The emergence of lead-glazed pottery in the Late Hellenistic and Roman Mediterranean: new investigations at Mytilene, Athens, and Ostia

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The Emergence of Lead-Glazed Pottery in the Late Hellenistic and Roman Mediterranean

New Investigations at Mytilene, Athens, and Ostia

ABSTRACT

The circumstances and chronology of the emergence of lead-glazed pottery in the Late Hellenistic and Roman Mediterranean remain heavily debated. This article presents a multidisciplinary discussion of pottery provenance and glazing technology based on the analysis of 94 samples from three sites: Mytilene, Athens, and Ostia. Through a critical review of published data and comparisons with other glazed ceramics, we discuss the emergence of lead-glazed pottery against the background of a highly interconnected, "global" world. We argue that mainland Greece played an important but hitherto unrecognized role in this development.

Lead-glazed pottery, which evokes expensive metalware through its molded decoration and vitreous surfaces, began to be produced in the eastern Mediterranean around the time of the Roman conquest of Cilicia in 64 BCE.[1] By this time, ceramic imitations of metalware, created by combining moldmade vessels (or wheelmade vessels with applied molded decoration) with the application of an iridescent coating, were not new. They represent a technologically diverse craft production that had become increasingly popular

1. More specifically, Hochuli-Gysel (2002, pp. 303, 312) mentions "un début palpable . . . à partir de la première moitié du I[er] siècle av. J.-C. . . . Son acme se situe aux époques augustéenne et tibérienne."

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across and beyond the Mediterranean during the previous two centuries.[2] The use of a lead-rich glaze, however, was a new development. It is one of the many technological innovations that took place in a context of increased economic, diplomatic, military, and political activity by the Romans in the eastern Mediterranean, which fostered contacts between the Roman Republic and the Hellenistic East.[3]

The geographic distribution of lead-glazed pottery finds, as well as their stratigraphic contexts, supports the idea that soon after this production began in Anatolia, lead-glazed pottery spread to Rome and central Italy. From there, new workshops started in the Rhône valley under the Julio-Claudians, and later in Britain, as well as in the Rhine and Danube regions, where they thrived until late antiquity.[4] The discovery of lead-glazed wares in contexts from the Roman Imperial period, notably in central Italy, Pannonia, and Gaul, as well as the diversification of pottery types covered with such glaze throughout the history of the Roman Empire, have both contributed to the identification of lead-glazed pottery as an integral—albeit uncommon—part of Roman material culture.[5]

The emergence of lead-glazed pottery thus seems to be another example of an originally Hellenistic invention that, through processes of adoption, adaptation, and diffusion, developed into a Roman innovation.[6] Indeed, glaze

from Mytilene and Ostia were prepared by Liard; those from the Athenian Agora are based on the drawings published by John Hayes (*Agora* XXXII). All profile drawings published in this article were inked by Christina Kolb. All rights for the depicted objects from Greece are reserved by the Hellenic Ministry of Culture, Hellenic Organization of Cultural Resources Development (H.O.C.RE.D.) (law 48/58/2021).

2. See Vickers and Impey 1986. Aside from Etruscan *ceramica argentata,* which was created by using a tin dip in the 4th century BCE (Michetti 2005, p. 99), most ceramic imitations of metalware in the Greek and Roman worlds were produced by the reducing or oxidizing firing of an iron-rich slip. Black-glazed vessels were produced especially in the Classical and Hellenistic periods.

3. Greene (2007) provides a survey of scholarship on the emergence of lead-glazed pottery, rightly underlining its innovative character as "an unprecedented experiment" in Late Hellenistic and Early Roman Asia Minor (p. 653). For the innovations generated by the Roman appropriation of Hellenistic culture and technology in general terms, see Moatti 2015.

4. In addition to other works cited below, see Martin 1992, 1994; Sfredda and Tassinari 1998 (central Italy); Magrini and Sbarra 2005 (northern Italy and the Adriatic region); Desbat 1986a; Gohier 2018a, 2018b (Gaul); Walton and Tite 2010 (Britain).

5. See, e.g., the proceedings of the international conference on Late Roman lead-glazed pottery in the eastern Alpine area and Danubian provinces in 2007 (Magrini and Sbarra 2009).

6. See the leading research on this topic in Greene 2007, p. 667. In the 1980s Maccabruni (1987, p. 168) suggested that lead-glazed pottery should be considered a Hellenistic type of ware: "La ceramica microasiatica ad invetriatura piombifera, benché in gran parte assegnabile al I sec. d.C., può considerarsi una produzione tipicamente ellenistica, frutto dell'applicazione di un rivestimento di origine orientale ad un repertorio tipologico di tradizione greca." Beyond the similar shine and colors, nonetheless, several scholars have highlighted the large technological difference between Late Hellenistic and Roman ceramic lead glazes on the one hand, and western Asiatic ceramic alkaline glazes on the other (see, e.g., Greene 2007, p. 660; Jackson and Greene 2008, p. 513). Walton and Tite (2010, p. 733) cautiously date the emergence of the first examples of lead-glazed pottery in the Greco-Roman world to "the late Hellenistic period (i.e., about the first century BCE)"; Tite et al. (1998, p. 242) mention that "the first use of lead glazes in the West seems to have occurred during the Roman era (first century BCE to first century CE)"; Hatcher et al. (1994, p. 431) note the absence of any evidence for lead-glazed pottery in pre-Roman archaeological contexts. De Benedetto et al. (2004) provide an archaeometric analysis of five lead-glazed pottery sherds found at Canosa in Apulia, which are deemed to be Augustan "on the basis of their stratigraphic position" (p. 616), although no stylistic information is provided for these sherds and considerable evidence of a Hellenistic occupation has been found at the site. Likewise, at Palmyra, Römer-Strehl (2016, p. 111, fig. 10) assigns the lead-glazed pottery assemblage to the Late Hellenistic–Early Roman transition, rather than to the Roman period per se. Farther east, however, the occurrence of lead-glazed pottery is recorded much earlier in antiquity, during the Han Dynasty (202 BCE–220 CE) (see, e.g., Greene 2007, p. 658, n. 1). Waksman and her colleagues pointed out the need to explore further the potential role of Chinese craftsmanship in the development of ancient Mediterranean lead-glazed pottery because of a noticeable similarity in the elemental composition of the glazes (Waksman et al. 2007, p. 134).

recipes and pottery types were both dramatically transformed between the first occurrences recorded in the 1st century BCE and late antiquity, while the main production centers of this ware also diversified throughout the Roman Empire.[7] Moreover, a distinction is often made between an earlier and totally distinct tradition of producing green-glazed pottery using alkaline glazes in Hellenistic western Asia and Egypt on the one hand, and the development of high-lead glazes in the Late Hellenistic and Roman world on the other. The potential role of Greek workshops in the transmission of new aesthetic fashions and technological practices between both worlds has also been overlooked. Research on this latter topic is being hampered by the assumption that lead-glazed pottery found in Greece was imported, although determinations of provenance have most often been made only on the basis of macroscopic examination of fabric and stylistic analyses of the finished products. Yet archaeometric analysis can help to determine the local or imported origin of the pottery and reconstruct networks of trade and exchange. It also allows for the reconstruction of the ancient glaze recipes and networks of knowledge sharing that were involved in the diffusion of this type of pottery across and beyond the ancient Mediterranean.[8]

The current state of scholarship presents a risk of compartmentalizing the ancient history of lead-glazed earthenwares both in time and in space, thereby hindering a full understanding of the processes, conditions, and chronology of the emergence of lead-glazed pottery in the ancient Mediterranean. We argue for the need to reappraise the study of this ware from a "global perspective"—that is, against the background of a highly interconnected, "global" ancient world where network power had an important role to play in the spreading of innovations. All across north Africa, Europe, and western Asia, the final two centuries BCE are pivotal in terms of expanded geographies and heightened interconnectedness. Many scholars, therefore, now argue for the importance of translocal and transregional approaches to understand processes of innovation and draw on globalization theory to do so.[9] Such approaches emphasize the interaction between the local, regional, and global, and the way in which this continuous interplay shapes societies and history. An emphasis on globalization invites us to think in terms of very large geographical units like "(western) Afro-Eurasia," as this study does (Fig. 1).[10] This approach usefully underlines the intense connectivity

7. As discussed below (p. 483), archaeometric analyses have identified the existence of various ceramic lead-glaze recipes in the ancient Mediterranean. The use of a lead-glaze slurry on noncalcareous pottery seems to have prevailed among the first productions of western Anatolian workshops and later in the Danube region. By contrast, the application of a mixture of lead oxide and silica on a calcareous clay body may originate in Late Hellenistic southern Anatolia; it spread to the Italian peninsula during the High Roman Empire, before further changes are recorded around the 4th or 5th century CE.

8. For the development of regional production centers of lead-glazed ware in Italy, Gaul, and the Rhine and Danube regions of the Roman Empire, see pp. 445–446, 448–449, below. The tradition of lead glazing continued until the High Middle Ages in northern Italy and the Balkans, and was exported to Constantinople, probably from western sources, around the 7th century CE (Waksman et al. 2007, p. 134). The tradition of using lead oxide compounds to produce monochrome ceramic glazes had a long history in the Late Roman, Byzantine, and post-Byzantine worlds, while the alkali glazing tradition was mainly used in the widespread turquoise glazed wares of the Sassanian and Islamic worlds (Waksman et al. 2007, p. 134; Freestone 2021).

9. For an introduction to the debate, see Pitts and Versluys 2015, 2021; see also Versluys 2021 for the recent state of the question. Examples of this approach include Hoo 2018; Mazurek 2018; Riedel 2018; Kouremenos and Gordon 2020.

10. By "western Afro-Eurasia," scholars usually mean the wider Mediterranean and Near East as well as north Africa. For the concept of Afro-Eurasia itself and the importance of using the term, see Dunn 2010.

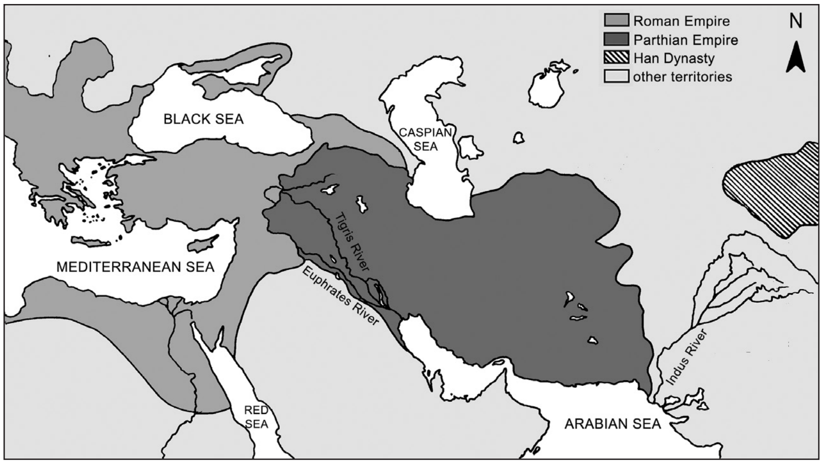


Figure 1. Map of western Afro-Eurasia in the Roman period, showing the territories discussed in this study. F. Liard, after Netchev 2022, CC BY-NC-SA 4.0

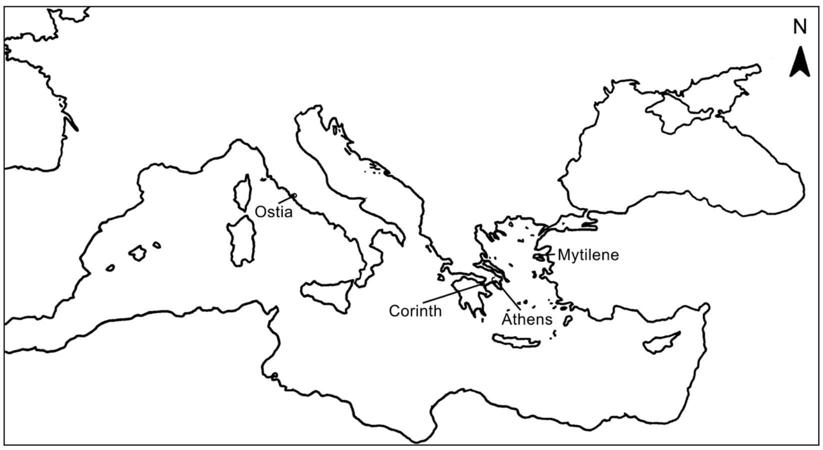


Figure 2. Map of the Late Hellenistic and Roman Mediterranean, showing the sites of the lead-glazed pottery workshops discussed in this study. F. Liard

within the region in the Hellenistic–Roman era and the importance of the network in accounting for processes of change.[11] As a result, the history of the region becomes less a history of separate cultural "containers" (Roman, Gallic, Greek, Anatolian, Syrian, Egyptian, Iranian, and so on), and more that of a single container variously characterized by flows and blockages in the movement of people and objects. Privileging connectivity and mobility thus facilitates narratives of this period that decenter Rome as the main pivotal force for the diffusion of these wares, in favor of a more complex polycentric conceptualization of empire.[12] Freed of concepts like Hellenization and Romanization, such an approach will enable us to understand developments in western Afro-Eurasia in the Late Hellenistic and Roman eras as the effects of collective actions and reactions that emanated from a "global" network.

This article should be seen as an application of this "global perspective." It presents a multidisciplinary analysis of 94 lead-glazed pottery fragments from well-documented stratigraphic contexts at three sites distributed across the Mediterranean: Mytilene, Athens, and Ostia (Fig. 2).[13] The scientific analysis of these fabrics and glazes in laboratory conditions is, we believe, crucial to renew the discussion on the emergence and chronology of lead-glazed pottery in the Late Hellenistic and Roman world.

In order to contextualize these results within the current state of research, we begin with a critical review of the published data and their

11. On the concept of network power, see Versluys, forthcoming.

12. See Pitts 2021; for a focus on innovation specifically, see Flohr 2016.

13. The sampled sherds come from the excavations by the CIG at the Sanctuary of Demeter on the Kastro of Mytilene, the excavations by the ASCSA in the Athenian Agora, and the Belgian-Italian excavations in the area of the Tempio dei Fabri Navales at Ostia.

interpretation, addressing several key questions: How have the emergence and chronology of lead-glazed wares been reconstructed? What workshops have been identified, and how has their interaction been understood? What has been written about the technological aspects of the production in this period?

WHEN AND WHERE DID LEAD-GLAZED POTTERY EMERGE?

Asia Minor

Beyond the generally accepted idea that lead-glazed pottery first emerged in the 1st century BCE in Asia Minor, the chronology of these first productions remains somewhat insecure: the earliest examples are attributed to the first half of the century by some,[14] and to the second half by others.[15] Be that as it may, these first productions are deemed contemporary with the increased political and economic activity of the Romans in the region.

A substantial number of lead-glazed pots and fragments were discovered at Tarsos in the mid-20th century. The presence of kiln wasters, molds, and stilts, as well as two damaged kilns, demonstrates the existence of a local workshop that began during the reign of Augustus, or perhaps slightly before.[16] Several possible wasters were also found at Çandarlı, near Pergamon.[17] Since then, several dozen fragments have turned up at various sites across Anatolia and on the eastern Aegean coastline, but architectural evidence for lead-glazed pottery workshops seems to be absent in most cases. A local workshop was tentatively identified at the South Baths at Perge after the discovery of lead-glazed pottery wasters, stilts, and molds.[18] Excavations at Laodikeia on the Lykos produced lead-glazed wares that are deemed to be local on the basis of style.[19] Lead-glazed ceramic vessels, wasters, and molds were also found during a rescue excavation at Mytilene, in a destruction layer dated to the 1st century BCE and the beginning of the 1st century CE based on associated finds.[20]

At these various sites, the archaeological contexts and associated finds support the idea that a local production of lead-glazed pottery thrived, broadly, between the 1st century BCE and the 1st century CE in Asia Minor, and most scholars assume a peak of lead-glazed pottery production during the Augustan period. This chronology, however, is based on a relatively limited diversity of pottery shapes, and it may have created a tendency to narrow the already brief existence of lead-glazed wares in the provinces of Asia and Cilicia even

14. E.g., Hochuli-Gysel 2002, pp. 303, 310.
15. Hayes (*Agora* XXXII, p. 57) suggests that Anatolian workshops were active in the "early Roman period (after ca. 50 BCE)" and that "the main series should date from ca. 30 BCE to 70/80 CE." Some other scholars (e.g., Tite et al. 1998, p. 242) propose a broader chronology for the first use of lead glazes in the Roman world, between the 1st century BCE and the 1st century CE.
16. Caley 1947, pp. 391–392; Goldman 1950, pp. 192–194.
17. Loeschcke 1912, pp. 396–397.
18. Atik 1995, pp. 18–58, nos. 1–72.
19. Tekkök et al. 2009, p. 102.
20. Archonditou-Argyri 1997; Hochuli-Gysel 2002, p. 305.

further.[21] It should also be noted that lead-glazed vessels in western Asia Minor are well embedded in local pottery traditions that go back to the Hellenistic period and are believed to have continued under the Romans. This is notably the case at Pergamon, where the beginnings of a decorative repertoire with appliqué designs can be traced back to the 2nd century BCE, and lead-glazed pottery shapes also reproduce local skyphos and kalathos types attested in other ceramic wares, as well as in silverware.[22]

Mainland Greece

In contrast with Asia Minor, a review of the published data highlights the remarkable scarcity of lead-glazed pottery from archaeological excavations at mainland Greek sites. It also reveals that mainland Greece has rarely been considered home to lead-glazed pottery workshops in antiquity.[23] In the great majority of cases, lead-glazed sherds are identified as imports by their styles, and supposed to come mainly from Italian and Anatolian workshops, but the assumption has never been verified by archaeometric analysis. This is surprising, since several black-glazed moldmade ware industries are documented in mainland Greece in the Late Hellenistic period.[24] Among these, Athens probably hosted the earliest and one of the finest productions, which may have inspired several workshops along the eastern Aegean coastline.[25]

In the Hellenistic Greek cities of Asia Minor and southern Anatolia, the production of moldmade and other related (for example, appliqué) table wares may have encouraged the local emergence of lead-glazed pottery around the middle of the 1st century BCE.[26] Against this backdrop, one should note the discovery, at Athens, of a few fragments of hemispherical moldmade bowls displaying local types of decoration (long-petal and imbricated-leaf designs) and covered with a layer of lead-rich glaze instead of the usual black glaze (Fig. 3). Unfortunately, the secondary deposition context of these sherds does not allow for a precise chronology of production: they may date to the end of the 1st century BCE, and a terminus ante quem in the 1st century CE is currently proposed.[27] In any case, a local

21. Cf. Greene 2007, p. 654. See also Goldman 1950, p. 192, nn. 125, 126.

22. Japp 2013, p. 169. A similar decorative repertoire characterizes the *Firniskeramik* at Pergamon; see Maccabruni 1987, pp. 167, 169, nn. 16–18 (with references).

23. Only a few scholars have suggested that lead-glazed pottery may have been occasionally produced in Greek cities: see, e.g., Rotroff in *Agora* XXII, p. 36; Greene 2007, p. 654.

24. Indeed, Athens is considered the earliest center of production of the so-called Megarian bowl, and other workshops later followed at Corinth, Argos, and Olympia in the Peloponnese. For Athens, see *Agora* XXII, pp. 9–11. For Corinth, see Edwards 1981; *Corinth* VII.7, pp. 92–96. For Argos and Olympia, see Hausmann 1996, pp. 38–103.

25. On the early Ephesian production of Megarian bowls, see Rogl 2014, p. 132; on the local adaptation of Attic table-ware shapes and decoration at Pergamon in the Hellenistic period, see Japp 2013, p. 165. Kyme also housed a production center of high-quality bowls (Bouzek 2005, pp. 55–56). At Tarsos in southern Anatolia, Athens provided the prototypes for the local production of various table wares during the Hellenistic period, but there is no archaeological evidence for a local fabrication of Megarian bowls (Jones 1950, pp. 152, 157, 163).

26. Late Hellenistic Pergamon, for example, had a production center of both appliqué ware and lead-glazed ware (Japp 2013, pp. 169–171). At Tarsos, bowls with molded and applied decoration are attested in the Late Hellenistic period, before lead-glazed vessels appear early in the Imperial period (Jones 1950, pp. 173–180).

27. Agora P 19819, P 20020: *Agora* XXII, p. 93, no. 409; *Agora* XXXII, pp. 208–209, nos. 872, 873; see below, Table 1, samples AS2360 and AS2379.

a b

Figure 3. Moldmade drinking vessels with long-petal decoration, covered with a lead-rich glaze, from the Athenian Agora: (a) AS2360; (b) AS2379. Scale 1:2. Courtesy Ephorate of Antiquities of the City of Athens; Agora Excavations

provenance seems plausible, stylistically speaking, and the date is deemed to be later than that of the black-glazed specimens.[28]

Rome and the Italian Peninsula

Lead-glazed pottery production may not have started at the same time across the Italian peninsula. In some parts of Magna Graecia, the earliest occurrences of this type of ware date back to the Augustan period, and petrographic analysis indicates a local or regional provenance.[29] A Campanian production of lead-glazed pottery has also been identified, but it may have begun in the course of the 1st century CE.[30] While table ware is heavily inspired by the shapes and decorative patterns found at Tarsos, other influences, including local and regional traditions, can be seen in other types of ceramics, such as oil lamps, terracotta figurines, and table amphoras.[31]

In the Cisalpine region, the earliest occurrences of lead-glazed pottery are dated to the end of the 1st century BCE as well.[32] A local industry may have started through the arrival, in the area of Padua, of Near Eastern merchants familiar with glass technology.[33] This idea is supported by similarities between the types and styles of lead-glazed pottery found in the northern Adriatic region on the one hand and those found at Tarsos, Pergamon, and Perge on the other.[34] Nevertheless, some other shapes have more in common with local pottery traditions, such as the Aco goblets, which are directly related to local terra sigillata specimens.[35] Technologically

28. *Agora* XXXII, p. 58.

