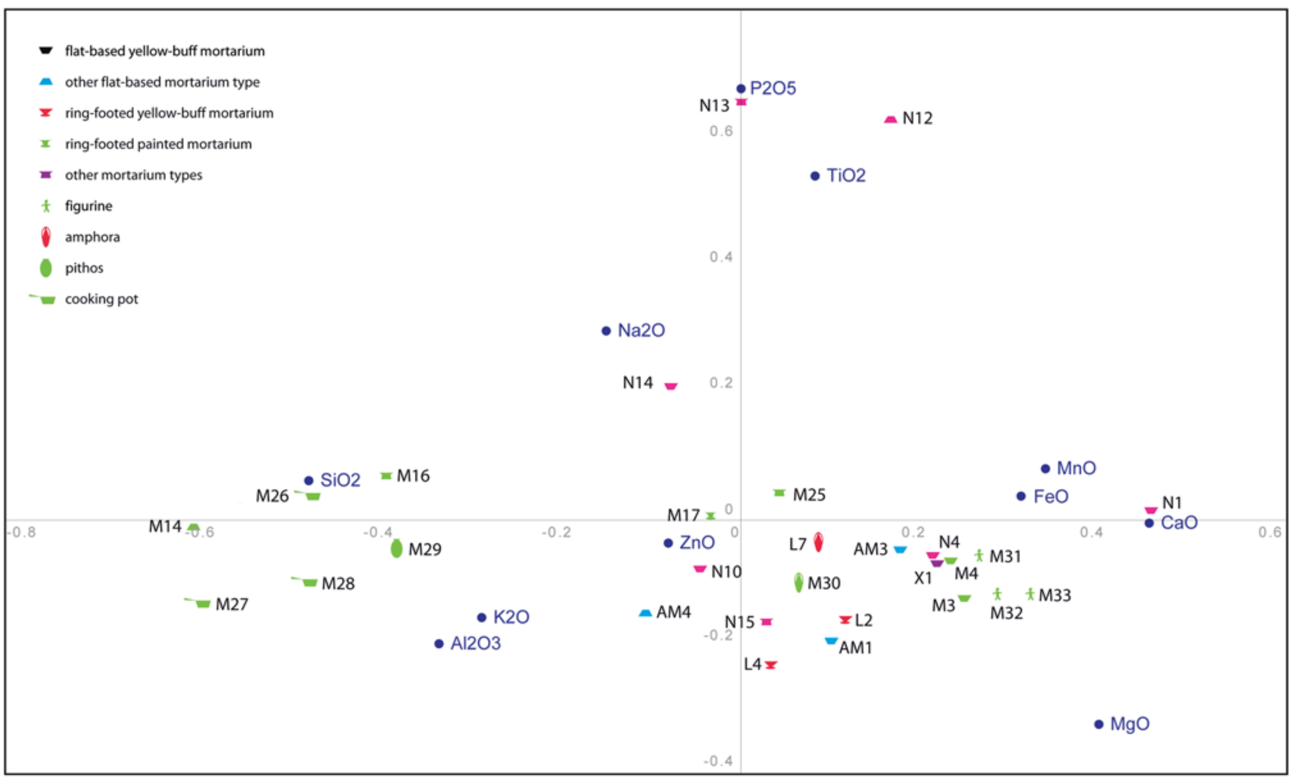

FIGURE 8. Principal component analysis of EDX results from all the samples discussed in this paper, first and second components (PC1, horizontal axis, 34% variance; PC2, vertical axis, 16% variance). Each symbol represents the mean of five bulk analyses for each sample. Different colours indicate the site at which the sample was found (green = Miletos, blue = Al Mina, red = Lachish, pink = Naukratis and purple = Xanthos). The symbol shapes indicate typology

The EDX analyses of the samples from the trading post of Al Mina in Syria (blue in Figure 8) show that the elemental composition of sample AM3 and perhaps also of AM1, both regular flat-based buff mortaria, are similar to those of the other flat-based yellow-buff types from Naukratis (N4), Miletos (M3 and M4) and Xanthos (X1), and to those of the Cypriot terracotta figurines (M31–M33), all of which have high positive PC1 values. In contrast, the flat-based 'red' mortarium (AM4) has a negative PC1 value, suggesting a different clay source with a lower calcium oxide content. Even though the flat-based yellow-buff mortaria from Al Mina are slightly coarser and richer in micritic pellets than those from Miletos, the results suggest that they could all come from a similar source. The association with the Cypriot material also suggests that this source is more likely to be Cyprus than the region of Al Mina itself, which, as suggested above, would have been a possibility on the basis of petrographic examination alone.

At Lachish in Palestine, the EDX results (red in Figure 8) suggest that sample L2, a ring-footed mortarium from the same petrographic group as three other samples, does not fit particularly well within the cluster of 'Cypriot imports'. Petrographic differences have also been observed in the different pastes used in the Lachish mortaria, which are of a later date than the likely Cypriot imports from Al Mina, Miletos and Naukratis. Even though there are certain similarities, the Lachish samples are fossiliferous and contain coarser minerals than those present in the other Cypriot imports. Nevertheless, they might come from Cyprus, and the elemental analyses are reasonably close to those for the Cypriot cluster. Sample L4, for which petrographic analysis had suggested production in Israel, appears not to belong to this cluster, while amphora L7 could fit in the Cypriot cluster as it shows a similar elemental composition to the probable Cypriot products, with relatively high magnesium, calcium and sodium, and low silicon and aluminium.