29. See, e.g., the multidisciplinary study of a small sample (five sherds) of lead-glazed pottery from Canosa in Apulia by De Benedetto et al. (2004). These sherds display “low-relief decoration and bichromatic appearance” (p. 616).

30. Desbat 1986a, p. 110.

31. For eastern influences on Campanian lead-glazed table ware, see Soricelli 1988, p. 248. For the Italian traditions reflected in the shapes and decoration of lead-glazed table amphoras, oil lamps, and terracotta figurines of the 1st century CE, see Di Gioia 2006, pp. 46, 66, 110.

32. Maccabruni 1987, p. 172; Brecciaroli Taborelli 2011, p. 129.

33. Maccabruni 1987, pp. 170–171; Brecciaroli Taborelli 2011, pp. 129, 132, n. 4.

34. Hochuli-Gysel 1977, pp. 137–142; Di Gioia 2006, p. 20; Brecciaroli Taborelli 2011, pp. 129, 132, nn. 4–6.

35. Maccabruni 1987, p. 178, n. 43; Soricelli 1988, p. 248 (with references); Sfredda and Tassinari 1998, p. 75.

speaking, this hypothesis, too, has its limitations, as glass technology is different from glaze technology.

The situation is still different in the region of Rome, where most of the archaeological evidence so far available for a local production dates to the High Empire. While the bulk of lead-glazed pottery found at Ostia comes from late Antonine contexts,[36] local production may have started in the second half of the 1st century CE. In the center of Rome, lead-glazed utilitarian pottery has been found in domestic contexts from the High Imperial period on both the Janiculum and Monte Testaccio. Excavations at Monte Testaccio brought to light the remains of kiln structures associated with fragments of lead-glazed pottery vessels (some of which are interpreted as wasters), alongside stilts and tools; the pottery fragments are stylistically attributable to the second half of the 1st century CE and the beginning of the 2nd century CE.[37] The decoration of the finest items of this production is reminiscent of the stylistic traditions of Asia Minor and northern Italy in the Augustan period and through the 1st century CE.[38] On the Janiculum, some experiments with lead glazing are suspected at a utilitarian coarse-ware pottery workshop dated to the Antonine period, on the basis of unfinished fragments of lead-glazed pottery in the same fabric used for other types of wares.[39]

WHERE AND HOW WAS LEAD-GLAZED POTTERY PRODUCED?

Asia Minor

In spite of the archaeological evidence for early lead-glazed pottery production at Tarsos and other locations in Asia Minor, the scarcity of multidisciplinary studies of these assemblages impedes a clear understanding of the regional distribution of workshops. Based on a stylistic and typological analysis of pieces from private and museum collections, Anne Hochuli-Gysel has been engaged in a long-term project to identify workshop productions from Tarsos, Smyrna (İzmir), western Asia Minor, and Italy.[40] Her pioneering work remains the primary reference for the typological and stylistic study of Early Roman lead-glazed pottery, and it provides a baseline for further research in light of new archaeological discoveries and methodological developments.

In line with this archaeological investigation, Helen Hatcher and her colleagues have performed chemical analyses of the fabrics of 100 museum

36. Martin 1992, pp. 323–324.

37. Porcari et al. 2010, p. 306 ("età flavio-traianea"). Similar products found in Arles and dated to the late 1st–late 2nd century CE may be related to the material from the Testaccio workshop (Gohier, Cappelli, and Cabella 2016, p. 589).

38. Porcari et al. 2010, pp. 303–307.

39. Gauckler 1912, pp. 239–240; Filippi 2008b; Giardino and Trosji 2008. This is notably the case for the ovoid vessel with a flat, inward-leaning rim, of the same type as described below for the sampled assemblage at Ostia (p. 468, n. 131). This type is dated from the reign of Nero to the end of the Antonine period (Olcese 2003, p. 92, pl. XXII; Gohier, Cappelli, and Cabella 2016, p. 589).

40. Hochuli-Gysel 1977, 2002; see also Gabelmann 1974.

pieces, and they compared their compositional groupings with Hochuli-Gysel's stylistic classification. They noted that the glazed pottery samples from Smyrna and Klazomenai in western Asia Minor were most likely made of the same clay, and that, while the fabrics from western Asia Minor, Tarsos, and Britain are all distinguishable from one another, the examples from Tarsos (which are also the most calcareous clays) most closely resemble those from Italy.[41] Nevertheless, this chemical data was not compared to the compositional fingerprint of ceramics of known origin or to locally available geological resources for further verification of the provenance. Beyond the general homogeneity of chemical composition found by Hatcher, Billur Tekkök and her colleagues have reported a local diversity of clay selection and processing practices within each stylistic group, as shown by a petrographic analysis of 22 fragments of lead-glazed pottery and molds found at Tarsos and dated to the Augustan period, some belonging to Hochuli-Gysel's Tarsos group and others to her western Asia Minor group.[42] By contrast, five skyphos fragments in the western Asia Minor stylistic group, found at Troy (Ilion) and dated to the Julio-Claudian period, occur in the same fabric.[43] These sample sets are small and exploratory, but they do suggest that stylistic traditions were locally diverse and that lead-glazed pottery products may have circulated on a strictly regional level in western Asia Minor.

Technological aspects of lead glazing are another promising thread of archaeometric research. Here, too, a significant step forward was made by Hatcher and her colleagues, who performed semiquantitative analysis on the glaze surfaces of their museum samples. Their results gave a hint that workshops in different parts of the Roman Empire used the same standard glaze-making recipe, with only some minor regional variation.[44] The portable method of analysis used, however, did not allow for the detection of some major and minor components of the lead glazes.[45] These results were extended by Marc Walton and Michael Tite, who tentatively identified the co-occurrence of two different recipes in Asia Minor: a lead oxide and silica mixture applied on a calcareous pottery fabric (identified among samples from Tarsos in southeastern Turkey) and a lead oxide powder applied on a noncalcareous clay body (identified among samples from Smyrna and Klazomenai in western Turkey).[46]

41. Hatcher et al. 1994, pp. 441–443, 448–449.

42. Tekkök et al. 2009, pp. 105–106. One main petrographic group is characterized by a red clay groundmass and relatively coarse inclusions, among which quartz is abundant. Three other fabrics display a light buff matrix with illitic minerals, a fine-grained red fabric, and a fabric with calcite and quartz inclusions. Three mold fragments occur in the first and second fabrics, indicating the probably local origin of these fabrics. One should note, however, the paucity of petrographic comparisons with other assemblages of lead-glazed pottery or local clay resources.

43. Tekkök et al. 2009, p. 114. This fabric has plentiful white mica laths, opaque minerals, and a few chert fragments. A sixth fragment does not have parallels elsewhere, and is interpreted by the authors (p. 113) as possibly a regional production.

44. Hatcher et al. 1994, pp. 443–444.

45. Hatcher et al. 1994, p. 441.

46. The research of Walton and Tite on Early Roman lead glazes is based on the statistical treatment of analytical data collected by Hatcher et al. (1994) for pottery of the 1st century BCE and 1st century CE. However, Walton and Tite (2010, p. 751) emphasize the difficulty of using this data for further research, as the analysis of the glazes using X-ray fluorescence spectrometry operated in air prevents the detection of elements with low atomic numbers (i.e., silicon and below). While the approximate silica content of the glazes could be determined after statistical treatment, the approximate aluminum content could not, and this element is crucial for clarifying the lead-glazing technology.

Mainland Greece

It is difficult to explain the near absence of lead-glazed pottery in mainland Greece, especially because this region is considered the birthplace of the Hellenistic moldmade bowl.[47] At Athens[48] and Corinth,[49] both important centers of moldmade pottery production in Hellenistic times, Roman lead-glazed table ware turns up only as scattered fragments in secondary deposition contexts, none of which have been previously subject to archaeometric analysis. However, some fragments reproduce the same decoration as local types of Hellenistic moldmade bowls (Fig. 3).[50] The existence of a 5th-century BCE lead-glazed Athenian vessel was announced in a conference paper in 2009, but this does not seem to have been published, and we do not take this evidence into account.[51]

The Italian Peninsula

In contrast to the scarcity of archaeometric analyses undertaken on finds from Asia Minor and mainland Greece, several analyses have been carried out on lead-glazed pottery found in Rome and Ostia.[52] The results of this research unanimously indicate the regional provenance of the clays used for most of this lead-glazed pottery; they also indicate the apparent absence of any imports from the East. Scholars have noted some variation in the texture and composition of this pottery from the 1st and 2nd centuries CE, and particularly in the mineral and rock inclusions of the fabrics. This allowed them, in some cases, to refine provenance ascriptions and to petrographically link these vessels to geological resources over a relatively extensive area of the Tyrrhenian region, from Campania through northern Latium to Umbria and southern Tuscany. Combined with the apparent absence of any long-distance imports in Rome during the period of the High Empire, this suggests the coexistence of various specialized workshops in the region, aimed at satisfying the local demand. This production may have lasted until the 5th century CE, retaining the same clays and tempers and showing few typological and stylistic developments, and with a notable tendency to reproduce "Archaic" or "Hellenistic" shapes and decorations.[53]

47. The so-called Megarian bowl, a hemispherical moldmade bowl of the Hellenistic period, is often seen as the invention of Athenian potters, possibly in imitation of silver and gold prototypes of Alexandrian manufacture, around the last quarter of the 3rd century BCE or slightly thereafter, with a significant representation in deposits of the first quarter of the 2nd century (*Agora* XXII, pp. 6–7; Rotroff 2006, pp. 375–376).

48. In the Athenian Agora, Hayes (*Agora* XXXII, pp. 57–58, 206–212, nos. 854–900) published 47 fragmentary lead-glazed vases and isolated sherds, among which more than half are treated as possible imports from western Asia Minor. The remaining sherds, for which no convincing parallels were found, are broadly classified as "various other regional classes," including suspected imports from Italy, Asia Minor (Perge, Tarsos), Syria, and Mesopotamia.

49. At ancient Corinth, a few isolated and fragmentary lead-glazed vessels have been found in different sectors of the site, some of which remain unpublished. Four pieces are reported from a Tiberian pottery deposit at the South Stoa (Hayes 1973, pp. 459–460, nos. 175–178, pl. 88). They are treated as mid-1st-century imports from the region of Tarsos. An intact modiolus discovered at the ancient harbor of Kenchreai is dated to the first half of the 1st century CE (Robinson 1972).

50. For Athens, see *Agora* XXII, p. 93, no. 409, pls. 69, 91; see also Greene 2007, p. 657, fig. 4 (P 20020). For Corinth, see C-1969-282 (F. Liard, pers. obs., July 2019). The shared decoration is discussed above (p. 444, n. 27).

51. Lillywhite 2009.

52. Giardino and Trosji 2008 (Janiculum); De Vito et al. 2017 (Monte Testaccio); Martin 1992 (Ostia).

53. Desbat 1986b, p. 38.

The functional range of lead-glazed pottery from Rome and Latium is clearly different from that in the northern Italian and eastern Mediterranean repertoires. The local assemblage displays the precious fine wares as well as less noble, often undecorated functional vessels. Aside from the stylistic and technological influence of the Hellenistic world evident in some of the finest table ware, fine vessels display types and shapes that are clearly inspired by Italian sigillata and *ceramica a pareti sottili* from the Augustan period and the early decades of the 1st century CE (see p. 446, n. 37, above). The decoration of larger table vessels combines molding with grooving, freehand, and appliqué decoration. The imbricate pine-cone pattern, which is present in terra sigillata, is also attested among large bowls and dishes.[54] The coarse kitchenware, on the other hand, reproduces local types of undecorated vessels that date back to the Augustan and Flavian periods.[55]

From the end of the 1st century CE onward, lead-glazed pottery was also exported from Latium to southern Gaul, where it gained some level of popularity. This is evidenced by the cargo of the Aléria 1 shipwreck near Corsica (ca. 90–130 CE), as well as by local workshops operating in Hérault as early as the 2nd century CE.[56] Imports from Latium have also been reported in Spain, Africa, and Hungary, as well as in England.[57] This again raises the possibility of a relatively early production of lead-glazed pottery in Latium in the High Empire, and the role of Rome as a focal center for the diffusion of this ware. The central Italian workshops were particularly prosperous, as the inhabitants of Rome do not seem to have imported any lead-glazed pottery, and Roman vessels were very popular in Italy and in Gaul, where they provided a source of inspiration for local productions.[58]

Finally, Walton and Tite have shown through archaeometric analysis that the lead-glazing technique on the Italian peninsula in general, and in Rome more particularly, followed the "Tarsos" tradition of the eastern Roman provinces in combining a calcareous clay with a lead oxide and quartz glazing mixture. In contrast, Gaulish lead-glazed pottery from the western Roman provinces was produced using noncalcareous clay in combination with lead oxide in a powder form.[59] Such associations of specific fabrics with particular glaze recipes may have been driven by the physical constraints of the materials used. Indeed, clay fabrics reacted in different ways with the lead oxide compound of the glaze during firing, which affected the appearance and resistance of the finished lead-glazed pottery.[60]

Central and Eastern Asia

Beyond Asia Minor, evidence for the ancient production of ceramic high-lead glazes in the Hellenistic East remains tenuous. Claims have been made for the erratic use of lead in pottery glazing in Egypt and the Middle East, without any Roman involvement whatsoever, but most of these assumptions were based on physical appearance alone and could not be confirmed by archaeometric analysis.[61] As early as 1947 Earle Caley suggested, although in general terms, that ceramic lead glazes may have been introduced as sporadic or even accidental applications prior to the 1st century BCE.[62] In 1936 Alfred Lucas used chemical data to identify the presence of lead in Egyptian glazed faience from the 22nd to the 30th Dynasty.[63] A more

54. Martin 1994, pp. 66–67, figs. 4:2, 5:1.

55. Desbat 1986a, p. 107; Martin 1994, p. 64 (with references).

56. Gohier 2018b, pp. 206–209.

57. Martin 1994, pp. 63–64 (with references).

58. Picon and Desbat 1986; Gohier 2018b, pp. 203, 206–207.

59. Walton and Tite 2010, p. 751.

60. Walton and Tite 2010, p. 752.

61. Hatcher et al. (1994, p. 431) could not identify the use of ceramic lead glaze prior to the Roman period in this region, despite an extensive search among Egyptian and Coptic pottery in museum collections.

62. Caley 1947, p. 393.

63. Lucas 1936, pp. 148–150 (faience variant F). Forbes (1950, p. 185) reports that "lead was used in glazes from the XVIIIth dynasty onwards," but the intentional character of the presence of lead in such early glazes should be further explored. Maccabruni (1987, p. 177, n. 3) states that lead glaze was not used to coat pottery in ancient Egypt.

recent analysis of 21 fragments of low-relief and bicolored Egyptian faience vessels in the Walters Art Museum revealed the use of a lead-alkaline glaze on a quartz faience body.[64] Although not associated with moldmade pottery craftsmanship, Ptolemaic faience thus constitutes the earliest known example of the intentional use of lead in ancient glazes.

Trace concentrations of lead have been found in blue- to green-colored alkaline ceramic glazes in pre-Roman contexts from the Near East. One group of examples comes from a Late Hellenistic context at Jebel Khalid on the Euphrates, a Seleukid military camp located in northern Syria. The green-glazed pottery assemblage at this site includes closed jars and open vessels, among them some characteristically Hellenistic shapes such as the echinus bowl, all covered with a layer of iridescent green glaze. These vessels are attributed to an advanced stage of the Seleukid presence in the region, around the second half of the 2nd century BCE.[65] The shapes and decoration are clearly Hellenistic, and petrographic analysis of the fabrics suggests the existence of a regional workshop exploiting clay resources in the Euphrates valley.[66] The so-called green glazes are alkaline glazes that contain small quantities of lead.[67]

This discovery is not unique in Mesopotamia; at Nippur, farther south on the Euphrates River, a substantial quantity of lead is reported in glazes of presumably Assyrian date.[68] It is also interesting that the alkaline green glazes from Jebel Khalid are different in composition from other regional products, such as those found at Dura Europos and Seleukeia on the Euphrates, which probably correspond to traditional Parthian technology. Even if the possibility of an incidental presence of lead as a coloring compound in these glazes cannot be ruled out, the idea of an experimental production in this Seleukid context of lead-alkali ceramic glaze cannot be dismissed either. The contemporaneous use of lead-alkali faience in Ptolemaic Egypt has led some scholars to suggest that lead-rich ceramic glazes were first produced by combining lead oxide with the traditional ingredients developed for alkaline glazes.[69]

As for the chronology of this practice, to date we have only a few unconvincing mentions of the use of ceramic lead-rich glazes in pre-Hellenistic

64. Mao 2000.

65. Jackson and Tidmarsh 2013; Jackson 2016, pp. 443, 445. The Romans did not resettle the site.

66. Jackson and Tidmarsh 2013, pp. 333–335. They note (p. 334) that "a riverine Euphrates source is supported by analysis of the fabric, which at Jebel Khalid is homogeneous and matches the descriptions of green-glazed fabrics from several different sites. . . . The geochemistry of the clay includes a mafic/ultramafic signature thought to be common to Euphrates riverine clays."

67. These glazes contain between 30 and 35 wt% of silica and about 8 wt% of alkali, while the alumina content is typically in the range of 2–3 wt%. Moreover, the particular color of the glazes was probably due the trace concentration of copper (ca. 30,000 ppm), perhaps combined with tin (ca. 1,800 ppm) in a pigment form. We suggest this interpretation based on results published in Garnett, Jackson, and Waudron 2011, p. 547, table 1. The PIXE analysis by Bailey, Garton, and Jackson (in Clarke et al. 1998, pp. 129–134) revealed the existence of ca. 100 ppm of lead in the Hellenistic alkaline glazes found at Jebel Khalid, and more than 1,000 ppm of lead (as well as traces of tin) in one 2nd-century CE Roman glaze found at Shash Hamdan; see also Garnett, Jackson, and Waudron 2011, p. 547; Jackson 2016, p. 447.

68. Jackson and Tidmarsh 2013, p. 334; Jackson 2016, pp. 448–449. The exact concentration of lead in this glaze remains unknown (see Garnett, Jackson, and Waudron 2011, pp. 546–547, n. 1). It should be noted, however, that an analysis by Toll (1943; included in Garnett, Jackson, and Waudron 2011, p. 547, table 1) detected up to 1,750 ppm of lead in a green glaze at Nippur from the Parthian period. Nevertheless, such trace occurrence of lead might be linked to the use of lead-based pigments for coloring the glaze, rather than being a specific ingredient of the glazing compound.

69. Hatcher et al. 1994, p. 431.

Mesopotamian contexts. Robert Forbes reported the mention of a lead-glaze recipe in Babylonian archives from ca. 1700 BCE, but this is not supported by archaeological evidence.[70] In 1928, Herbert Harrison suspected the occurrence of lead in ceramic glazes in Mesopotamia from as early as 600 BCE, but the use of lead as an ingredient of the glaze slurry has not been verified by archaeometric analysis.[71]

At the time when lead-glazed pottery was produced in the Roman Empire, some alternative glaze recipes were found in remote eastern locations where the technological knowledge associated with this invention remained unknown. Ain Sinu, a Parthian military outpost located in modern Iraq, on the main route between Singara and the Tigris, provides an interesting example. The site was conquered by the Romans and occupied by Roman soldiers between 197 and 364 CE. The pottery assemblage of the 2nd century CE includes several vessels covered with a green alkaline glaze, which, however, contains small quantities of lead (ca. 0.50 wt% of lead oxide). On the basis of an archaeometric analysis of these glazes, Jonathan Wood and his colleagues have suggested that Roman alkali natron glass was recycled and applied as a surface cover on this local Parthian pottery.[72] Indeed, similar composition ratios (in main oxides) have been highlighted in contemporaneous Roman glass, which was colored using lead-based and tin-based pigments, and which could explain the presence of trace quantities of lead in this pottery.[73] Thus we seem to be dealing with the merging of aesthetic traditions of pottery glazing, with the aim of creating a surface coating that would look like the Roman glaze, but using recycled Roman glass rather than a Roman pottery glaze recipe.

Finally, the early production of lead-rich ceramic glazes in eastern Asia must be stressed. In China, two types of low-fired ceramic glazes using lead as a flux emerged as early as the Warring States period (ca. 475–221 BCE).[74] This is nearly four centuries earlier than the earliest Mediterranean specimens of lead-glazed pottery. One object in which the use of lead in Chinese glaze technology is first attested, the glass "eye-bead," is believed to have a western origin encompassing the Mediterranean region, Mesopotamia, and central Asia. This western prototype was made of a type of lead-free, silica-based glass. The addition of lead as an ingredient of the glaze slurry used in the "eye" pattern of the bead is considered an independent Chinese development of the Warring States period.[75] Both types of glaze flourished during the Han Dynasty (202 BCE–220 CE), when these techniques

70. Forbes 1966, p. 133.

71. Harrison 1928, pp. 52–53. For archaeometric analysis of Mesopotamian ceramic glazes, see Hedges and Moorey 1975; Hedges 1976. The specimens studied were dated between 1300 BCE and 550 CE, and turned out to be mainly composed of alkali, lime, and silica. Nonetheless, Hill et al. (2007, p. 423) also assign the first use of a lead glaze on ceramics to the 2nd millennium BCE, and we have noted above the occurrence of traces of lead, perhaps in the form of pigments, in Assyrian glazes from the 1st millennium BCE.

72. See Wood and Hsu 2020; Wood and Greenacre 2021, p. 2.

73. The trace elemental composition of the Parthian glazes at Ain Sinu have not been published. It would be particularly useful to determine whether tin, another component of glass and glaze pigments in Roman times, was also present in these glazes.

74. Lang and Cui 2017. Lead-silica glazes and lead-barium-silica glazes were then in use, the first type exhibiting green and blue hues and the second type red, yellow, and brown (see Chen, Wen, and Wang 2020, p. 2, with references).

75. The specific type of glaze used in this case is a lead-barium low-fire glaze. See Chen, Wen, and Wang 2020, pp. 4–5, fig. 3. It is thus different from the lead-alkali glazes used in Ptolemaic Egypt, and from the green glazes covering Seleukid and Parthian pottery.

circulated widely across China, and the two glazes were sometimes applied to the same vessel.[76] Further technological advancements that may go back to the Warring States period involve the use of both calcium and lead as fluxing agents in pottery glazes. This is also the time when protoporcelain appeared, with the prevalent use of calcium oxide over lead oxide as the main fluxing agent.[77] In contrast to the Mediterranean use of this type of ware, in the Han Empire lead-glazed pottery was only used for burial objects and architectural elements.[78]

This evidence clearly demonstrates that the use of lead oxide in glazed pottery existed before and beyond the Hellenistic and Roman world. It also reveals that lead was used as an ingredient in ceramic glazes from eastern Asia well before the emergence of lead-glazed pottery in Cilicia. Some fertile grounds for cultural interaction were fostered by the strategic position of the Euphrates valley on commercial routes that had long linked the Late Hellenistic and Roman Mediterranean with the Near East and Asia, and that intensified during the period of the early Silk Roads (ca. 100 BCE–250 CE).[79] In view of the dense connectivity that characterized the Afro-Eurasian network in this period, the emergence of high-lead glazes in Roman Republican and Augustan Asia Minor and Italy should be reconsidered from a more general perspective than has thus far been the case. The study of related artifacts, such as glass vessels, for instance, has already suggested that contacts between the Roman world and the Han Empire influenced their manufacture, exchange, and consumption across Afro-Eurasia.[80] Here we explore these relationships by confronting published archaeological data on workshop outputs and technocultural traditions with new archaeometric analysis of lead-glazed pottery from three representative contexts in the Mediterranean region.

THE SAMPLE SETS AND THEIR ARCHAEOLOGICAL CONTEXTS

To provide new insights into the emergence of lead-glazed pottery in the ancient Mediterranean, we analyzed the provenance and technology of 94 ceramic fragments selected from substantial assemblages found at three sites: the city of Mytilene on the island of Lesbos, off the coast of western Asia Minor; Athens in mainland Greece; and Ostia, the harbor city of ancient Rome located at the mouth of the Tiber on the Tyrrhenian Sea (Table 1). We discuss the three sampled assemblages from east to west.

76. Chen, Wen, and Wang 2020, pp. 5–7, figs. 3, 4.

77. Wang et al. 2019, pp. 1–2, 5.

78. Wang et al. 2019, p. 2. One may wonder whether this was due to the toxicity of the lead.

79. On the strategic location of the Euphrates valley and its role in the development of commercial contacts with the East, see Valtz 2002, p. 335; see also, more generally, Benjamin 2018. The cultural contacts between the Han Dynasty of China and western Asia were recently highlighted in an exhibition at the University of Hong Kong of early glass vessels that display technological and stylistic influences from countries along the Silk Road ("Blown and Tooled: Western Asian Influences in Ancient Glass in China," September 2022–February 2023).

80. Henderson, An, and Ma 2018, p. 93.

TABLE 1. SAMPLED SHERDS AND PETROGRAPHIC FABRICS, BY SITE

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
SANCTUARY OF DEMETER, MYTILENE								
MYT02	MYT87IP1134.25394	1st century BCE–Augustan	skyphos	wheelmade with appliqué decoration	spray of pomegranate in buff clay	bottle green (ext.), ocher yellow (int.)	local	1A
MYT04	MYT87IP538.24839	1st century BCE–Augustan	small kalathos	wheelmade with appliqué decoration	irregular "comma" pattern in buff clay	bottle green (ext. and int.)	local	1A
MYT07	MYT87IP1103.25393	1st century BCE–Augustan	skyphos	wheelmade with appliqué decoration	ivy leaves and fruit in buff clay	bottle green (ext. and int.)	local	1B
MYT11	MYT87IP514.24836	1st century BCE–Augustan	open drinking vessel	moldmade	spray of pomegranate in buff clay	ocher yellow (ext. and int.)	local	1A
MYT12	MYT87IP537.24833	1st century BCE–Augustan	open drinking vessel	moldmade	frieze of olive alternating with triangles in buff clay	ocher yellow (ext. and int.)	local	1A
MYT15	MYT89IP479.23591	1st century BCE–Augustan	open drinking vessel	moldmade?	ivy leaves and fruit in buff clay	ocher yellow (ext. and int.)	local	1A
MYT21	MYT90IP498B	1st century BCE–Augustan	globular jug?	wheelmade with appliqué decoration	frieze of dots and drops in buff clay	ocher yellow (ext. and int.)	local	1A
MYT22	MYT90IP604	1st century BCE–Augustan	small semiclosed vessel	wheelmade with appliqué decoration	frieze of dots and drops in buff clay	ocher yellow (ext.), unglazed (int.)	local	1A
MYT25	MYT89IP257	1st century BCE–Augustan	skyphos	moldmade	pillar or column in buff clay, horizontal groove on floor	dark ocher yellow (ext. and int.)	local	1A
MYT31	MYT90IP319	1st century BCE–Augustan	footed cup	wheelmade	ribbed decoration (fluted)	orange yellow (ext. and int.)	local	1A
MYT32	MYT_Uninventoried	1st century BCE–Augustan	cup	wheelmade	ribbed decoration (fluted)	orange yellow (ext. and int.)	local	1A
MYT33	MYT87IP830.25191	1st century BCE–Augustan	chalice or kalathos	wheelmade	no decoration preserved	ocher yellow (ext. and int.)	local	1A
MYT34	MYT90IP635	1st century BCE–Augustan	chalice or kalathos	wheelmade	no decoration preserved	ocher green (ext.), ocher yellow (int.)	local	1A
MYT35	MYT87IP542.24826	1st century BCE–Augustan	skyphos with ring handles	moldmade?	handle plate with plain upper surface and two spirals	ocher yellow (ext. and int.)	local	1A
MYT38	MYT89IP149.23440	1st century BCE–Augustan	skyphos	wheelmade (base)	no decoration preserved	ocher yellow (ext. and int.)	local	1A

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
MYT39	MYT90IP296	1st century BCE–Augustan	inkwell?	wheelmade	no decoration preserved	dark ocher yellow (all surfaces)	local	1A
MYT40	MYT89IP537B.43626	1st century BCE–Augustan	kantharos	wheelmade (foot), moldmade (body)	no decoration preserved on foot; figural decoration on body	ocher yellow (ext. and int.)	local	1A
MYT41	MYT87IP527.24893	1st century BCE–Augustan	kantharos or chalice	wheelmade (foot)	grooves and rouletted patterns	ocher green (ext. and int.)	local	1A
MYT43	MYT90IP638	1st century BCE–Augustan	chalice	wheelmade (foot)	light grooves and rouletted patterns	ocher yellow (ext. and int.)	local	1A
MYT44	MYT90IP297	1st century BCE–Augustan	chalice	wheelmade (foot)	grooves	ocher green (ext. and int.)	local	1A
MYT46	MYT87P581.24866	1st century BCE–Augustan	kantharos	wheelmade (foot)	grooves	ocher green (ext. and int.)	local	1A
MYT48	MYT87IP541.24876	1st century BCE–Augustan	large cup	moldmade	relief band with rouletted or stamped patterns	ocher green (ext. and int.)	local	1A
MYT49	MYT89IP2390	1st century BCE–Augustan	semiclosed vessel (small jug?)	moldmade	grooves	ocher yellow (ext. and int.)	local	1A
MYT52	MYT90IP648	1st century BCE–Augustan	open drinking vessel	moldmade	pillar or column, swags of drapery	ocher green (ext. and int.)	local	1A
MYT53	MYT87IP552.24865	1st century BCE–Augustan	skyphos	moldmade?	groove (poorly preserved)	ocher yellow (ext. and int.)	local	1A
MYT61	MYT90IP497D	1st century BCE–Augustan	jug?	moldmade	row of triangular petals alternating with oak leaves; groove	ocher yellow (ext. and int.)	local	1A
MYT62	MYT90IP497B	1st century BCE–Augustan	jug?	moldmade	row of triangular petals alternating with leaves in buff clay; groove	ocher yellow (ext. and int.)	local	1A
MYT63	MYT90IP497H	1st century BCE–Augustan	jug?	moldmade	two rows of triangular petals alternating with oak leaves, separated by groove	ocher green (ext. and int.)	local	1A
MYT64	MYT90IP497A	1st century BCE–Augustan	jug?	moldmade	two rows of triangular petals alternating with oak leaves, separated by groove	ocher yellow (ext. and int.)	local	1A

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
MYT65	MYT90IP641	1st century BCE–Augustan	open vessel with applied basket handle	wheelmade	groove under rim	ocher yellow (ext. and int.)	local	1B
MYT66	MYT90IP499A_C	1st century BCE–Augustan	globular vessel	moldmade with appliqué decoration	spirals and medallion with central drop pattern in buff clay	ocher green (ext. and int.)	local	1A
MYT73	MYT87IP776.24698	1st century BCE–Augustan	skyphos with ring handles	moldmade with applied handle	band with rouletted or stamped patterns under rim; handle plate with ridged decoration, longitudinal groove, and two spirals	ocher yellow (ext. and int.)	local	1C
MYT84	MYT87IP534.24837	1st century BCE–Augustan	small drinking vessel	wheelmade?	line of dots under rim and vegetal/leaf pattern in buff clay	dark ocher yellow (ext. and int.)	local	1A
AGORA, ATHENS								
AS2359	P 20819 (865)	ca. 25–50 CE	skyphos	moldmade	hobnail pattern on body	ocher yellow (ext. and int.)	Tarsos?	5
AS2360	P 19819 (872)	1st century CE	cup or small skyphos, high inward-sloping rim with chamfered lip	moldmade	slender vertical petals with rows of dots between	bottle green (ext.), ocher green (int.)	Tarsos?	5
AS2361	P 25941 (868)	Early Roman	skyphos	wheelmade	tree; part of a stool(?) in buff clay	ocher green (ext.), ocher yellow (int.)	Mytilene?	1A
AS2362	P 22111 (877)	first half to mid-2nd century CE, with residual material	kantharos	moldmade with wheel-turned rim	irregular “comma” pattern like windblown grass	bottle green (ext.), ocher yellow (int.)	Perge?; rim comparable to Italian sigillata	4
AS2364	P 17209a (862)	first half of 1st century CE	skyphos with band handles	moldmade	slightly overlapping rows of olive leaves with dots above and below the tips	bottle green (ext. and int.)	–	6
AS2365	P 32171 (900)	second quarter to mid-1st century CE	open vessel (kalathos?) with conical body, vertical rim with flange, low foot ring	wheelmade	lip marked off by groove	ocher green (ext.), bottle green (int.)	–	5

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
AS2366	P 25561 (897)	end of 2nd century CE	large closed vessel	wheelmade	no decoration preserved	bottle green (ext.), unglazed (int.)	Italy? Asia Minor? Mesopotamia?	8
AS2367	P 14824 (870)	ca. 50–70 CE, but containing pottery as late as 4th century CE	kalathos or modiolus with everted horizontal rim and vertical handle with two longitudinal grooves	moldmade with wheel-turned rim	tendrils of ivy with leaves and fruit	bottle green (ext.), ocher green (int.)	Perge?	7
AS2369	P 19666a (880)	Classical with Early Roman disturbance	cup or bowl with torus foot, chamfered on bottom, and concave inner surface	moldmade	no decoration preserved	ocher green (ext. and int.)	–	7
AS2370	P 4488 (875)	1st to early 2nd century CE	footed cup with vertical offset concave rim, short wide neck, rounded shoulder	wheelmade	no decoration preserved	bottle green (ext. and int.)	–	8
AS2371	P 9844 (878)	ca. 80–100 CE	kantharos or goblet	moldmade	lanceolate leaves arranged in six-petal rosettes	green (ext. and int.), iridescent	rim comparable to Italian sigillata	4
AS2373	P 18303 (895)	1st or 2nd century CE?	bowl or jug	wheelmade	shallow horizontal ribbing; vertical drop-shaped motifs in buff clay	green (ext.), golden yellow (int.), iridescent	Italy?	2
AS2374	P 9089 (866)	early 1st century to 50 CE	skyphos	moldmade	band of ovolos with traces of rosettes	bottle green (ext.), ocher green (int.)	–	6
AS2375	P 2453 (854)	ca. 25–50 CE	skyphos with ring handles	wheelmade	band of raised dots and spray of pomegranate in buff clay on body; handle plate with volutes and appliqué leaf at base of ring	ocher green (ext.), ocher yellow (int.)	Mytilene	1A
AS2376	P 6995 (899)	late 1st century BCE to ca. 70–100 CE	small keel-rimmed bowl	wheelmade	no decoration preserved	bottle green (ext. and int.)	–	5

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
AS2377	P 6821 (856)	Early Roman	skyphos with ring handles	moldmade	ribbon knotted at top and small leaf decoration on body; handle with longitudinal groove and appliqué leaf at base	ocher green (ext.), ocher yellow (int.)	–	6
AS2378	P 32191 (898)	second half of 2nd century CE, or slightly later	large closed vessel with stump of handle or tripod foot	wheelmade	no decoration preserved	bottle green (ext.), ocher green (int.)	Mesopotamia? Cilicia?	5
AS2379	P 20020 (873)	Early Roman	cup	wheelmade	vertical petals with rows of dots between	olive brown (ext. and int.)	–	6
AS2380	P 6900 (858)	late 1st century CE, with much early 1st-century material	skyphos with ring handles	moldmade	vegetal motif(?) in buff clay on body; appliqué leaf at base of handle	bottle green (ext.), ocher yellow (int.)	Mytilene	1A
AS2381	P 14517 (887)	Late Roman (residual)	saucepan (trulla) with flat horizontal handle	moldmade?	longitudinal ridge on top?	ocher yellow (ext. and int.)	–	7
AS2569	P 9927 (882)	2nd century CE	kantharos or stemmed cup?	moldmade	three horizontal ridges below rim; rows of ovolos alternating with inverted lanceolate leaves on body	blue green (ext.), olive brown (int.)	stylistic affinities with Smyrna group	8
AS2570	P 9068 (860)	Early Roman	skyphos with ring handles	moldmade	three bands of pine-cone ovolo on body; appliqué leaf at base of handle	glaze decayed	stylistic affinities with Tarsos group	5
AS2571	P 18358 (885)	mid-1st century CE or later	situla	moldmade	band of ovolo below shoulder; drips of glaze on lip from inverted firing position	blue green (ext.), olive brown (int.)	–	6
AS2572	P 14870 (874)	Late Roman (residual)	footed cup	moldmade	band of egg-and-dart, the eggs decorated with a leaf pattern	blue green (ext.), olive (int.)	stylistic affinities with Tarsos group	6
AS2573	P 5745a (863)	mixed 1st and 3rd centuries CE	skyphos with band handles	moldmade	swag of drapery hanging from knot	yellowish green (ext.), olive (int.)	–	6

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
AS2574	P 12360 (884)	3rd century CE (probably residual)	situla (deformed, highly vitrified fabric)	moldmade	band of ovolo and rosette	glaze almost totally destroyed	–	5
AS2575	P 17744 (890)	no context	kantharos	moldmade	lanceolate leaves flanked by pine cones in at least three rows	green (ext.), green (int.)	Asia Minor?	5
TEMPIO DEI FABRI NAVALES, OSTIA								
OST01	92 FN 12 78	surface find	shallow cup with torus foot	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST02	93 FN 08 01	mixed	large bowl with rounded rim	wheelmade	no decoration preserved	green (ext.), golden yellow (int.)	local or regional	2
OST03	93 FN 10 61	end of 2nd century CE	pitcher with ring foot, square in section	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST04	93 FN 24 12	end of 2nd century CE	shallow cup with torus foot, chamfered on bottom	wheelmade	no decoration preserved	bluish green (ext. and int.), iridescent	local or regional	2
OST05	94 FN 10 142	mixed	goblet or skyphos	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	3
OST06	95 FN 15 48	end of 2nd century CE	wide-mouthed globular cup	wheelmade	pine-cone shells in buff clay	green (ext.), golden yellow (int.)	local or regional	2
OST07	94 FN 15 50	end of 2nd century CE	olla	wheelmade	drips of glaze on lip from inverted firing position	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST08	94 FN 15 51	end of 2nd century CE	olla	wheelmade	drips of glaze on lip from inverted firing position	bluish green (ext.), golden yellow (int.), iridescent	local or regional	3
OST09	94 FN 15 103	end of 2nd century CE	pitcher	moldmade?	applied vertical twisted handle with fluted grooves	bluish green, iridescent	local or regional	2
OST10	94 FN 16 72	surface find	pitcher(?) with ring foot, square in section	wheelmade?	horizontal groove on lower body	bluish green (ext. and int.), iridescent	local or regional	2

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
OST11	94 FN 16 74	surface find	olla	wheelmade	no decoration preserved	greenish ocher (ext. and int.), iridescent	local or regional	2
OST12	94 FN 16 99	surface find	bell-shaped cup with flat base	wheelmade	no decoration preserved	green (ext. and int., including underside of base)	local or regional	2
OST13	94 FN 16 291	surface find	kalathos?	wheelmade	figural decoration (Herakles?)	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST14	93 FN 22 01	mixed	large bowl with rounded lip	moldmade	rows of pine cones on lower body	bluish green (ext.), very altered	local or regional	2
OST15	94 FN 25 82	end of 2nd century CE	shallow cup with torus foot	wheelmade	no decoration preserved	bluish green (ext. and int.), iridescent	local or regional	2
OST16	94 FN 25 83	end of 2nd century CE	krater or chalice	wheelmade	no decoration preserved	bluish green (ext.), very altered	local or regional	3
OST17	94 FN 25 98	end of 2nd century CE	cup or kylix with internal ridge	wheelmade	groove under rim	bluish green (ext. and int.), iridescent	local or regional	3
OST18	94 FN 26 50	mixed	large bowl with rounded lip	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST19	94 FN 26 51	mixed	kalathos	wheelmade	appliqué handles with figural decoration; drips of glaze on handle surface from inverted firing position	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST20	94 FN 26 52	mixed	handleless cup with conical ring foot	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST21	94 FN 26 54	mixed	handleless cup with conical ring foot	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST22	94 FN 32 07	mixed	krater or chalice	wheelmade	no decoration preserved	bottle green (ext.), golden yellow (int.), iridescent	local or regional	2

(continued on next page)

TABLE 1 *(continued)*

Sample	*Excavation Inv. No.*	*Context Date*	*Type*	*Technique*	*Decoration*	*Glaze Color*	*Presumed Provenance*	*Fabric*
OST23	94 FN 45 17	mixed	globular cup	wheelmade	pine-cone shell patterns in buff clay	green (ext.), golden yellow (int.)	local or regional	2
OST24	94 FN 145 18	end of 2nd century CE	pitcher with ridge under rim	wheelmade	no decoration preserved	greenish ocher (ext. and int.), iridescent	local or regional	2
OST25	95 FN 02 200	end of 2nd century CE	pitcher	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.)	local or regional	2
OST26	95 FN 04 11	end of 2nd century CE	large bowl with rounded lip	wheelmade	no decoration preserved	green (ext.), golden yellow (int.), iridescent	local or regional	2
OST27	95 FN 10 05	mixed	krater or chalice with flat rim, triangular in section	wheelmade	no decoration preserved	bluish green (ext.), iridescent	local or regional	3
OST28	96 FN 23 20	mixed	pitcher with ring foot, square in section	wheelmade?	horizontal groove on lower body	bluish green (ext. and int.), iridescent	local or regional	2
OST29	96 FN 16 65	construction of the fullery	krater or chalice	wheelmade	grooved decoration	bluish green (ext.), golden yellow (int.), iridescent	local or regional	3
OST30	97 FN 06 11	mixed	cup or kylix	moldmade?	grooves under rim; drips of glaze on lip from inverted firing position	bottle green (ext.), golden yellow (int.)	local or regional	2
OST31	97 FN 06 12	mixed	cup or kylix	moldmade	figural decoration	dark ocher yellow (ext. and int.)	local or regional	2
OST32	97 FN 06 13	mixed	plate with rounded lip	wheelmade	no decoration preserved	bluish green (ext.), golden yellow (int.), iridescent	local or regional	2
OST33	97 FN 34 65	end of 2nd century CE	pitcher	wheelmade?	horizontal grooves under rim	bluish green (ext. and int.), iridescent	local or regional	2
OST34	97 FN 34 66	end of 2nd century CE	pitcher with ring foot, square in section	wheelmade	no decoration preserved	bluish ocher (ext.), greenish ocher (int.), iridescent	local or regional	3

Note: Samples from Mytilene and Athens not selected for destructive archaeometric analysis have been omitted. Data on the presumed provenance of the Mytilene samples is based on previous research by Archontidou-Argyri (1997); data on the context, type, decoration, and presumed provenance of the Athens samples is from Hayes (*Agora* XXXII). Data on the context and presumed provenance of the Ostian samples is from the excavation report of the Belgian-Italian excavations in the area of the Tempio dei Fabri Navales at Ostia. Parenthetical numbers following the inventory numbers of Athenian samples are catalogue numbers in *Agora* XXXII. Abbreviations: ext. = exterior; int. = interior.

Mytilene

Approximately 100 fragmentary lead-glazed vessels have been found during excavations in the Sanctuary of Demeter on the acropolis of Mytilene.[81] Of these, 33 sherds were selected for petrographic analysis (Table 1). The sanctuary was in use from the Archaic period to the 1st or early 2nd century CE.[82] It was later included within the walls of the Byzantine Kastro. The exact chronology of the lead-glazed pottery is still a subject of debate; a full presentation of the stratigraphic context of its discovery will appear in a future publication.[83] According to the current state of archaeological research on this assemblage, as described below, a production date around the second half of the 1st century BCE is suggested for these vessels.