As these results demonstrate, the integrated use of complementary scientific techniques can provide a wider picture of the history of these archaeological objects than would otherwise be possible. The study of the thin sections allowed the different fabrics of the mortaria to be identified, characterizing the minerals and the size and shape of the particles, which indicate whether they were added by the potters as temper or were naturally present in the clay. This method was useful for the analyses of the Milesian cooking pots and the painted mortaria, where the clays were heavily tempered with sand. In particular, this type of analysis allowed the identification of the coarse basalt inclusions and the microfossils characteristic of the Lachish ceramics. On the other hand, some fabrics, such as those of some flat-based yellow-buff mortaria, are too fine to be differentiated using polarized light microscopy, and additional methods are necessary to describe differences or similarities between groups and to suggest potential provenances. In this study, elemental analysis of thin sections by EDX was used to group samples on the basis of their elemental composition. The resulting clusters, which also included Milesian and Cypriot reference material, aided the association of samples with likely Cypriot, Milesian and other origins. Earlier NAA on some of the samples indicated a Cypriot origin for many of them, and also helped to pinpoint an Egyptian centre of production [8, 10]. Conversely, the petrographic analyses anchored within the main group of likely Cypriot imports two flat-based buff mortaria (N5 and N6) from Naukratis that earlier NAA had classified as separate and distinct [8; pp. 41–42].

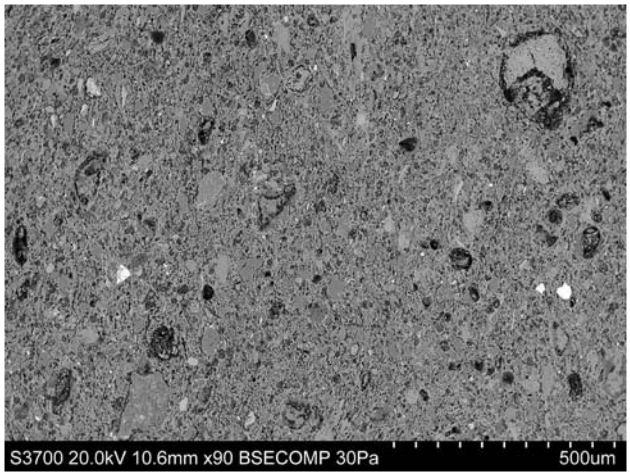

FIGURE 9. SEM image (90×) of a sample of a flat-based buff mortarium from Naukratis (sample N1), showing a very fine highly fired structure with fine mineral inclusions

In addition to suggesting provenance, a number of technical observations can also be made. The typical Cypriot flat-based buff mortaria were manufactured using a very specific recipe, employing finely levigated clay, which is fine-grained and slightly micritic from a serpentine formation. Most of the fabrics of the flat-based Cypro-Phoenician type mortaria were vitrified, indicating that the mortaria were fired at high temperatures, exceeding 850°C, Figure 9. The final product had a well-defined shape with a hard paste, which was difficult to break, giving the vessels a long service life. The Cypriot ring-footed mortaria from Lachish were fired at lower temperatures, as testified by the abundance of micritic pellets and microfossils, and have coarser inclusions, with serpentine and pyroxene probably added deliberately as a sand temper. Their fabric is nevertheless tough and sturdy, with the inclusions quite possibly aiding effective grinding. Since similar clay recipes were also used for amphorae and terracotta figurines, it is hard to judge the much-debated issue of to what extent the materials were dictated by tradition or by the specific technological choices made to enhance the functionality of the mortaria [29, 30]. Undoubtedly, however, the fabric was highly suited to its purpose, and the wide distribution of Cypriot mortaria seems to suggest that customers appreciated this functionality.

Local imitations that copied the shape and manufacturing technique of the Cypriot flat-based mortaria, but using different and often coarser clays, were produced both in Miletos and Naukratis. In both places, however, the local products failed to match the quality and functionality of the

Cypriot mortaria; the Milesian and Naukratite brown flat-based mortaria examined were both fired below 850°C and generally appeared softer and less sturdy. In due course local potters began to manufacture grinding bowls of different and distinctly local shapes, such as those with added spouts. This may have been in part a response to specific local culinary needs, and was achieved by adapting local clay recipes that had been in use for other shapes. Such seems to be the case with the sixth-century BC painted, ring-footed mortaria from Miletos, the fabrics of which are reminiscent of some Milesian cooking pot fabrics.

CONCLUSIONS

Three main observations emerge. First, Cyprus was identified as a major production centre for mortaria throughout the Archaic period, trading its products not just to Palestine but also to the East Greek region. Second, local copies were made of this common import in Miletos, Naukratis and, it seems, Palestine, followed by the development of more distinctly local types. Third, many different clay recipes were used to manufacture mortaria-shaped vessels, but among these it is the Cypriot mortaria that possessed a superior functionality due to the clay paste and firing regime used.

The wide distribution of Cypriot mortaria in the Eastern Mediterranean for several centuries from around 700 BC onwards must be seen in the context of an increasingly interconnected Mediterranean with far-reaching trade routes along which travelled not only staples of daily life and luxury goods but also new culinary practices. It suggests the existence of a distinct Eastern Mediterranean *koine* with regard to food processing technology that crossed the boundaries of several civilizations. But the spread of culinary practices and other social and cultural factors alone cannot explain the widespread and continued popularity of these plain, utilitarian household vessels. The observations reported here suggest that, at least in part, it was their superior functional qualities that made Cypriot mortaria so attractive to customers in Ionia, Lycia and Palestine, and the trading posts of Naukratis and Al Mina.

Like cooking pots, pottery mortaria appear to constitute another category of household pottery where a specific vessel function could influence the choice of clay fabric and technology, and where a superior product made in specialized workshops found a wide distribution, even across cultural borders.

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