The sherds come from the so-called Roman dump, a thick stratum covering the area of the sanctuary, which contained many pottery fragments but was devoid of any architectural remains. This archaeological context may be divided into two chronological phases, the first dated to the late 1st century BCE–early 1st century CE, the second to the mid- to late 1st century CE, with possibly a few vessels of the early 2nd century CE.[84] The continued use of the area, however, which included the digging of garbage pits during the Ottoman period, makes it difficult to clearly distinguish the two separate Roman phases among the material from the dump. The excavators currently believe that there is a very large quantity of material from the late 1st century BCE to the early 1st century CE, with only a small amount of material from the mid- to late 1st century CE.[85] Moreover, on the basis of internal evidence within the assemblage itself, this context probably represents the last period of use of the Sanctuary of Demeter, and probably the last recorded level at the site before the medieval occupation.[86] It remains unclear whether the lead-glazed pottery was used in the sanctuary, or whether these sherds are earlier in date and were discarded here sometime after their final use.[87]

The lead-glazed pottery assemblage includes mostly fragile isolated sherds, together with one mold with acorn appliqué decoration, several nonjoining fragments of skyphoi and pitchers, one fragmentary pitcher, and a rather flat disk-shaped object that may be identified as an inkwell.[88] The types and shapes, the decorative repertoire and techniques, and the macroscopic fabric characteristics of this pottery exhibit a great homogeneity. Most fragments come from small drinking cups, either

81. The excavation was carried out between 1984 and 1992 by the CIG and the University of British Columbia, under the direction of Caroline Williams and Hector Williams.

82. For a detailed account of the archaeological remains at the sanctuary, see Cronkite 1997.

83. C. Williams, pers. comm. (May 2020).

84. C. Williams, pers. comm. (April 2023).

85. C. Williams, pers. comm. (April 2023).

86. Williams and Williams 1991, pp. 176–178; 2007, pp. 100–101; Williams 1998, p. 321.

87. There is a gap in the archaeological record between the Early Roman and Middle Byzantine periods (Williams and Williams 1991, p. 184). At the Sanctuary of Demeter, the following sequence of levels was established during excavation: at least two phases of an Ottoman settlement of the 17th–18th century (destroyed by earthquake); a rich Late Hellenistic–Early Roman level of apparently dumped fill; three Hellenistic levels; and a very modest Archaic–Classical level (Williams and Williams 1991, p. 176).

88. The main characteristics of the pottery assemblage are described in Williams and Williams 2007, pp. 104–105. The inkwell seems complete, as all surfaces are lead-glazed and there is no trace of break. An inkwell found at the Testaccio workshop in Rome has a similar base with wheel marks, although its profile is very different (Porcari et al. 2010, p. 308, figs. 18, 19). Similar inkwells have been found at the Athenian Agora and have been identified as imports from the region of Rome on stylistic grounds (*Agora* XXXII, p. 211, no. 896).

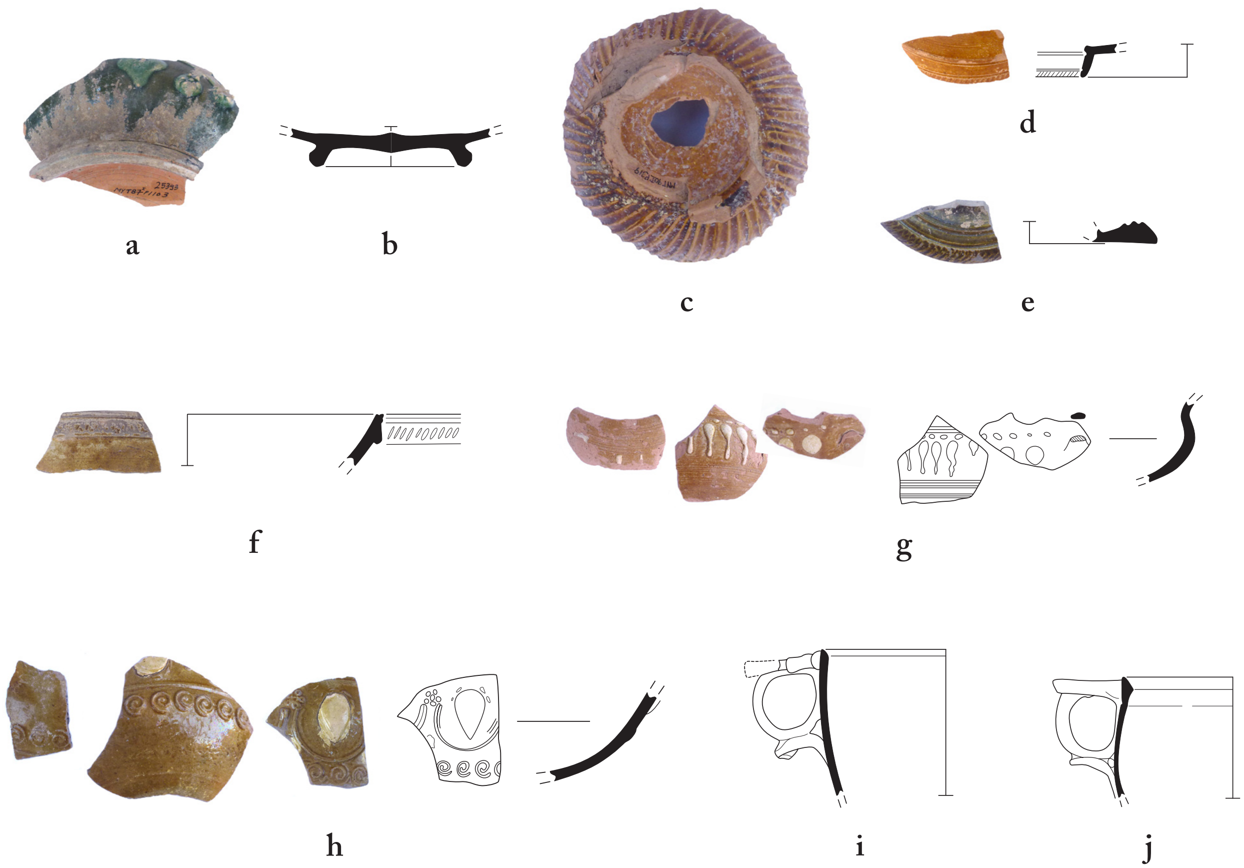


Figure 4. Pottery samples from Mytilene and Athens, identified by petrographic analysis as productions of Mytilene: (a) skyphos (MYT07); (b) skyphos (MYT38); (c) footed cup (MYT31); (d) chalice (MYT43); (e) kantharos or chalice (MYT41); (f) large cup (MYT48); (g) globular jug(?) (MYT21); (h) globular vessel (MYT66); (i) skyphos with ring handles (AS2375); (j) skyphos with ring handles (AS2380). Scale 1:3. Photos courtesy Ephorate of Antiquities of Lesbos

ring-based skyphoi and globular cups (Fig. 4:a–c) or footed chalices (Fig. 4:d, e), with or without applied handles.[89] Some stamped dish bases are also represented.[90]

Rouletting is attested on the rim or around the foot or ring base of several vessels (Fig. 4:e, f). The exterior surfaces are decorated with figural or floral patterns, either freehand on wheel-thrown vessels (Fig. 4:g) or molded on moldmade vessels (Fig. 4:h). These decorative patterns are most often executed in a buff clay that contrasts with the pink color of the vessel surface. Molded patterns in the pink fabric of the vessel body are also sparsely attested, however, sometimes in combination with the use of molded or freehand relief decoration (Fig. 4:h). Two fragments of globular footed cups (Fig. 4:c), covered with an orange-yellow glaze, have fluted designs on the lower part of the body that recall 4th-century BCE Gnathian ware from Apulia.[91] Some black-glazed hemispherical moldmade bowls, which occur in small numbers in the Roman dump, also display the same fluted motif.[92]

The vessels from this assemblage share many stylistic similarities with the lead-glazed pottery from the ancient city of Mytilene published by Aglaïa Archontidou-Argyri, who considered it probably local.[93] As

89. Williams and Williams 2007, p. 104.

90. C. Williams, pers. comm. (March 2023).

91. See, e.g., Miše 2013, pp. 106–107, fig. 4 ("Alexandrian group") and pp. 108–110, figs. 5, 6 ("Late Canosan group").

92. F. Liard, pers. obs. (October 2021).

93. Archontidou-Argyri 1997.

Hochuli-Gysel noted, many drinking vessels have an undecorated band with a row of pendent ovolos under the rim.[94] Vegetal decoration on the body is rather stiff; it includes sprays of ivy leaves and flowers,[95] vine leaves and grapes, oak leaves and acorns, pomegranates, and what appear to be acanthus leaves. Figural scenes are common, including birds (cranes), four-legged animals, human face masks, and characters in an architectural setting; several fragments may display mythological figures.[96] Different types of skyphos handles were produced at Mytilene (Fig. 4:i, j), and it is unclear whether different handle types correspond to different vessels.[97]

The lead-glaze layer is dull and strikingly thin on some vessels. It displays shades of mustard yellow, orange yellow, and ocher yellow (on all surfaces), or bottle green (either on all surfaces or on the outer surface only, with a yellow-glazed inner surface).

The evidence supports the production of this lead-glazed pottery in the 1st century BCE. First, the stratigraphic association of these fragments with several types of fine Hellenistic pottery suggests an early date. Ephesos lamps, a characteristic lamp type of the 1st century BCE, were found in the same context, including a variant with basket handles that is not attested elsewhere and could be of local manufacture.[98] Several fragments of so-called portrait bowls have also been found. These red-glazed bowls were made on the wheel, but the portrait medallions were made in molds and then attached to the floor of the bowl before firing, when both were still in a leather-hard state. The medallions depict the same distinctive male figure in profile, following the Late Hellenistic tradition of realism.[99] These bowls have been dated to the final decades of the 1st century BCE and the first decades of the 1st century CE.[100]

Second, stylistic evidence points to an early chronology. The shapes and decoration of the lead-glazed vessels are similar to those of 1st-century BCE material from rescue excavations in the area of the northern harbor of Mytilene.[101] The combination of a standardized fabric and notably diverse decorative techniques (molding, appliqué, and freehand) may be symptomatic of the early experimental stages in the local production of this type of ware.[102]

Third, archaeological evidence suggests a flourishing moldmade ceramic and coroplastic industry at Mytilene around the time of the Roman conquest in the 1st century BCE. Tools and wasters associated with lead-glazed pottery have been discovered near the northern harbor, which is believed to have become the main commercial center of the city in the Hellenistic period; this workshop is thought to have been active in the early decades of the 1st century BCE.[103] Molds for making pottery and figurines have also been found in the Late Hellenistic levels under room C of the Roman peristyle

94. Hochuli-Gysel 2002, p. 311.

95. Similar patterns are documented at Perge (Atik 1995, pp. 28–30, 34–35, nos. 16, 21).

96. Williams and Williams 2007, p. 104.

97. A skyphos from Cyprus even combines two different types of handles; see Hochuli-Gysel 1976, pp. 230–231, no. 1, fig. 1, pl. XXXVII. A diversity in skyphos handle types is reported for the Anatolian mainland, notably at Perge (Atik 1995, p. 35, fig. 18) and at Tarsos (Hochuli-Gysel 1977, pls. 4–8).

98. Williams 1989, p. 167.

99. Williams 1998, pp. 321–322.

100. Williams 1998, p. 329.

101. Archonditou-Argyri 1997.

102. See Maccabruni 1987, pp. 168–169 (with references).

103. Archontidou-Argyri 1997; Williams and Williams 2007, p. 100. On the northern harbor as the main commercial and craft-production area of the city during the Hellenistic period, see Kourtzellis 2013, p. 13; Kourtzellis and Theotokis 2021.

building near the northern harbor.[104] The "portrait bowls" mentioned above, as well as "Mytilene sigillata" (or Mytilene "Red Gloss"), are also interpreted as local products made at the end of the 1st century BCE.[105]

Last but not least, the high level of homogeneity in the macroscopic fabric characteristics among the Late Hellenistic and Early Roman pottery from Mytilene (including the lead-glazed pottery) suggests a local industry;[106] these wares include terracotta figurines and unguentaria of the Hellenistic period,[107] the "portrait bowls" of the Late Hellenistic period,[108] and "Mytilene sigillata."[109] Such a level of homogeneity may be considered uncommon: at Tarsos, for instance, different clays were used for different types of moldmade wares, and petrographic analysis indicates the use of diverse types of clay for lead-glazed pottery.[110]

Athens

A set of 27 lead-glazed pottery samples from the Athenian Agora was selected from the lead-glazed pottery assemblage previously published by John Hayes (Table 1).[111] This selection includes serving vessels such as kantharoi and kalathoi, large plain vessels, and skyphoi and other types of cups. The provenances suggested by Hayes were based on typological and stylistic characteristics, but petrographic analysis sheds new light on these vessels and allows for the identification of imports as well as local and regional products. The shapes and decoration in each petrographic group are discussed below (pp. 473–477).

Ostia

A set of 34 lead-glazed pottery fragments was selected from an assemblage of ca. 80 sherds discovered at ancient Ostia, in the fill of a fullery that was in operation between the second half of the 1st and the first half of the

104. Williams and Williams 1988, p. 142; 1991, p. 183. Some of the material indicating ceramic production is from the end of the 1st century BCE or the first decades of the 1st century CE. Likewise, the material found with a crucible in the same area is dated to the Late Classical–Early Hellenistic period (Williams and Williams 1988, pp. 142–143).

105. For "Mytilene sigillata," see Williams 1998, p. 324. This ware is currently assigned to the 1st century BCE and has the same fabric as local Late Hellenistic figurines (Williams and Williams 2007, pp. 100–101).

106. Hand specimens of lead-glazed pottery and other types of fine ware at Mytilene all display the same type of pinkish (2.5YR 6/6–7/4) to gray (10R 6/1–2.5YR 6/1) fabric with creamy buff barbotine decoration (7.5YR 7/3). Only one lead-glazed pottery fragment is in a creamy buff fabric (MYT73). The pinkish-gray fabric is well fired and even overfired at the core, as indicated by the darker gray tinge and the presence of plentiful very fine pores. It is smooth to the touch, with a very fine silty texture; common fine golden mica silts are visible with the naked eye, as well as sparsely scattered chalky white particles and very rare dark brown silts. Fine wares during the Hellenistic and Roman periods at Mytilene seem to be usually high-fired; see Williams and Toli 1990. Williams and Williams (1988, p. 147) note that while this clay was suitable for small-sized molded figurines, it might have been too soft and friable for plates, bowls, and closed vessels.

107. Williams and Williams 1986, pp. 150 (unguentaria), 152 (figurines): "There is mounting evidence to suggest a local coroplastic workshop in Mytilene. Extrapolating from the numbers of terracottas found in our small trenches and those reported from as yet unpublished excavations in the town supports the likelihood and economic feasibility of such an industry even with Pergamon and Myrina relatively nearby. . . . Other evidence of local manufacture was the discovery of duplicate and triplicate figures from the same mould."

108. Williams 1998, p. 323.

109. Williams and Toli 1990, pp. 105–107. Both molds and pottery fragments have been found in this distinctive fabric.

110. Goldman 1950, p. 191; Tekkök et al. 2009; and see p. 447, above.

111. See p. 448, n. 48, above.

2nd century CE (Table 1). After the fullery was abandoned, the site was used for the temple of the *Fabri Navales,* constructed during the reign of Marcus Aurelius or Commodus.[112] Lead-glazed fragments constitute only a small portion of the mixed pottery found in the fill, and they may represent a fairly long period of production, possibly starting under Augustus or in the early years of the 1st century CE, and continuing into the late Antonine period.[113] The fragments exhibit a range of pale buff fabric colors, ranging from pinkish to creamy buff with sparse rounded dark sand grains, as well as fewer orange silts, chalky white dots, and very fine sparkly silts.

The lead-glazed pottery assemblage includes fine table ware as well as coarse vessels for the storage and preparation of food. The drinking vessels in fine fabrics are relatively varied in types and shapes, some of which show similarities with black-gloss pottery of the Republican and Augustan periods from the *Ager Portuensis,* while others resemble vessels *a pareti sottili* attributed to the Augustan period and the High Empire in the broader region of Rome.

Fragments of handleless footed cups, for instance, identified by their lower profile and glazed underside (Fig. 5:a), are typologically related to the black-gloss cups with folded and hemmed rims that were common in the *Ager Portuensis* during the 3rd century BCE, and to others with stamped palmette decoration dated to the same period.[114] Like the handleless cups from Ostia, both of these vessel types have a large, shallow tronconical body and a conical ring foot with a central cone on the underside.[115] Shallow cups with a torus foot, chamfered on the bottom and with a glazed underside, are reminiscent of black-gloss examples with stamped decoration from the *Ager Portuensis,* dated to the 2nd century BCE.[116] Likewise, rounded cups with grooved or figurative molded designs resemble black-gloss examples from the 3rd century BCE.[117]

Footless goblets with a narrow base and a piriform body (Fig. 5:b) share features with Aco goblets found in Rome (narrow footless base), with some Republican black-glazed skyphoi found at Ostia (piriform body), and with Etruscan tin-foiled situlae found north of Rome.[118] These goblets also have a glazed underside, like the footless bell-shaped cups (Fig. 5:c) that recall the similar examples *a pareti sottili* from the early Imperial period found on the Janiculum.[119] Globular, wide-mouthed cups with a short everted rim display a freehand decoration of pine-cone scale motifs that is likewise reminiscent of the cups *a pareti sottili* found in the fill of the

112. Tempio dei Fabri Navales (regio III, insula II, 1–2). On the archaeological context of the fullery, see De Ruyt and Van Haeperen 2018.

113. F. Liard, research in progress.

114. For cups with a hemmed rim, see Olcese and Capelli 2011, p. 129 (Morel 2538); Olcese 2018, pp. 103–104, fig. 3.19. For cups with stamped palmette decoration, see Olcese et al. 2010, pp. 10–11; Olcese and Coletti 2016, p. 288, no. 55, fig. 57.

115. E.g., Manzini in Olcese and Coletti 2016, pp. 166, 172, fig. 1:c (Morel 2621).

116. E.g., Olcese and Coletti 2016, p. 328, no. 201, fig. 1 (Morel P.121).

117. E.g., Olcese and Coletti 2016, p. 281, no. 40.6, fig. 41.

118. On the Augustan production of Aco goblets, see Desbat 1985; Lavizzari Pedrazzini 2000. Lead-glazed examples of Aco goblets have been found on the Janiculum in Rome (via Sacchi); see Filippi 2008b, p. 305, no. 42, fig. 6. For Ostian examples of black-glazed skyphoi (Morel 4373) dated to the late 4th and 3rd centuries BCE, see Olcese and Coletti 2016, pp. 315–316, no. 161. On Etruscan situlae with molded decoration and tin foil dated to the late 4th and 3rd centuries BCE, see Michetti 2003, p. 167, nos. 140, 143, 144, fig. 9.

119. See, e.g., Puppo 2008, pp. 118, 126, figs. 2.3, 2.13, 2.15.

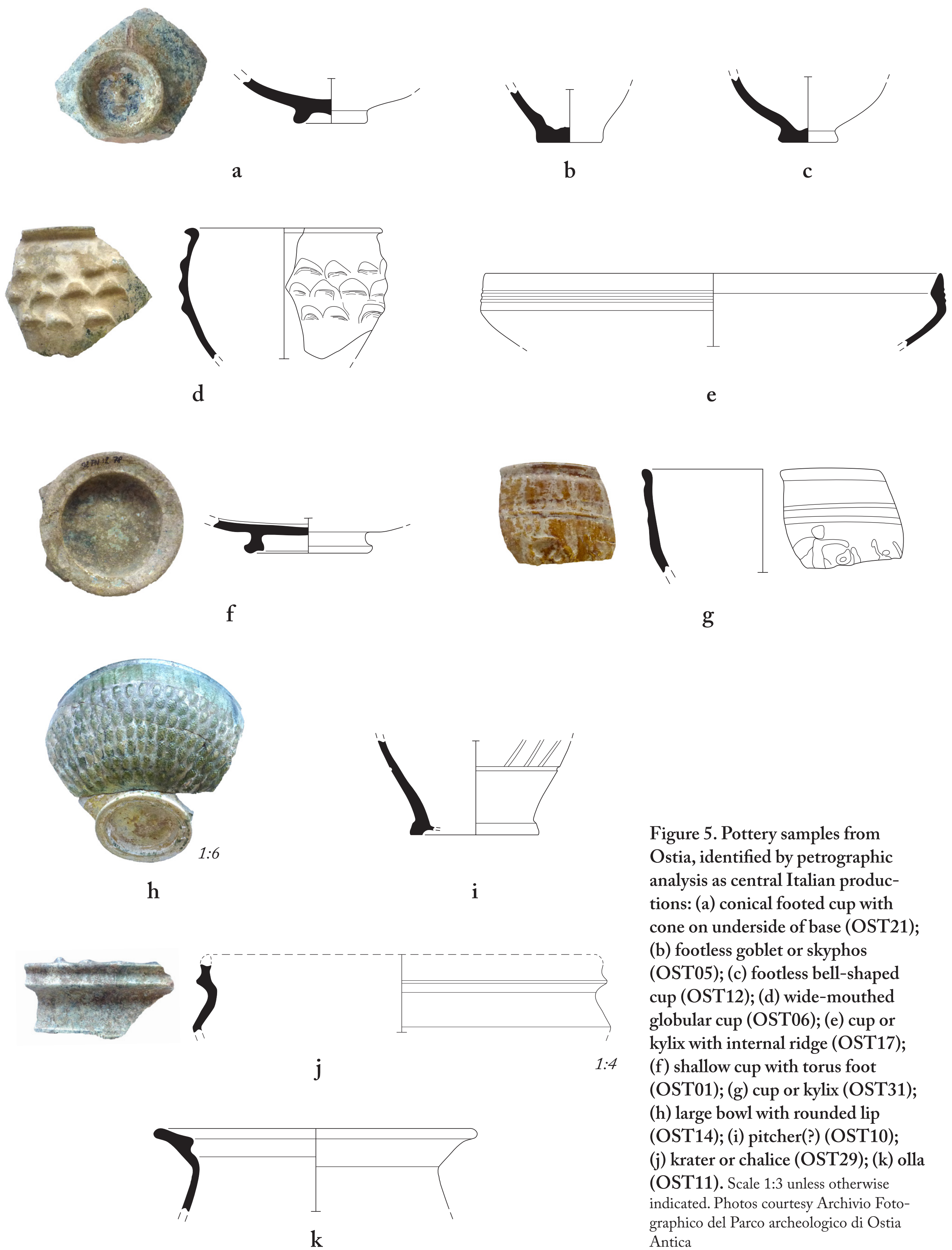


Figure 5. Pottery samples from Ostia, identified by petrographic analysis as central Italian productions: (a) conical footed cup with cone on underside of base (OST21); (b) footless goblet or skyphos (OST05); (c) footless bell-shaped cup (OST12); (d) wide-mouthed globular cup (OST06); (e) cup or kylix with internal ridge (OST17); (f) shallow cup with torus foot (OST01); (g) cup or kylix (OST31); (h) large bowl with rounded lip (OST14); (i) pitcher(?) (OST10); (j) krater or chalice (OST29); (k) olla (OST11). Scale 1:3 unless otherwise indicated. Photos courtesy Archivio Fotografico del Parco archeologico di Ostia Antica

fullery at Ostia (Fig. 5:d).[120] This decoration is also attested among other types of lead-glazed vessels in Rome.[121] Cups or kylikes with a vertical rim and internal ridge (Fig. 5:e, f) provide further points of comparison with the finds from via Sacchi on the Janiculum, in stratigraphic contexts assigned to 125–180/190 CE.[122]

Some kylikes, cups, and bowls stand out for their molded decoration with figural and vegetal patterns, which recall the stylistic tradition of Asia Minor in the 1st century BCE and early 1st century CE. However, the execution of this decoration is less careful than that of the eastern prototypes, and most often the patterns appear in the same clay as the pottery fabric (Fig. 5:g).[123] Likewise, some large bowls with a rounded lip are decorated with rows of pine-cone scales and/or olive sprays in a static rendering (Fig. 5:h).[124] Only the lead-glazed pottery from the Testaccio area in Rome displays molded decoration in a buff clay that suggests a closer link to the traditions of Asia Minor.[125]

Lead-glazed utilitarian vessels do not have molded decoration, but rather appliqué designs; others are devoid of any relief decoration. These diverse medium-sized and large containers reproduce a range of functions and shapes that occur in other types of ware and are characteristic of domestic assemblages for the service, storage, and preparation of food in the area of Rome during the Imperial period. Similar lead-glazed specimens have been found on the Janiculum[126] as well as elsewhere in Rome,[127] and at the Terme del Nuotatore in Ostia.[128]

Pitchers, large bowls, and ollae, as well as kraters, basins, and large chalices are the most common types of coarse lead-glazed wares in the assemblage from the fullery at Ostia. They most often lack relief decoration on the body and rims, but they have twisted and pinched handles that clearly recall glassware and metalware.[129] Pitchers display spiral fluted decoration with grooves (Fig. 5:i).

Some ceramic containers for the preparation of food are also coated with a lead glaze at Ostia. They include large kraters with two thumb rests attached to the rim, and medium-sized vessels with tooled rims that can

120. C. De Ruyt, pers. comm. (January 2020).

121. E.g., bell-shaped vessels identified as oinochoai found on the Janiculum (Filippi 2008b, p. 305, no. 38, fig. 6). Bell-shaped cups or chalices dated from the 2nd century to the end of the 4th century CE are reported in other areas of Rome as well (Coletti 2012, p. 183, no. 2, fig. 1, with references).

122. For finely decorated cups, see Filippi 2008b, pp. 298–302, fig. 3. For cup bases with torus foot, see Filippi 2008b, pp. 302, 305, nos. 13, 40, figs. 2, 6.

123. There are a few exceptions nonetheless, such as sample OST23.

124. The pine-cone decoration observed on the large bowl OST14, and more generally on lead-glazed vessels found in central Italy, remotely recalls that of drinking vessels found in the eastern Mediterranean. Comparable specimens include a skyphos in the Limassol Museum in Cyprus, found during excavations at Episkopi (Hochuli-Gysel 1976, pp. 235–236, no. 11, fig. 3, pl. XXXVIII), another skyphos found at Perge (Atik 1995, pp. 31–34, no. 19; for a deconstructed version of this pattern, see pp. 54–55, no. 70), and a skyphos (AS2570) and a kantharos (AS2575) from the Athenian Agora, discussed below (p. 473).

125. Filippi 2008b, pp. 298–302, fig. 3 (esp. the skyphoi); Porcari et al. 2010, pp. 306–307, figs. 10–17.

126. Filippi 2008b, pp. 304–306, figs. 5, 6 (from stratigraphic contexts dated to 125–180/190 CE).

127. Meneghini and Staffa 1992; Marucci 2006, pp. 67–68, table 4.

128. Martin 1992, pp. 324–325, figs. 1–9. These vessels were found, together with pottery in terra sigillata, in two different strata of leveling works dated to the reigns of Hadrian and Marcus Aurelius.

129. Lead-glazed jugs with twisted handles are reported from, e.g., the Capitou workshop in Hérault (2nd century CE), as well as from Arles and the Gulf of Fos (Gohier 2018b, p. 204). A jug from Arles with molded spiral grooves on the body (Gohier 2018b, p. 205, fig. 2.14) is assigned to the mid-3rd century CE.

be identified as large chalices or possibly basins of the Augustan period (Fig. 5:j).[130]

Fragments of ollae, semiclosed vessels with a large mouth, a flattened rim leaning inward with an internal ridge for a lid, an ovoid body, and two pinched strap handles, are also relatively common (Fig. 5:k). Aside from the lead-glazed type, the shape occurs in other types of ware at Ostia, in Rome, and elsewhere in central Italy from the Early Imperial until the late Antonine period.[131]

Finally, several coarse vessels found at Ostia display drips or a thicker layer of glaze on the lip. This indicates that the pottery was placed in the kiln in an inverted position, like at Perge, where large vessels stilts were found, and a reconstruction of their use has been proposed by Nese Atik.[132] It remains uncertain whether a decorative effect was sought or not.

NEW EVIDENCE FROM OUR DATASETS

In the following sections we discuss first the provenance and then the glazing technology of the pottery samples described above. Some observations regarding the elemental composition of the pottery fabrics will also be offered; this data is intended solely to help distinguish between different glazing techniques and traditions, without drawing conclusions about clay selection practices and provenance.

Locating Workshops and Characterizing Their Production

Petrographic analysis has allowed us to confirm the importance of workshops operating in the area of Rome during the High Empire, and to identify at least three other production centers of lead-glazed pottery in the Aegean region: Mytilene, Attica, and the Corinthia, the last two of which were previously unknown or ill-defined. Our description begins with the previously known centers (Mytilene, central Italy) and continues with those newly identified on the basis of our archaeometric results (Attica, the Corinthia). The main characteristics of the fabrics are presented in Table 2 and illustrated in Figure 6, while the detailed petrographic data and provenance ascriptions of the sherds are discussed in the Appendix.[133]

Mytilenean Workshops

Our sampling strategy at Mytilene followed the identification of a local workshop output by Archontidou-Argyri based on stylistic and typological observations.[134] As explained above (pp. 461–464), we sampled lead-glazed table-ware fragments from the Sanctuary of Demeter, with particular attention to drinking vessels, and to a lesser extent serving vessels. Petrographic analysis confirmed that the bulk of the samples are of the same, probably local fabric (fabric 1A, 1B), which is noncalcareous and highly micaceous (phyllitic), although some variations in the relative proportions of the diverse constituents are visible (Table 2; Fig. 6:a). One sample displays traces of a mix with a related buff clay that was also used for the relief decoration of several vessels (fabric 1C; see the Appendix). The pottery in fabric 1 displays stylistic similarities with the second and third groups of the so-called

130. Lead-glazed footed chalices with similar tooled rims are documented by Hochuli-Gysel (1977, pp. 37–38, fig. 16) and attributed by style to Asia Minor workshops. Some basins in other wares found at Ostia also display a tooled rim, although their profile is different from our sample (see Olcese 2003, pl. XXXVII:1, dated to the Augustan or Claudian period). It should be noted that OST29 is the only sample of our assemblage that comes from the construction level of the fullery (see Table 1).

131. For a detailed review of this shape, see Olcese 2003, p. 92, olla type 1, pl. XXII (with references).

132. Atik 1995, pp. 22–28, figs. 11–14.

133. The petrographic analysis of the ceramic samples, and their comparison with published thin-sections of geological and archaeological materials and other data, was performed by Liard at the Fitch Laboratory of the British School at Athens. Munsell color codes are not provided, as we noticed a substantial variation of clay color within each petrographic group.

134. Archontidou-Argyri 1997.

TABLE 2. PETROGRAPHIC CHARACTERISTICS OF THE FABRICS IN THE SAMPLE SET

Fabric	*Matrix (XPL)*	*C:f:v (10 μm)*	*Inclusion Size and Shape*	*Porosity*	*Inclusions (Dominant)*	*Inclusions (Accessory)*	*TCFs*
MYTILENE							
1A, 1B	silvery gray to yellow (1A), some with streaks of reddish brown (1B); locally overfired; moderate to low OA; highly micaceous, with white micas (+++)	10:80:10	most inclusions <0.1 mm, sometimes up to 0.2 mm; coarser specimens 0.20–0.30 mm; sr	vughy fabric, with medium elongate voids	white micas forming the groundmass (+++), quartz (++), white mica phyllite and shale (+)	white mica quartzite (--), arenite siltstone (--), feldspar (--), depleted serpentinite (--), greenschist (---), micaceous mudstone (---)	no clay pellets
1C	ocher yellow; very weak OA; pure clay texture	15:80:05	<0.05 mm	relatively vughy fabric, mostly medium elongate voids	white micas (+)	quartz (--), depleted serpentinite (--)	no clay pellets
CENTRAL ITALY							
2	dark greenish ocher; no OA; pure clay texture with coarse silts scattered throughout: quartz/feldspar (++), white mica muscovite (--)	25:65:10	0.08–0.014 mm; 0.20–1.5 mm; sr to r	compacted, with few medium to large voids	quartz/feldspar silts (+++), detritic products of granitic rock: alkali feldspars, plagioclase, biotite (+++), basalt (++)	rhyolithic lava (-), microgabbro (--), depleted microfossils (---), metasiltstones (---), metamorphic quartz (---)	dark red clay pellets (--), secondary calcite infillings (-)
3	dark greenish ocher; no OA; silty texture with quartz/feldspar (++), rubified biotite (+), white mica (-)	05:85:10	0.08–0.10 mm; 0.20–0.30 mm (sparse); sa to a	compacted, with few medium to large voids	quartz and alkali feldspar silts (++), rubified biotite (+), hematite dots (+)	fresh biotite laths (-), gneiss (--), acid igneous rock (---), depleted microfossils (---)	dark red TCFs (--), secondary calcite infillings (+++)
UNKNOWN PROVENANCE							
4	reddish orange to brown; weak OA; silty texture, with quartz, feldspars, white micas (++)	20:70:10	0.04–0.08 mm; 0.10–0.30 mm	few voids, mostly medium and large	quartz silts (++), white mica silts (++), feldspars (+), colored and white mica metasandstone (+), white mica shales (+)	schist (--), pyroxene (--), basaltic rock (--)	micrite pellets (-), red TCFs (---)

(continued on next page)

TABLE 2 *(continued)*

Fabric	*Matrix (XPL)*	*C:f:v (10 µm)*	*Inclusion Size and Shape*	*Porosity*	*Inclusions (Dominant)*	*Inclusions (Accessory)*	*TCFs*
ATTICA							
5	greenish ocher; silty to coarse silty texture, with few quartz and feldspar silts (+), white mica (-), oxidized biotite (-), muscovite (---)	25:65:10	>0.10 mm; 0.10–0.80 mm; sa	relatively vughy, with small to large voids	quartz and feldspar silts (++), quartz (++), white mica schist (++), silvery shale (+), quartzite (+)	gneiss (-), muscovite shale (--), muscovite, quartzic meta-siltstones (---), depleted limestone (---)	red TCFs (---), red clay pellets (---), secondary calcite infillings of voids in some samples
6	reddish orange to brown ocher to brownish red; OA very weak to absent; coarse silty texture with quartz (++), feldspar (+), chlorite (++), oxidized biotite (+), muscovite (-)	25:65:10	<0.10 mm; 0.20–1.00 mm; sr to sa	relatively vughy, with large voids	quartz (++), white mica schist (++), meta-arenite with biotite and white micas (+), white and colored mica schist (+), chlorite (++), quartzite (+), phyllite (+)	white-mica shale (-), muscovite (--), gneiss (---), colored mica shale (---), serpentinite (---), chert (---)	reddish-brown TCFs from silt to sand sizes (+), locally grading into semiplastic red mudstones (--), micritic pellets (---)
THE CORINTHIA							
7	reddish brown to ocher yellow; OA absent; silty texture with quartz/feldspar (++), chlorite (+), white mica (-)	18:70:12	0.08–0.10 mm; 0.20–1.20 mm; sa to sr	relatively vughy, with medium voids	meta-arenite (++), quartz (++), chert and radiolarite (+), litharenite sandstone (+), graywacke (+)	calcimudstone (-), white and colored mica quartzite (-), plagioclase (depletion products from igneous rocks) (--), colored mica shale (--), quartzite (--), schist (---)	micrite pellets (+), dark red TCFs (--)
8	ocher green; OA absent; very fine silty texture, with white mica, oxidized biotite, quartz/feldspar (-)	20:70:10	0.02–0.06 mm; 0.10–0.25 mm; sa to r	few voids, mostly medium	quartz (++), feldspar (++), arenite siltstone grading into chert (+), chalcedony (+)	radiolarian chert (-), low-metamorphic rock (--), biotite flakes (--)	red clay pellets (--), calcimudstone (-), secondary calcite infillings throughout

Note: The ratio of occurrence of rock inclusions and clay-rich concentrations is reported as dominant material (+) or accessory material (-) using the following abbreviations: 15%–30% (+++), 8%–15% (++), 5%–8% (+), 5%–3% (-), 3%–1% (--), less than 1% (---). Other abbreviations: a = angular; sa = subangular; r = rounded; sr = subrounded; OA = optical activity; TCF = textural concentration feature; XPL = cross-polarized light.

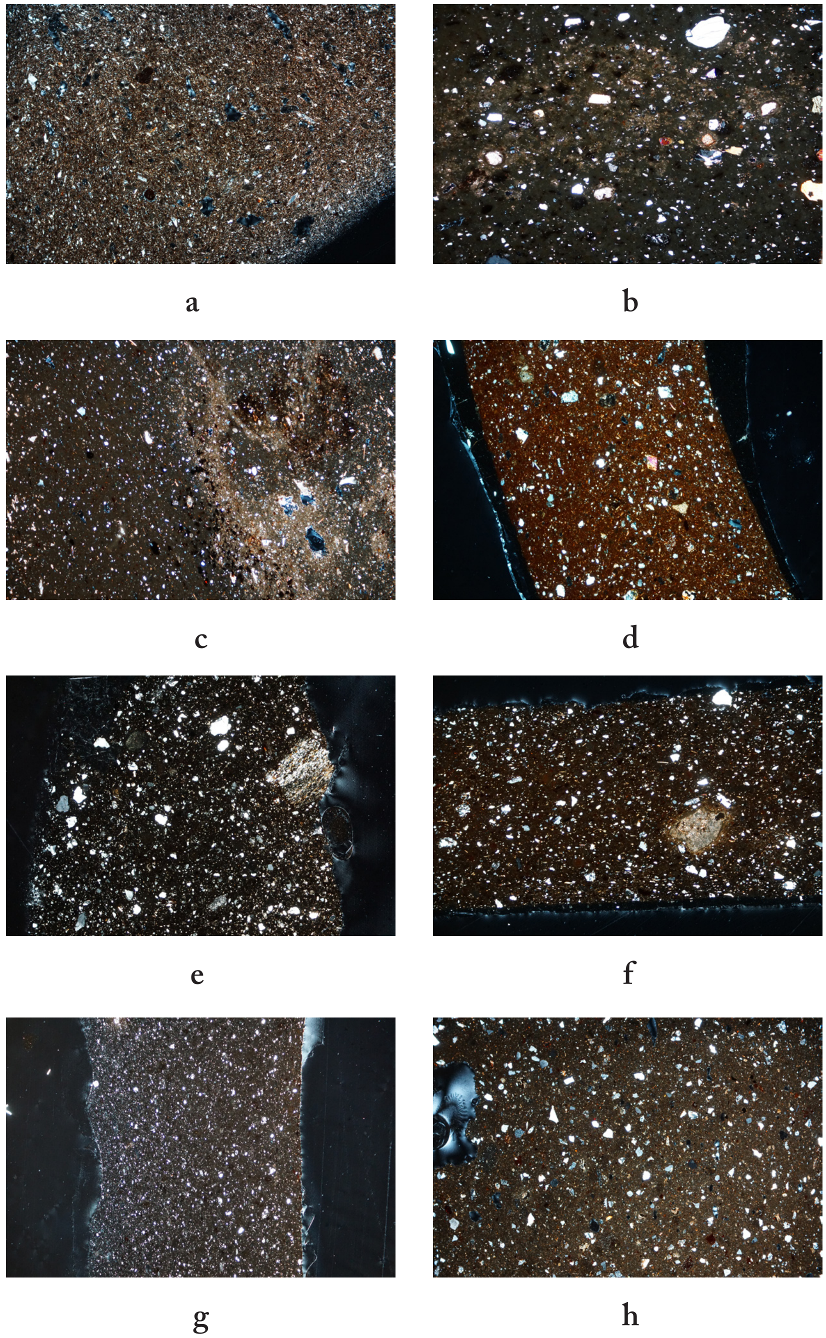


Figure 6. Petrographic photographs of the pottery fabrics identified in this study: (a) fabric 1A (MYT41); (b) fabric 2 (OST25); (c) fabric 3 (OST29); (d) fabric 4 (AS2371); (e) fabric 5 (AS2574); (f) fabric 6 (AS2573); (g) fabric 7 (AS2369); (h) fabric 8 (AS2366). All examined under cross-polarized light (XPL) with a field of view of 4.4 mm. Photos F. Liard

Smyrna workshop and with the early production of the southwestern Asia Minor workshops as defined by Hochuli-Gysel.[135]

Several skyphoi from the Athenian Agora identified by Hayes as possible imports from Mytilene or western Asia Minor are in a pinkish to gray, micaceous, and seemingly overfired fabric with relief decoration executed in creamy buff clay. Petrographic analysis confirmed that three of these vessels are in fabric 1 (AS2361, AS2375, AS2380; Fig. 4:i, j).[136]

Our analysis of the Mytilene assemblage gives a picture of a specialized production of lead-glazed table ware with a high level of standardization in raw material procurement, pottery types, shapes, and decorative repertoire. This ware was exported to other regions of the Aegean under

135. Archontidou-Argyri 1997; Hochuli-Gysel 2002, p. 305.

136. A fourth sample (AS2360), however, identified by Hayes as a possible Tarsos product, has been identified petrographically as an Attic product; see below.

Roman control, notably Athens, but probably other commercial hubs as well.[137]

Central Italian Workshops

The pottery samples from Ostia are split between two mineralogically related fabrics, both likely to be of local or regional provenance. These fabrics are well documented in the literature (see the Appendix). Our current interpretation is that these two fabrics are connected with the Pliocene clayey formations that crop out in different regions of upper Latium into Umbria and southern Tuscany, and on the Tyrrhenian coast near Tarquinia and Cerveteri.

The bulk of the Ostia samples are in fabric 2, a dark greenish to ocher fabric under crossed polars with sparse coarse sandy magmatic and basaltic fragments and derivative minerals (Table 2; Fig. 6:b). This fabric is clearly connected with Roman lead-glazed utilitarian pottery from the Julio-Claudian, Flavian, and Antonine periods found at Ostia,[138] as well as on the Janiculum and at Monte Testaccio in Rome.[139]

Fabric 3 mainly differs from fabric 2 in the occurrence of granitic fragments and few microfossils. It matches the geology found over a large area stretching from Tuscany to Campania. A few samples from Ostia are in fabric 3 (Table 2; Fig. 6:c), mostly from vessels designed for the storage, preparation, and consumption of liquids, such as chalices, kraters, kylikes, and goblets (OST05, OST08, OST16, OST17, OST27, OST29). These vessel types may be the earliest in date among the Ostian sample set; they do occur in fabric 2, but are more common in fabric 3. This observation may help to distinguish between two successive stages of development in the central Italian lead-glazed ware industry, which obviously partly overlapped, given that some pottery types occur in both fabrics. In this regard, the exact provenance of fabrics 2 and 3 in upper Latium or neighboring areas would be particularly interesting to identify in future research.

Hayes identified one wheelmade bowl or jug from the Athenian Agora (AS2373) as a possible import from Italy, and he noted stylistic affinities between two kantharoi (AS2362, AS2371) and northern Italian vessels with similar rims.[140] However, petrographic analysis indicates that only the first of these vessels displays characteristics of the Ostian pottery (fabric 2).

Unknown Provenance

The other two samples mentioned above (AS2362, AS2371, both from kantharoi or related shapes) display a micaceous fabric with metamorphic and basaltic rock inclusions, although they have been diversely attributed stylistically (preliminarily identified as fabric 4 on the basis of these two samples; see Table 2; Fig. 6:d). Hayes suggested Perge as a possible origin for AS2362, on the basis of the "comma" decoration suggesting windblown grass, executed in a buff clay (Fig. 7), but he also noted parallels between the rims of both vessels and those in some northern Italian products. Sample AS2371 displays a very high, plain vertical rim comparable to that found in some Italian sigillata vessels; it is decorated with a network of lanceolate leaves arranged in six-petal rosettes.[141] Despite some obvious mineralogical resemblance between these two samples, petrographic evidence is so far too

137. At least three fragments found at ancient Corinth (C-1962-178, C-1962-179, C-1965-108) may also be imports from Mytilene: they display the same decorative techniques and patterns, as well as the same glaze and fabric colors (F. Liard, pers. obs., July 2019).

138. Martin 1992, pp. 324, 326.

139. Giardino and Trosji 2008, pp. 318–319; Gohier, Cappelli, and Cabella 2016, pp. 590–591.

140. *Agora* XXXII, pp. 209, 211, nos. 877, 878, 895. For one of the kantharoi (no. 878 = sample AS2371), Hayes compared the similarly shaped rim of an Italian sigillata chalice of the mid-1st century CE (*Agora* XXXII, p. 191, no. 705; cf. also p. 190, no. 698), with decoration that borrows patterns from the Annii of Arezzo.

141. For sigillata chalice rims of the mid-1st century CE, see *Agora* XXXII, pp. 190–191, nos. 698, 705.

Figure 7. Pottery sample from Athens, for which a provenance has not been identified petrographically: kantharos (AS2362). Scale 1:2. Courtesy Ephorate of Antiquities of the City of Athens; Agora Excavations

few to propose a reliable provenance to the one and the other of these two items of pottery. Therefore, as mentioned in the Appendix, this "fabric 4" will not be further discussed in the frame of this article, but awaits further definition through future sampling instead.

Attic Workshops

Despite the widely shared assumption that mainland Greece did not produce any lead-glazed pottery in antiquity, several samples from the Athenian Agora were convincingly identified as Attic products.

The pottery samples that we propose to identify as Attic occur in two mineralogically related low-calcareous and micaceous fabrics. Both display white (and fewer colored) micas, as well as inclusions of white mica schists and mica-rich quartzite. These minerals and rocks are common components of ancient pottery in fine to coarse fabrics produced in Attica.[142] It is interesting that one of the samples (situla AS2574, in fabric 5; Fig. 8:a) displays clear evidence of warping, suggesting a probable kiln waster.

Finely decorated moldmade drinking vessels as well as undecorated wheelmade vessels of various sizes are in fabric 5, a fine dark green fabric with rounded inclusions of white mica/quartz-rich schist (Table 2; Fig. 6:e). Plain vessels include a type of open bowl or jar with a conical body and vertical rim (AS2365, AS2376).[143] The larger of these two fragments, possibly from a kalathos, has a vertical concave rim with one groove parallel to the lip on the outer surface (AS2365; Fig. 8:b). Fine decorated vessels in the same fabric display stylistic affinities with products associated in previous studies with Asia Minor. For instance, Hayes suggested a possible origin in Mesopotamia or Cilicia for a large coarse vessel (AS2378) based on macroscopic fabric characteristics,[144] and he identified a skyphos with a hobnail pattern (AS2359; Fig. 8:c) as a possible import from Tarsos on the basis of its style and fabric.[145] While such hobnail patterns are documented across Asia Minor,[146] they also occur among terracotta lamps at Corinth that are suspected to have been manufactured by Athenian potters in the 1st and 2nd centuries CE.[147] Another skyphos with an appliqué leaf-shaped handle support and bands of pine-cone ovolos (AS2570; Fig. 8:d) and a kantharos with lanceolate leaf and pine-cone rows (AS2575) appear in this fabric. For these two vessels, Hayes highlighted stylistic affinities with decorative traditions from Asia Minor.[148]

A very fine version of fabric 5, exhibiting a tighter network of fine inclusions (quartz, white mica), is represented by a skyphos with long-petal

142. Farnsworth 1964, p. 223; 1970, p. 10; see also *Agora* XXXIII, pp. 16–28; Pentedeka, Georgakopoulou, and Kiriatzi 2012, pp. 125–128, 164. As discussed in the Appendix, these minerals and rocks occur in a series of Attic utilitarian coarse wares from antiquity and later periods.

143. *Agora* XXXII, p. 212, nos. 899, 900, fig. 28.

144. *Agora* XXXII, pp. 211–212, no. 898. This fragment is in a pale buff clay, soft and powdery, with barely any visible inclusions to the naked eye, except from some rare dark grits (10YR 8/3–8/4).

145. *Agora* XXXII, p. 208, no. 865 (see also pp. 208, 211, nos. 872, 892).

146. For this type of decoration on lead-glazed pottery at Perge, probably from the Augustan period, see Atik 1995, pp. 51–52, no. 58. The same motif is found on Late Hellenistic Megarian bowls at Tarsos, Priene, Antioch, and Pergamon; see Goldman 1950, p. 223, nos. 144, 158 (with references).

147. *Corinth* IV.2, pp. 70–73, 166–167, pl. VII (Broneer's type XX). On the production of this type of lamp by Athenian potters, see Thompson 1933, p. 204; *Agora* VII, pp. 15–16, pl. 14 ("Alpha Globule Lamps").

148. *Agora* XXXII, pp. 207, 210, nos. 860, 890.

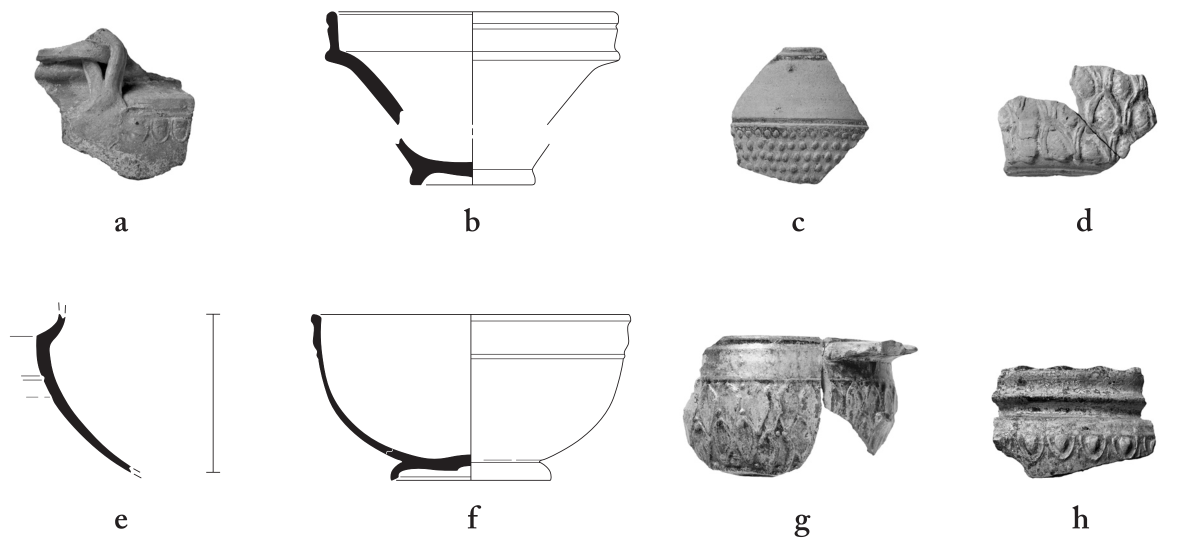


Figure 8. Pottery samples from Athens, identified by petrographic analysis as local productions: (a) situla (AS2574); (b) open vessel (kalathos?) (AS2365); (c) skyphos (AS2359); (d) skyphos with ring handles (AS2570); (e) cup or small skyphos (AS2360); (f) cup (AS2379); (g) skyphos with band handles (AS2364); (h) situla (AS2571). Scale 1:3. Photos courtesy Ephorate of Antiquities of the City of Athens; Agora Excavations

decoration and rows of dots between, a style that is reminiscent of Late Hellenistic bowls from Attica (AS2360; Figs. 3:b, 8:e).[149]

Another petrographically related fabric, fabric 6, displays a brown groundmass and coarse inclusions of white mica schist and other low-metamorphic rocks with both white and colored mica subgrains, as well as few colored slates (Table 2; Fig. 6:f). This fabric is represented by several moldmade drinking vessels, among which are skyphoi with different handle types and relief decoration. One cup has long-petal patterns (AS2379; Fig. 8:f), and a skyphos has rows of slightly overlapping olive leaves (AS2364; Fig. 8:g).[150] Other drinking vessels display pendent ovolo and leaf patterns (AS2374, AS2571, AS2572; Fig. 8:h) and drapery with knotted ribbons (AS2377, AS2573).[151] One (AS2374) has decoration similar to a skyphos with ring handles found at Perge and dated to the second half of the 1st century CE.[152] A footed cup (AS2572) displays affinities with drinking vessels from the Tarsos group defined by Hochuli-Gysel.[153]

Our sample set includes a diversity of pottery types, decorative styles, and glaze colors, and the petrographic characteristics of the fabrics point to the use of several clay sources, which could indicate a diversity of workshops operating in or around the urban center of Athens. One recurrent characteristic, however, is the thickness of the glaze toward the vessel rim. This indicates that the pottery was placed upside down in the kiln, like the central Italian vessels described above (p. 468).

While several stylistic affinities have been highlighted between Attic productions in fabrics 5 and 6 and finds from Asia Minor, two decorative patterns represented in our sample set deserve particular attention: long-petal decoration and rows of overlapping olive leaves. Two vessels

149. *Agora* XXXII, p. 208, no. 872.

150. *Agora* XXXII, pp. 207, 209, nos. 873, 862, respectively.

151. *Agora* XXXII, pp. 207–210, nos. 866, 885, 874, 856, 863, respectively.

152. Atik 1995, pp. 31–34, no. 19; see also pp. 54–55, no. 70.

153. Hochuli-Gysel 1977, pp. 166–167, nos. T 183, T 189, cited by Hayes (*Agora* XXXII, p. 209, no. 874).

mentioned above (AS2360, AS2379) replicate the long-petal decoration of black-glazed Megarian bowls commonly found in Athens and identified as local on stylistic and petrographic grounds.[154] These lead-glazed cups or small skyphoi carefully reproduce the long rounded petals as well as the lines of jeweling in between.[155] The close stylistic resemblances between black-glazed and lead-glazed specimens provides a hint that lead-glazing started in Attica before the local type of Late Hellenistic black-glazed long-petal bowl went out of use. The black-glazed prototypes are well represented in Athens through the late 2nd and early 1st centuries BCE.[156] They are still found in numbers among destruction debris from Sulla's attack in 86 BCE, but may have vanished soon after, and probably did not survive the end of the 1st century BCE in Athens.[157] However, Susan Rotroff suggests that Late Hellenistic molds may have been preserved and that a sporadic use was made of them in Early Roman times.[158] Hayes acknowledges that the chronology of the two lead-glazed specimens of long-petal bowls found in the Athenian Agora remains challenging: the context in which these vessels were discovered indicates an early Roman Imperial date, most probably within the 1st century CE, but the vessels are probably earlier than the bulk of the inventoried lead-glazed pottery found in the Agora Excavations.[159]

A third skyphos (AS2364) displays patterns of overlapping rows of olive leaves decorated with dots above and below the leaf tips.[160] This lead-glazed example can be compared to black-glazed "imbricate bowls" with decoration consisting of overlapping leaves or petals, which were produced in great quantities in Athens from the last quarter of the 3rd century BCE to the early 1st century CE.[161] Rotroff identified the same medallion on black-glazed imbricate bowls from the 1st century BCE and on black-glazed long-petal bowls of the workshop of Apollodoros from the same period.[162] Both types are considered Athenian productions of the Late Hellenistic period. Our results indicate that both styles were continued for lead-glazed pottery in the Late Hellenistic or Early Roman period, until the end of the 1st century CE.

Possible Corinthian Production

Six samples from the Athenian Agora—three large table vessels, two table wares, and a saucepan handle—display petrographic characteristics that are compatible with the geology of the broader region of Corinth. These samples are also similar to other pottery fabrics identified as Corinthian, although a full match has not been found. Therefore, the remarks that follow should

154. The petrographic characteristics of these vessels are currently being studied by Liard.

155. Several molds with similar long-petal decoration and jeweling have been found in the Athenian Agora; see, e.g., *Agora* XXII, p. 86, pl. 64, nos. 353, 355–357.

156. On the Attic production of such bowls after the mid-2nd century BCE, see *Agora* XXII, pp. 35–37. In a more recent reassessment of the archaeological evidence, Rotroff (2006, pp. 366–367, table 2) identified the occurrence of the earliest fragments of such bowls in deposits dated to the transition between the 3rd and the 2nd century.

157. *Agora* XXII, pp. 17, 36; Vogeikoff-Brogan 2000, pp. 304, 306, nos. 27–33, fig. 10.

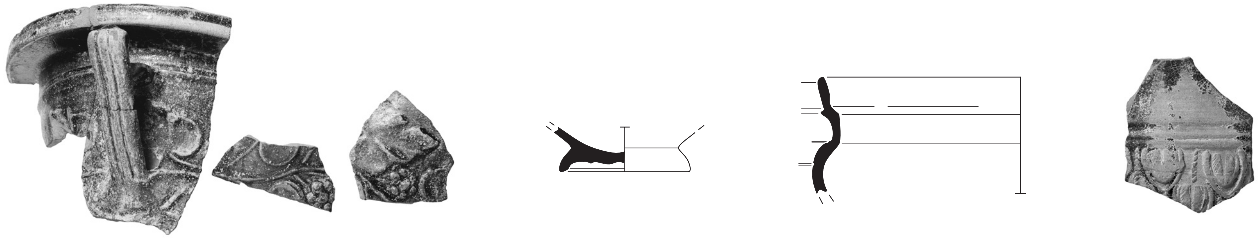
158. *Agora* XXII, p. 36.

159. *Agora* XXXII, pp. 8–9, 57–58, 208–209, nos. 872, 873; see also *Agora* XXII, p. 93, no. 409, dated by context to the 1st century CE.

160. *Agora* XXXII, p. 207, no. 862.

161. *Agora* XXII, pp. 16–17. A mold with a similar overlapping leaf pattern was found on the Pnyx (PNP 298: Edwards 1956, p. 100, no. 61, pl. 44), along with fragments of other Hellenistic molds and bowls.

162. *Agora* XXII, p. 17 (comparing p. 48, no. 35, with p. 85, no. 340).



a b c d

Figure 9. Pottery samples from Athens, identified by petrographic analysis as Corinthian products: (a) kalathos or modiolus (AS2367); (b) cup or bowl with torus foot (AS2369); (c) footed cup (AS2370); (d) kantharos or stemmed cup (AS2569). Scale 1:3. Photos courtesy Ephorate of Antiquities of the City of Athens; Agora Excavations

be understood as preliminary suggestions that may need reassessment in light of future investigations.

The handle of a saucepan or trulla (AS2381) is in a reddish-brown to ocher-orange fabric with poorly sorted inclusions of quartz, quartzic, and litharenite sandstones and fewer (radiolarite) chert inclusions (fabric 7; Table 2; Fig. 6:g). Some low-metamorphic rocks composed of white mica and quartz subgrains occur erratically within the group, and are common in one kalathos or modiolus (AS2367; Fig. 9:a). This vessel has a vertical handle with two longitudinal grooves on the spine and a pinched top, and decoration on the body of ivy tendrils with leaves and fruit. Hayes identified it as a possible Perge product on the basis of this decoration, although the running ivy pattern also recalls the West Slope decoration on other fine Hellenistic drinking vessels found at Corinth.[163] A more elaborate version of the same type of decoration is found on a lead-glazed modiolus from Kenchreai.[164] The abnormal treatment of the handle of AS2367 similarly recalls glass vessels at Corinth.[165] A cup or bowl with a torus foot, chamfered on the bottom, has also been assigned to fabric 7 (AS2369; Fig. 9:b); it recalls the Ostian productions of the Early Imperial period mentioned above.[166]

Two wheelmade vessels—a large, closed vessel, unglazed on the interior (AS2366), and a footed cup (AS2370; Fig. 9:c)—and one moldmade vessel—a kantharos or stemmed cup with a band of ovolo (AS2569; Fig. 9:d)—occur in a different fabric.[167] Fabric 8 displays honey-brown to ocher colors in crossed polars, and inclusions of quartz and chert, and fewer shales and mudstones (Table 2; Fig. 6:h).

As we discuss in the Appendix, the compositional characteristics of fabrics 7 and 8 match those of Corinthian pottery analyzed elsewhere.

163. *Agora* XXXII, p. 208, no. 870; *Corinth* VII.7, pp. 68 (n. 20), 84–86, 161–163, nos. 48–51, 54, 55, 60, 62, figs. 7–9, pls. 6, 7 (cyma kantharoi).

164. Robinson 1972. The decoration is described (p. 356) as "two large complexes of leaves, tendrils and fruit of the grape, ivy and olive. . . . The leaves, tendrils and fruit of the ivy and the leaves of the olive are executed *en barbotine;* the tendrils, leaves and fruit of the grape and the tendrils and fruit of the olive are applied."

165. Hayes (*Agora* XXXII, p. 208, no. 870) compares *Corinth* XII, pp. 102–104, n. 657. Following up on Hayes's observation, we noted similarities with other glass vessel fragments discovered at Corinth and assigned to the Late Republican or the Early Imperial period (e.g., MF-1985-117, a dilekythos jug handle from east of the Theater: *Corinth* XIX.1, p. 113, no. 372, fig. 16, pl. 19).

166. *Agora* XXXII, p. 209, no. 880.

167. *Agora* XXXII, pp. 209–211, nos. 897, 875, 882, respectively.

They may originate in different parts of the Corinthian region, indicating decentralized production of lead-glazed pottery at Corinth. The pottery samples in fabrics 7 and 8 also seem to differ in types and styles from those of the Athenian production.

It is notable that two types of serving vessel from the Roman colony at Corinth (the kalathos or modiolus and the footed cup) share several characteristics with the lead-glazed pottery from central Italy during the period of the High Empire: the fabrics are similar, and the footed cup AS2370 displays, like the Ostia specimens, a short wide neck with a vertical offset concave rim and horizontal grooves on the upper profile. Moreover, the relief decoration of the lead-glazed examples is most often executed in the same clay as the ceramic body.

Reconstructing the Lead-Glaze Technology

In order to explore the technological knowledge associated with the production of lead-glazed pottery in the Mediterranean, we analyzed microstructural and bulk chemical characteristics of the fabrics and glazes of 48 of the samples discussed above, using scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS).[168] The results are presented in Tables 3–5. Our goal was to identify the materials and recipes that were used for coating the ceramics, and to assess the level of homogeneity in these practices both regionally and over time.

Archaeological high-lead glazes are defined as containing more than 40 wt% lead oxide (PbO), as well as less than 3 wt% alkali, and an alumina (Al_2O_3) content typically in the range of 2–7 wt%.[169] All the analyzed glazes in our sample set, with one exception, display such composition patterns. Sample AS2376, an early type of glazed keel-rimmed bowl from the Athenian Agora that is tentatively ascribed to the late 1st century BCE or 1st century CE, is the only sample in our assemblage to display a glaze composition that is closer to the lead-alkali type; its glaze contains 31.5 wt% of lead and 4 wt% of alkali.[170]

168. These analyses were performed by Ben Amara and Liard at Archéosciences Bordeaux, Université Bordeaux Montaigne. The low vacuum SEM-EDS (JEOL, 6460LV) was typically run at 20 Pa and 20 kV on polished cross-sections of the glazed ceramics. EDS allows for a quantitative analysis of major (>1 wt%) and minor (0.1–1 wt%) elements. The calibration uses standards of the Oxford Instruments company as well as glass standards for the analysis of the glazes (Na: Corning B; Si, K, Pb: BCR-126A; Ca: Corning D). The bulk chemical composition of the fabrics and glazes was determined by scanning the electron beam on areas as large as possible, up to 0.3 × 0.3 mm, to ensure a composition representative of the glaze and to minimize alkali drift (ion migration) during the irradiation. At least six analyses were performed on the glazes and on the fabrics. We deliberately avoided feldspar particles in the glaze analyses, as those have a different composition that might affect the result.

169. Tite et al. 1998, p. 242; Tite 2009, p. 2069.

170. A lead-alkali glaze is characterized by a PbO content in the range of 13–35 wt% and a total alkali content in the range of 5–11 wt% (Tite 2009, p. 2069).

TABLE 3. MAIN ELEMENTAL COMPOSITION OF POTTERY FABRICS, BY PROVENANCE, NORMALIZED TO 100 WT%

Fabric	*Sample*	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*
MYTILENE									
1A	AS2361	0.54	2.32	26.36	56.25	5.15	1.59	1.06	6.73
	AS2375	0.74	2.10	24.02	59.32	4.71	1.70	0.99	6.41
	AS2380	0.77	2.13	24.91	56.82	5.04	2.43	0.94	6.95
	MYT04	0.63	1.11	24.20	60.26	4.09	4.15	0.89	4.67
	MYT11	0.69	2.27	24.40	58.04	5.04	1.54	1.05	6.97
	MYT15	0.68	2.09	24.20	57.53	4.71	2.68	0.96	7.15
	MYT21	0.63	1.44	25.28	57.31	5.13	3.57	0.91	5.74
	MYT25	0.89	1.44	27.49	56.36	4.62	0.69	1.00	7.50
	MYT31	0.70	2.13	25.38	56.37	4.91	2.42	0.98	7.11
	MYT34	0.82	2.50	23.55	57.95	4.78	2.17	1.03	7.20
	MYT35	0.70	2.31	24.77	58.30	4.97	1.39	0.98	6.58
	MYT41	0.61	1.75	24.89	59.01	5.00	1.54	1.06	6.14
	MYT43	0.65	2.04	25.31	58.41	5.00	1.45	0.99	6.15
	MYT48	0.71	1.94	25.34	58.35	4.89	2.13	0.84	5.81
	MYT52	0.74	2.11	24.84	57.82	5.04	2.22	0.91	6.33
	MYT66	0.74	2.50	25.61	56.67	5.08	1.36	0.99	7.06
1B	MYT07	0.42	1.44	21.32	66.48	3.20	1.75	0.87	4.51
CENTRAL ITALY									
2	AS2373	0.95	2.71	17.87	55.44	3.40	12.17	0.71	6.76
	OST01	0.85	2.83	16.47	53.91	2.88	16.41	0.63	6.01
	OST02	0.92	2.83	16.82	54.91	2.86	14.64	0.67	6.34
	OST11	1.50	3.13	17.05	56.82	2.19	11.95	0.75	6.61
	OST19	0.96	2.85	16.87	54.04	2.84	15.11	0.69	6.64
	OST20	0.97	3.07	17.46	55.40	2.82	13.14	0.69	6.44
	OST21	1.04	2.75	16.71	55.05	2.90	14.86	0.65	6.03
	OST23	1.42	2.72	17.18	57.33	2.50	12.17	0.66	6.03
	OST30	0.93	3.08	15.85	53.20	2.89	17.15	0.70	6.20
	OST31	0.92	2.91	16.54	56.04	3.00	13.78	0.67	6.14
	OST33	1.44	2.96	17.11	57.08	2.49	11.86	0.68	6.37
3	OST08	1.13	3.06	14.15	52.64	2.75	20.48	0.57	5.22
	OST16	0.93	3.84	14.22	49.85	2.68	22.59	0.58	5.32
	OST17	0.95	3.58	14.62	52.30	2.77	20.12	0.60	5.07
	OST29	0.88	4.62	14.97	55.64	2.52	15.46	0.61	5.30
UNKNOWN PROVENANCE									
4	AS2362	0.89	3.68	15.92	54.39	2.82	15.10	0.64	6.56
	AS2371	0.98	4.29	17.31	60.41	3.20	6.26	0.73	6.81
ATTICA									
5	AS2359	1.20	4.71	16.44	55.75	1.77	12.78	0.67	6.69
	AS2360	1.03	4.28	16.69	59.07	3.16	8.36	0.67	6.75

(continued on next page)

TABLE 3 *(continued)*

Fabric	*Sample*	Na_2O	*MgO*	Al_2O_3	SiO_2	K_2O	*CaO*	TiO_2	Fe_2O_3
5	AS2365	0.93	3.21	17.12	55.30	1.51	14.36	0.70	6.87
	AS2376	0.92	4.82	16.77	51.66	2.16	15.88	0.68	7.11
	AS2378	0.69	5.01	13.88	54.67	1.42	15.52	0.81	7.98
6	AS2364	0.63	4.88	18.12	54.27	2.70	11.22	0.67	7.51
	AS2374	1.01	3.36	16.51	56.57	2.42	12.98	0.72	6.42
	AS2377	0.78	3.24	15.04	61.91	2.75	9.11	0.70	6.47
	AS2379	0.77	2.87	16.62	59.29	2.43	9.66	0.90	7.46
THE CORINTHIA									
7	AS2367	0.83	3.12	16.94	55.95	2.25	12.84	0.88	7.19
	AS2369	0.75	1.93	16.25	62.95	2.10	7.66	0.79	7.57
	AS2381	1.01	3.90	16.52	57.66	2.81	10.16	0.72	7.22
8	AS2366	1.60	2.41	15.32	59.45	3.10	12.26	0.63	5.24
	AS2370	0.74	2.13	15.91	61.81	2.44	10.20	0.65	6.11

Note: Values expressed in wt%, after subtraction of traces of lead oxide found in some samples.

Among the high-lead glazes, the alkali and alumina concentrations show different patterns (Table 4; Fig. 10). Six glazes originating from Mytilene and attributed to the late 1st century BCE or Augustan period, and one glaze from Attica that may be contemporary display alkali contents higher than ca. 3.5 wt%, up to ca. 7.5 wt%.[171] Most of the other samples display less than 2 wt% of alkali. The glazes from Mytilene also display a substantial alumina content, with Al_2O_3 concentrations between 5 and 12.5 wt%, and most samples containing more than 8 wt% alumina. By comparison, the other samples display alumina contents lower than 6.9 wt% (and mainly lower than 5.5 wt%, down to 1.1 wt%) (Table 4). Therefore, the Mytilene glazes have a particularly high concentration in clay constituents.

These results pertain to the composition of the finished glazed ceramic product and do not necessarily reflect the different ingredients selected for the glaze recipe, because the glaze is formed by the interaction between the glaze slurry and the underlying ceramic body during firing. For instance, when a lead oxide compound is used as the sole ingredient, the lead diffuses into the ceramic body during firing, reacting with it to form the glaze, and thereby changing the final composition of the glazed pottery surface. By contrast, when lead oxide is mixed with silica, these two ingredients react together during firing to form the glaze, into which there is some subsequent diffusion of the fabric components such as alumina, alkali, calcium, iron, and magnesium.[172]

Our aim was thus to distinguish between the use of a lead oxide (usually in a powder form, in suspension in water) and the use of a lead oxide and silica mixture (typically a quartz-rich sand or crushed quartz), and to detect the addition of clay as a binding material. To do so, using a formula developed by Derek Hurst and Ian Freestone, we subtracted the lead content from the glaze composition and renormalized the results to 100% (Table 5).[173]

This treatment of the data indicated that both lead-glaze recipes are represented among our sample set. The silica data of most of the samples

171. For Mytilene, see samples AS2361, AS2375, MYT04, MYT07, MYT34, MYT41; for Attica, see AS2376.

172. Tite et al. 1998, pp. 249–250.

173. Hurst and Freestone 1996.

TABLE 4. MAIN ELEMENTAL COMPOSITION OF CERAMIC GLAZES, BY PROVENANCE, NORMALIZED TO 100 WT% (WITH MAIN ALKALI CONTENT SPECIFIED IN LAST COLUMN)

Fabric	*Sample*	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*	*CuO*	*PbO*	*$Na_2O + K_2O$*
MYTILENE												
1A	AS2361	5.66	0.57	9.35	34.51	1.80	2.92	0.24	1.74	1.71	41.49	7.46
	AS2375	4.63	0.90	7.46	31.83	1.21	2.64	0.19	1.44	1.14	48.56	5.84
	AS2380	0.31	1.11	11.22	24.07	1.00	2.46	0.45	3.02	n.d.	56.36	1.31
	MYT04	4.49	0.57	5.80	35.95	1.75	4.28	0.19	1.03	1.56	44.39	6.23
	MYT11	0.23	1.16	10.08	23.12	0.97	2.32	0.42	2.92	n.d.	58.77	1.21
	MYT15	0.44	0.93	11.32	27.10	1.39	2.51	0.37	2.60	n.d.	53.34	1.83
	MYT21	0.24	0.75	10.65	23.48	1.16	2.57	0.39	2.52	n.d.	58.25	1.41
	MYT25	0.54	0.59	12.43	24.30	1.27	0.32	0.36	3.22	n.d.	56.97	1.81
	MYT31	0.36	0.95	9.41	20.85	1.13	2.66	0.32	2.38	n.d.	61.95	1.49
	MYT34	2.67	0.79	5.28	22.72	0.90	3.29	0.15	1.56	1.17	61.45	3.58
	MYT35	0.24	1.17	10.26	23.32	1.08	2.63	0.41	2.62	n.d.	58.24	1.31
	MYT41	1.89	0.81	7.68	30.57	1.55	2.59	0.28	1.95	n.d.	52.68	3.44
	MYT43	0.43	1.10	10.87	24.58	1.28	2.13	0.45	2.51	n.d.	56.65	1.71
	MYT48	0.39	1.03	10.48	24.58	1.27	2.94	0.36	2.33	n.d.	56.62	1.66
	MYT52	0.21	1.13	10.80	24.38	0.88	2.19	0.48	2.88	n.d.	57.01	1.08
	MYT66	0.23	0.99	8.34	26.18	0.96	1.62	0.31	2.55	n.d.	58.82	1.19
1B	MYT07	4.80	0.69	6.27	36.39	1.44	3.31	0.11	1.13	1.77	44.10	6.23
CENTRAL ITALY												
2	AS2373	0.52	1.08	6.90	38.19	1.33	5.03	0.19	2.36	0.81	43.60	1.85
	OST01	0.43	0.86	3.87	25.65	0.96	4.70	n.d.	1.26	1.57	60.62	1.39
	OST02	0.48	0.73	4.30	33.81	1.01	4.05	n.d.	1.31	0.85	53.45	1.48
	OST11	0.52	0.95	4.22	37.74	1.12	4.53	n.d.	1.90	1.01	47.99	1.65
	OST19	0.21	0.60	2.70	32.03	0.61	2.92	n.d.	1.23	1.85	57.86	0.82
	OST20	0.35	0.67	3.68	29.14	0.69	3.54	n.d.	1.11	1.88	58.94	1.04
	OST21	0.20	0.58	4.71	30.59	0.62	3.17	n.d.	1.23	2.14	56.76	0.82
	OST23	0.40	0.62	3.11	32.41	0.60	3.33	n.d.	1.76	1.49	56.23	1.00
	OST30	0.53	0.76	5.51	32.36	0.97	4.05	n.d.	1.53	1.46	52.85	1.50
	OST31	0.26	0.65	3.33	28.49	0.48	3.18	n.d.	2.96	n.d.	60.58	0.74
	OST33	0.58	0.43	2.15	30.09	0.82	2.91	n.d.	0.97	1.67	60.34	1.40
3	OST08	n.d.	0.14	1.11	29.51	0.24	1.75	n.d.	0.80	0.79	65.61	0.24
	OST16	n.d.	0.33	1.62	25.62	0.32	2.23	n.d.	0.58	1.80	67.49	0.32
	OST17	0.16	0.42	1.51	29.43	0.38	2.69	n.d.	1.00	1.34	63.08	0.54
	OST29	0.04	0.28	1.25	29.70	0.28	2.36	n.d.	0.57	1.60	63.92	0.33
UNKNOWN PROVENANCE												
4	AS2362	0.51	0.68	2.73	30.39	0.94	2.71	n.d.	1.21	2.22	58.61	1.45
	AS2371	0.40	0.80	2.70	32.21	0.66	1.80	n.d.	1.23	1.62	58.58	1.06

(continued on next page)

TABLE 4 *(continued)*

Fabric	*Sample*	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*	*CuO*	*PbO*	*$Na_2O + K_2O$*
ATTICA												
5	AS2359	0.15	0.29	2.64	11.76	0.51	11.34	n.d.	1.37	0.64	71.30	0.66
	AS2360	0.41	0.47	1.37	31.67	0.49	1.45	n.d.	0.77	1.72	61.64	0.90
	AS2365	0.84	0.69	2.35	37.07	1.18	3.60	n.d.	1.14	1.72	51.39	2.02
	AS2376	1.35	1.21	5.00	49.83	2.66	4.65	0.22	2.27	1.30	31.52	4.00
	AS2378	1.19	0.74	5.23	38.64	1.58	3.69	n.d.	1.40	1.49	46.02	2.77
6	AS2364	0.32	0.93	3.65	34.48	0.96	2.66	n.d.	1.38	1.74	53.88	1.28
	AS2374	0.32	0.43	1.86	31.15	0.52	1.79	n.d.	0.84	1.24	61.85	0.84
	AS2377	0.54	0.60	3.24	34.15	0.76	1.73	n.d.	1.19	1.58	56.17	1.30
	AS2379	0.46	0.85	6.07	34.78	1.26	3.17	0.14	1.69	0.83	50.75	1.72
THE CORINTHIA												
7	AS2367	0.16	0.43	1.38	27.48	0.24	2.12	n.d.	1.05	2.85	64.30	0.40
	AS2369	0.36	0.59	5.15	38.46	1.12	2.37	0.12	1.69	1.32	48.82	1.48
	AS2381	0.18	0.63	6.37	39.83	0.54	2.15	0.17	4.94	2.12	43.07	0.72
8	AS2366	0.32	0.55	3.11	33.72	0.76	3.36	n.d.	0.84	1.83	55.45	1.09
	AS2370	n.d.	0.70	4.90	29.17	0.56	3.29	n.d.	1.52	1.30	58.55	0.56

Note: Values expressed in wt%. Values lower than 0.10 wt% are at the detection limit of the EDS and are reported as not detected (n.d.).

from Mytilene fall on (or close to) the unity line (Fig. 11), indicating that in these samples the glaze and the fabric contain the same amount of silica; therefore, sand was not added to the lead compound to form the glaze.[174] Conversely, all of the samples from mainland Greek and central Italian workshops, as well as the few remaining samples from Mytilene, display more silica in their glaze than in the underlying fabric, indicating that these glazes were formed by mixing lead with silica (Fig. 11).[175] Our analysis also confirmed that noncalcareous clays (with lime contents less than about 5 wt% CaO) were selected for the pottery fabrics on Lesbos, while calcareous clays (with lime contents greater than 5 wt% CaO) were used for lead-glazed pottery production in Attica, the Corinthia, and central Italy (Table 3). Finally, the pottery fabrics from Mytilene stand out for their high alumina contents (>20 wt%); potassium contents are also distinctly higher than in the other fabrics (ca. 2–5 wt%). This composition pattern is responsible for the relatively high alumina contents of all the local glazes, irrespective of the recipe that was used (Fig. 12); this occurred either through digestion of

174. This is the case in samples AS2380, MYT07, MYT11, MYT15, MYT21, MYT25, MYT31, MYT35, MYT43, MYT48, and MYT52.

175. Five samples from Mytilene display a normalized silica content that is higher in the glaze than in the ceramic body. However, the difference remains in the range of ca. 4 wt%, which is relatively low when compared to the ratios recorded in the samples from other workshops. The samples exhibiting this ratio are AS2361, AS2375, MYT34, MYT41, and MYT66 (see Tables 3, 5).

TABLE 5. MAIN ELEMENTAL COMPOSITION OF CERAMIC GLAZES, BY PROVENANCE, AFTER SUBTRACTION OF LEAD OXIDE AND COLORANT (COPPER OXIDE) AND NORMALIZATION TO 100 WT%

Fabric	*Sample*	*Na_2O*	*MgO*	*Al2O3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*
MYTILENE									
1A	AS2361	9.96	1.00	16.46	60.76	3.17	5.15	0.43	3.07
	AS2375	9.20	1.79	14.82	63.28	2.41	5.25	0.39	2.86
	AS2380	0.70	2.55	25.71	55.16	2.30	5.63	1.03	6.93
	MYT04	8.30	1.06	10.72	66.51	3.23	7.93	0.35	1.90
	MYT11	0.56	2.80	24.45	56.08	2.36	5.63	1.01	7.09
	MYT15	0.94	2.00	24.26	58.07	2.98	5.38	0.80	5.56
	MYT21	0.58	1.79	25.50	56.22	2.79	6.16	0.93	6.03
	MYT25	1.25	1.37	28.89	56.47	2.95	0.74	0.84	7.48
	MYT31	0.94	2.49	24.72	54.80	2.97	7.00	0.83	6.24
	MYT34	7.15	2.12	14.12	60.80	2.42	8.81	0.41	4.17
	MYT35	0.56	2.80	24.59	55.90	2.58	6.31	0.98	6.28
	MYT41	3.99	1.70	16.22	64.61	3.28	5.47	0.58	4.13
	MYT43	0.99	2.54	25.08	56.70	2.95	4.91	1.04	5.80
	MYT48	0.91	2.38	24.17	56.65	2.92	6.77	0.84	5.36
	MYT52	0.48	2.64	25.15	56.78	2.04	5.10	1.11	6.70
	MYT66	0.55	2.41	20.26	63.57	2.33	3.93	0.75	6.19
1B	MYT07	8.86	1.27	11.59	67.21	2.65	6.11	0.21	2.09
CENTRAL ITALY									
2	AS2373	0.94	1.94	12.41	68.71	2.39	9.05	0.33	4.24
	OST01	1.14	2.27	10.23	67.85	2.53	12.43	0.22	3.34
	OST02	1.04	1.60	9.42	73.99	2.20	8.87	n.d.	2.87
	OST11	1.03	1.87	8.28	74.00	2.21	8.88	n.d.	3.73
	OST19	0.53	1.49	6.69	79.49	1.50	7.25	n.d.	3.04
	OST20	0.90	1.72	9.40	74.36	1.76	9.03	n.d.	2.84
	OST21	0.47	1.41	11.47	74.42	1.52	7.72	n.d.	3.00
	OST23	0.94	1.47	7.37	76.65	1.43	7.88	0.11	4.16
	OST30	1.17	1.67	12.05	70.81	2.11	8.85	n.d.	3.34
	OST31	0.65	1.65	8.45	72.27	1.22	8.06	0.20	7.51
	OST33	1.53	1.14	5.66	79.19	2.15	7.67	0.11	2.55
3	OST08	0.12	0.42	3.32	87.82	0.73	5.21	n.d.	2.39
	OST16	0.00	1.09	5.27	83.44	1.04	7.27	n.d.	1.89
	OST17	0.45	1.17	4.25	82.70	1.07	7.55	n.d.	2.81
	OST29	0.12	0.82	3.62	86.13	0.82	6.83	n.d.	1.65
UNKNOWN PROVENANCE									
4	AS2362	1.30	1.73	6.97	77.59	2.41	6.92	n.d.	3.09
	AS2371	1.00	2.01	6.78	80.95	1.67	4.52	n.d.	3.08

(continued on next page)

TABLE 5 *(continued)*

Fabric	*Sample*	*Na_2O*	*MgO*	*Al_2O3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*
ATTICA									
5	AS2359	0.54	1.03	9.40	41.91	1.82	40.42	n.d.	4.89
	AS2360	1.13	1.27	3.75	86.45	1.33	3.97	n.d.	2.10
	AS2365	1.79	1.47	5.02	79.05	2.52	7.68	n.d.	2.42
	AS2376	2.00	1.80	7.45	74.17	3.96	6.93	0.33	3.38
	AS2378	2.26	1.41	9.96	73.60	3.01	7.03	n.d.	2.66
6	AS2364	0.72	2.10	8.24	77.69	2.16	5.99	n.d.	3.10
	AS2374	0.87	1.16	5.04	84.41	1.41	4.84	n.d.	2.27
	AS2377	1.28	1.42	7.68	80.84	1.81	4.10	n.d.	2.82
	AS2379	0.95	1.76	12.54	71.83	2.60	6.54	0.28	3.49
THE CORINTHIA									
7	AS2367	0.49	1.31	4.19	83.64	0.73	6.46	n.d.	3.18
	AS2369	0.72	1.18	10.34	77.14	2.25	4.76	0.23	3.38
	AS2381	0.34	1.15	11.63	72.67	0.98	3.92	0.31	9.01
8	AS2366	0.76	1.28	7.27	78.93	1.79	7.87	0.14	1.97
	AS2370	n.d.	1.75	12.20	72.66	1.40	8.21	n.d.	3.79

Note: Values expressed in wt%. Values lower than 0.10 wt% are at the detection limit of the EDS and are reported as not detected (n.d.).

the clay fabric by lead during firing or, for some of the samples at least, by intentional addition of clay to the lead suspension as a binding agent. The elevated levels of calcium recorded in the Mytilene glazes, however, require a different explanation that will be investigated below (Fig. 13).

Several lead-glaze recipes have been identified in the ancient Mediterranean. As noted above, Walton and Tite identified the use of a lead-glaze slurry with no silica in combination with a noncalcareous pottery fabric in the area of Smyrna and Klazomenai in western Asia Minor in the 1st century BCE to 1st century CE.[176] By contrast, contemporaneous sherds found at Tarsos in southern Asia Minor and identified as probable local products are in a calcareous fabric coated with a lead oxide and silica mixture.[177] Lead-glazed pottery found at Canosa in Apulia and dated to the Augustan period, as well as objects produced in Campania and found at Pompeii and Herculaneum, combine a noncalcareous fabric with a glaze made from lead oxide and silica.[178] Italian products dated from the 1st to the 4th century CE exhibit a calcareous fabric and a glaze obtained by mixing lead and silica, while contemporary productions from central Gaul and the Danube region have a noncalcareous fabric coated with a lead oxide powder. In the 4th–5th century CE, a technological change is recorded among Italian workshops, which also start to use noncalcareous fabrics glazed with a lead oxide powder.[179]

Against this backdrop, our results confirm that various lead-glaze recipes coexisted across western Afro-Eurasia in antiquity. They also suggest the concurrent use of distinct glazing techniques at a local scale; at

176. Walton and Tite 2010, p. 735. Nonetheless, it should be stressed that the local provenance of this pottery was not confirmed by fabric analysis.
177. Walton and Tite 2010, pp. 750–751.
178. De Benedetto et al. 2004; Giannossa et al. 2015.
179. Walton and Tite 2010, p. 752.

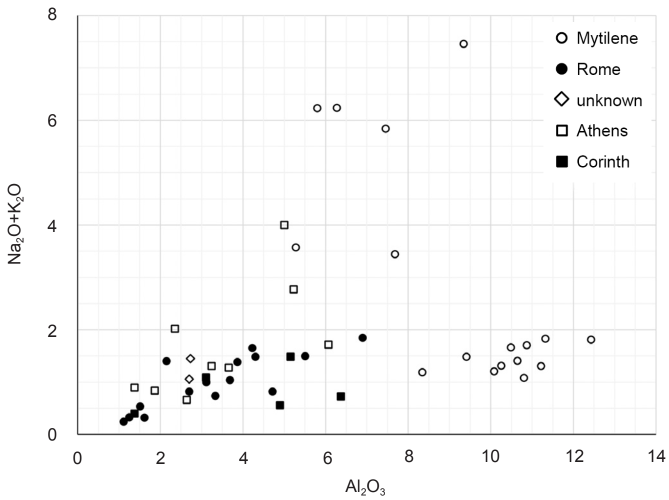


Figure 10. Binary plot of the alkali and alumina contents of the glazes, by provenance. A. Ben Amara

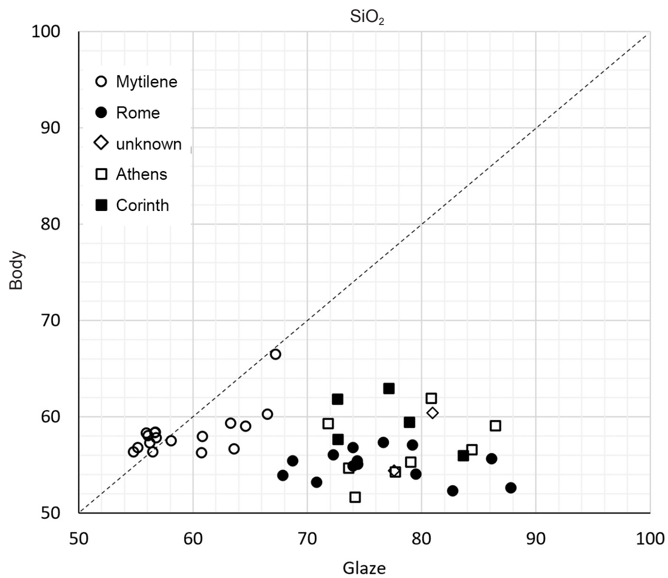


Figure 11. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of silica. A. Ben Amara

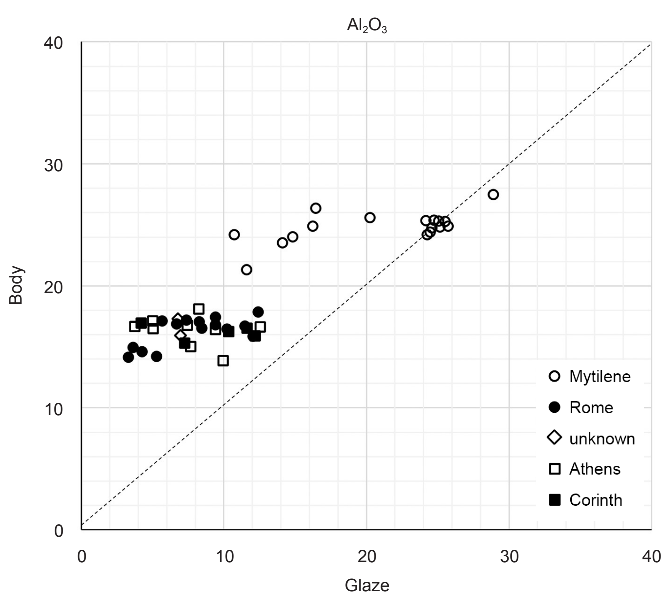


Figure 12. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of alumina. A. Ben Amara

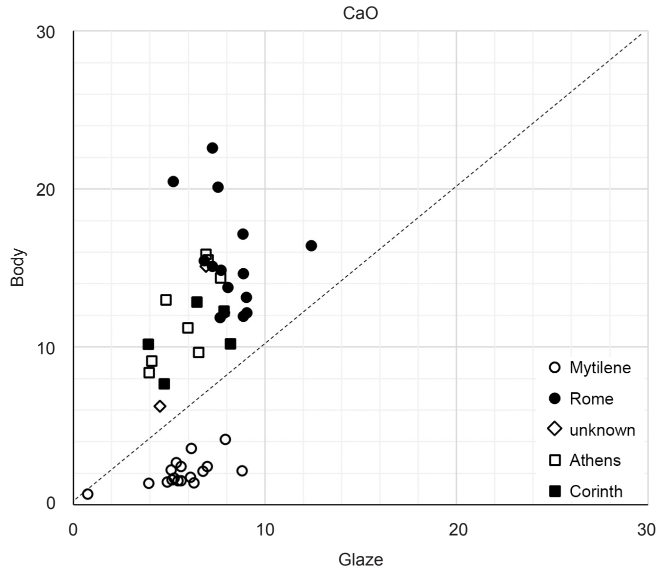


Figure 13. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of calcium. A. Ben Amara

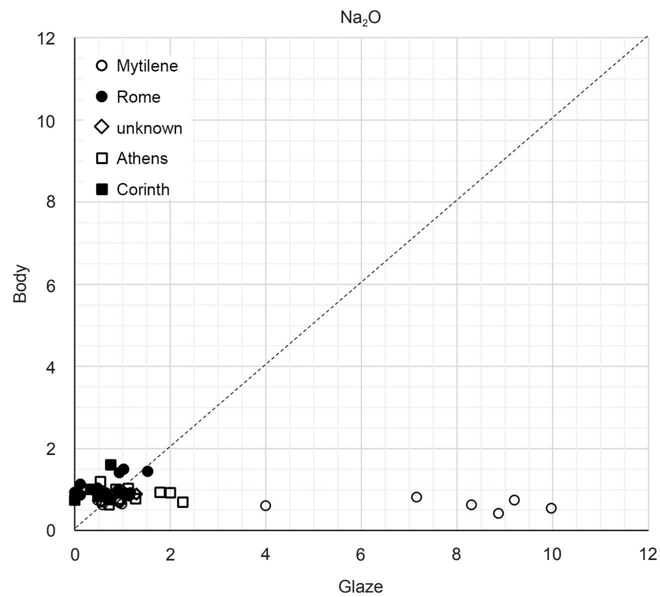


Figure 14. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of sodium. A. Ben Amara

Mytilene, for example, it seems that either a lead oxide powder or a lead and silica mixture may have been used over a noncalcareous pottery fabric. Our results also align with the suggestion by Walton and Tite that the recipe identified at Tarsos, which combines a lead oxide and silica mixture with a calcareous fabric, became popular in the Roman world from the 1st century CE onward; indeed, our data clearly indicate the diffusion of this recipe in mainland Greece (Attica, the Corinthia) and in the region of Rome during the High Empire.

As mentioned above, potters from Mytilene may have intentionally added some clay as a binding agent to the glaze slurry. Nonetheless, the clay used must have been different from those employed for the pottery fabric, as the noncalcareous composition of the pottery fabrics can hardly explain the presence of more than 2 wt% CaO in the normalized concentration of all these glazes (Table 5; Fig. 13). The normalized concentration of sodium (Na_2O) in the Mytilenean products is also noteworthy: it comprises

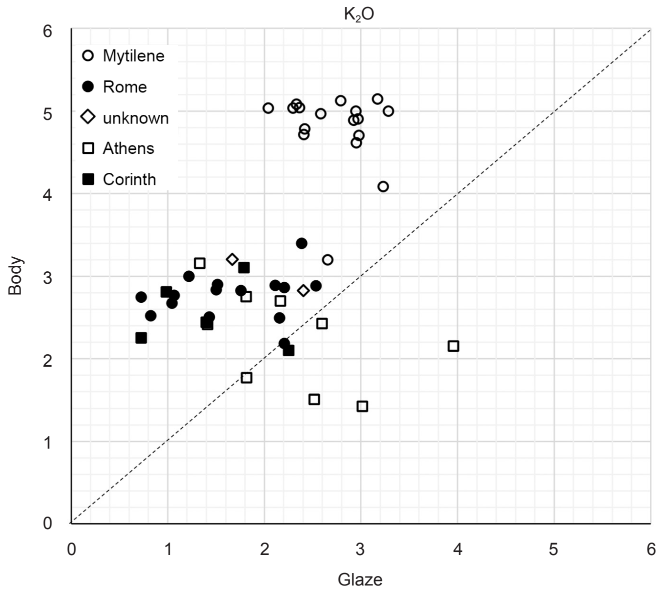


Figure 15. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of potassium. A. Ben Amara

between 4 and 9 wt% in six of these glazes (Table 5; Fig. 14).[180] In the samples that may have been glazed with a mixture of lead oxide and silica, such unusual ratios of calcium and sodium could result from the use of a quartz-rich sand that naturally contains some clay particles (such as alumina, lime, or alkali), but this explanation is, once again, not valid for most of the Mytilenean products, which were coated with a lead oxide powder with no addition of silica. Another possibility is the use of a glaze slurry composed of a lead oxide solution intentionally enriched with calcium (and sodium), potentially in the form of lime or a calcareous clayey material.[181] In the same way, some products of Attic workshops display more sodium and/or potassium in the glaze than in the clay body (Figs. 14, 15), but in this case the pattern might be due to the mixing of the lead compound with a silica-rich sand that naturally contains such elements as impurities.

All the analyzed glazes, except those from Mytilene, were colored by the addition of small quantities of copper oxide (CuO), ca. 1–4 wt% (Table 4).[182] The Mytilene samples, however, were colored with iron oxide, probably by the diffusion during firing of the iron oxide that is naturally present in the underlying red fabric (Fig. 16). In contrast to the other workshops represented in our sample set, the use of copper oxide as a coloring agent seems to have been particularly rare at Mytilene, a further demonstration of the change in technological practices and the overall impression of experimentation that characterizes this pioneer production center in the 1st century BCE.[183] The practice of coloring ceramic glazes using iron oxide is also reported at the Seleukid settlement at Jebel Khalid, and darker green

180. Samples AS2361, AS2375, MYT04, MYT07, MYT34, and MYT41.

181. See Tite et al. 1998, p. 249.

182. The Hellenistic green glazes from Jebel Khalid also contain substantial trace concentrations of copper (ca. 30,000 ppm; see Garnett, Jackson, and Waudron 2011, p. 547, table 2; and n. 67, above).

183. The occurrence of copper oxide is attested only in glaze samples AS2361, A2375, MYT07, and MYT34.

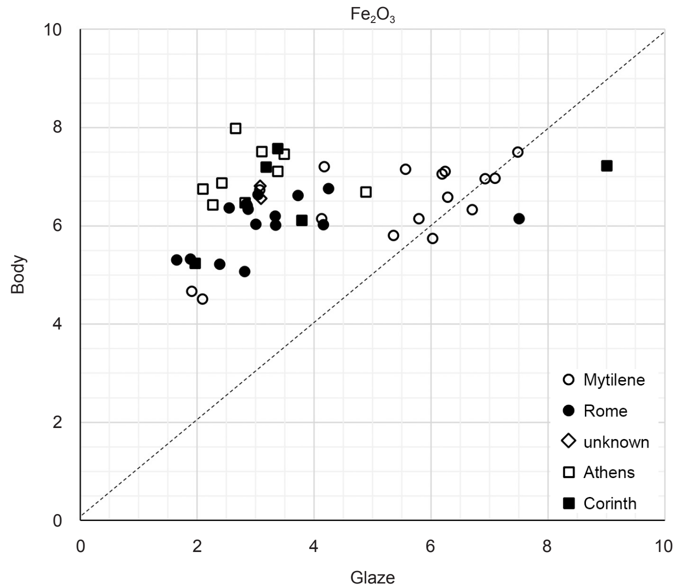


Figure 16. Enrichment-depletion plot of glaze compositions, versus body compositions, after subtraction of lead oxide content and colorant (copper oxide) and normalization to 100 wt%: concentrations of iron. A. Ben Amara

glazes (colored with copper oxide) are characteristic of later periods of antiquity in this region of Syria.[184] The current state of research, although based on a small number of samples, suggests a change in technological practice concomitant with the Roman presence in the territory.

The alkali enrichment of the lead glazes from Mytilene may be representative of the merging of different glazing traditions at a Hellenistic and Roman crossroads between the Mediterranean and Asia. It may be inherited from the long-lasting tradition of producing lead-alkali glazes, which is known from Ptolemaic Egypt and is probably related to developments in Seleukid Syria (see pp. 449–451, above).

Finally, a resemblance also emerges between the glazes from Mytilene and contemporaneous lead glazes in China. In the Han Empire of the 1st century BCE, calcium-lead glaze was one of the various types of glaze applied on a noncalcareous clay body. Our statistical treatment of a small set of published data allows us to suggest that at least some of these Chinese glazes were produced using a lead oxide slurry, with no addition of silica (Tables 6–8). Moreover, these Han glazes appear to have been enriched in a range of other elements that are constituents of calcareous clays (CaO, MgO, K_2O, Al_2O_3), which suggests that a calcareous soil, rather than lime per se, may have been added as a fluxing agent to the glaze slurry. This recipe is fairly similar to what we have identified among the 1st-century BCE glazes from Mytilene. A much wider pool of data is, of course, required before reaching any conclusion about a possible transfer of technology or suggesting an east Asian technocultural influence on the glazed pottery production of Late Hellenistic Asia Minor. In view of the intense connectivity that characterizes the era, however, such a thing would not be impossible. Be that as it may, our results are in line with previous work pointing to local diversity and experimentation, as well as the dissemination of aesthetic taste (that is, the green glaze) and the gradual adaptation of technological practices (that is, glazing techniques, from alkaline to high-lead recipes).[185]

184. Jackson 2016, p. 444. Samples dated to the Parthian and Roman periods in the region repeatedly seem to exhibit traces of copper in the glaze; see Garnett, Jackson, and Waudron 2011, p. 547, table 2.

185. E.g., Hatcher et al. 1994; Tekkök et al. 2009; Garnett, Jackson, and Waudron 2011; Jackson 2016.

TABLE 6. GLAZE COMPOSITION OF CHINESE POTTERY COVERED WITH CALCIUM-LEAD GLAZE FROM THE HAN DYNASTY

Sample No.	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*P_2O_3*	*Ti_2O_3*	*MnO*	*CuO*	*SnO_2*	*PbO*	*Total*
4	37.04	10.88	3.96	0.96	3.17	0.55	2.08	0.24	0.51	0.03	1.15	0.02	38.93	99.52
24	38.7	13.28	3.54	1.01	6.28	0.54	4.67	0.39	0.58	0.05	0.06	0.06	30.35	99.51

Note: Data after Wang et al. 2019, p. 5, table 2. Values expressed in %.

TABLE 7. CLAY BODY COMPOSITION OF CHINESE POTTERY COVERED WITH CALCIUM-LEAD GLAZE FROM THE HAN DYNASTY

Sample No.	*Na*	*MgO*	*Al_2O_3*	*SiO_2*	*K_2O*	*CaO*	*TiO_2*	*Fe_2O_3*	*Total*
4	0.1	0.2	15.4	76.8	2.6	0.7	0.4	3.6	99.8
24	0.6	0.2	19	70.9	3	1.1	0.9	4.3	100

Note: Data after Wang et al. 2019, p. 7, table 3. Values expressed in %.

TABLE 8. GLAZE COMPOSITION OF CHINESE POTTERY COVERED WITH CALCIUM-LEAD GLAZE FROM THE HAN DYNASTY, AFTER SUBTRACTION OF LEAD OXIDE AND COLORANT (COPPER OXIDE) AND NORMALIZATION TO 100 WT%

Sample No.	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*P_2O_3*	*Ti_2O_3*	*MnO*	*SnO_2*
4	62.31	18.30	6.66	1.62	5.33	0.93	3.50	0.40	0.86	0.05	0.03
24	56.01	19.22	5.12	1.46	9.09	0.78	6.76	0.56	0.84	0.07	0.09

Note: Data after Wang et al. 2019, p. 5, table 2. Values expressed in wt%.

CONCLUSIONS

The emergence of lead-glazed pottery in the Hellenistic and Roman Mediterranean is a subject that is still poorly understood. Building on the important work by Greene and others, this study has presented a reassessment of the published scholarship and contributed new archaeological and archaeometric data that allow for a better understanding of the complex networks of Mediterranean and Afro-Eurasian contacts that lay behind the invention of high-lead Hellenistic and Roman pottery glazes in the 1st century BCE.

Aside from the well-documented emergence of lead-glazed pottery in Asia Minor, our analyses strongly suggest the existence of workshops in mainland Greece that catered to local consumption from at least the middle of the 1st century BCE. This implies that the lead glazing of moldmade wares was a broader development in the Aegean world than has hitherto been assumed on the basis of stylistic and macroscopic evidence.

The main conclusion that emerges from the provenance analysis of our samples is that each of the three cities studied relied on regional products.

This is especially the case for Ostia and Mytilene. Athens seems to have been located at the crossroads of different trade routes running east–west across the Mediterranean, with lead-glazed pottery products arriving both from Asia Minor and from Rome. At the same time, however, the city was located in a fertile region for molded pottery production, in which various workshops in both Attica and the Corinthia shared a long history of glazed moldmade ware production. At Mytilene, Athens, Corinth, and Ostia, the types and styles of lead-glazed pottery are deeply rooted in local traditions that produced ceramic imitations of metalware (either through molding or black-glazing) over several generations. The main innovation was the application of a new type of glaze containing lead as its main ingredient.

The regional diversity of stylistic and technological traditions shows that we are not dealing with a phenomenon that emanated from Rome and was spread by Roman imperialism. Our analyses instead suggest the existence of regional responses by local workshops to the widespread diffusion of new technological know-how and artistic tastes that apparently spread widely and easily through the network. Roman imperialism enhanced and intensified the power of an Afro-Eurasian network that was functioning in the Hellenistic era. As a result, Hellenistic traditions from the eastern Mediterranean, Asia, and the Nile valley were to play a prominent role all over the Roman *imperium.* Such processes are encapsulated by the term "glocalization": the adaptation of global developments to local needs, or the reciprocal interactions of global and local conditions that, one could say, constitute one another.[186]

Our results confirm the observation by Walton and Tite that (at least) two different lead-glaze recipes concurrently developed in the Late Hellenistic and Early Roman world, and that they were combined with specific fabrics. Moreover, we can single out an experimental "transition" at the Mytilene workshop, where a lead oxide slurry was applied on a red ceramic fabric. The practice of adding lime, alkali, or both ingredients (as in the form of a calcareous clay) is also documented for the eastern region of Afro-Eurasia, where ceramics were coated with a lead glaze maybe as early as the 5th century BCE (see pp. 451–452, above). Likewise, the practice of coloring the glaze with copper (responsible for a greenish-blue sheen) appears to have developed mainly in a Roman context, among the workshops of central Italy and mainland Greece during the High Empire. By contrast, the 1st-century BCE products at Mytilene do not follow this practice: instead, iron oxide is responsible for the ocher-yellow color of the glaze, a characteristic that is also documented for Hellenistic glazes from parts of the Seleukid kingdom.

To better understand the emergence of lead-glazed pottery in the Hellenistic and Roman world, we have argued for the importance of an Afro-Eurasian perspective. The network of the highly interconnected, "global" ancient world in this era should be our point of departure in

186. For glocalization, see Robertson 1995, p. 32: "The global is not in and of itself counterposed to the local. Rather, what is often referred to as the local is essentially included within the global"; for an application to the Roman period, see Riedel 2018. Knappett (2011, p. 10) defines glocalization as the ability of individuals to operate across different scales.

trying to map and explain the spreading of innovations. Global networks overcome distance and civilizations, and they forge new relations. Innovation is often created out of the elements that such networks draw together and the novel combinations they allow for, as our reconstruction of the emergence of lead-glazed pottery in the Mediterranean has illustrated. Some of these develop into new standards that, in their turn, both strengthen and widen the network further, as shown by the diffusion and impact of lead-glazed pottery in Roman Europe. Instead of seeing Roman imperialism as the main catalyst, we would, therefore, rather argue for the importance of network power to understand the emergence and diffusion of the innovation that was lead-glazed pottery.[187] The network was both the prerequisite for these innovations to happen as well as the force that propagated the new practices and fashions. In our view, the "unprecedented experiment" that was lead-glazed pottery[188] should therefore be regarded, and further investigated, as the result of a process of cocreation, perhaps even on an Afro-Eurasian scale. In this scenario, many small steps were taken over a longer period of time by many different actors in many different locations before coalescing into this innovative result.[189] We hope that the new data presented in this study illustrate the feasibility of this approach and will play a role in the further investigation of lead-glazed pottery as a connected history.

187. For network power in general, see Versluys, forthcoming. The importance of historical processes like Roman imperialism or "Romanization" should not be denied, but we should understand these processes also in terms of network power.

188. Walton 2004, p. 5.

189. This observation is in line with the "developmental approach" to innovation of Knappett and Van der Leeuw (2014); see also Ziman 2000, on innovation as an evolutionary process.

Appendix

Provenance Ascription of Sampled Lead-Glazed Pottery Fabrics Using Thin-Section Petrography

This appendix provides a report on the mineral characteristics of the main fabric groups identified by thin section petrography, and on possible provenance ascriptions proposed for these fabrics through comparisons with published data and other petrographic collections of archaeological pottery and geological samples. Therefore "fabric 4," which is represented by only two samples in our collection, is omitted in this appendix: as explained above (p. 472), further pottery samples identified through future petrographic research are needed before a precise description and provenance ascription of this fabric can be proposed.

Mytilene: Fabric 1

Petrographic Description

Fabric 1 is a very fine, micaceous, noncalcareous fabric that is packed with white mica laths. Coarse inclusions are very rare, although a few samples appear to have been deliberately tempered with fine sand.[190] These inclusions consist of subrounded arenite, silvery shale, and anchimetamorphic phyllite with white micas, rare greenschist, micaceous mudstone and sandstone, and very rare (depleted) limestone.

Three variants have been identified based on the texture and apparent composition of the groundmass. Some samples display a very fine texture and mostly silvery gray to yellow colors with limited streaks of reddish-brown material (fabric 1A). Other samples display more extensive streaks with a dominance of reddish-brown clay (fabric 1B). Moreover, the relief decoration is often made in a highly micaceous buff clay, probably a kaolinite. One sample (MYT73) is made in this ocher-yellow, highly micaceous clayey material (fabric 1C). Both clays appear to derive from white mica phyllites and shales observed as inclusions in the ceramic fabrics.[191] The low

190. Samples MYT34, MYT38, MYT44, MYT49, and MYT61.

191. Late Hellenistic appliqué ware found at Ephesos was likewise decorated with appliqué patterns in the refined clay used for the ceramic fabric; see Peloschek and Lätzer-Lasar 2014, p. 61.

calcareous content of fabric 1, as well as its high concentration in alumina and silica, have been confirmed by SEM-EDS (Table 3).

Provenance Ascription

The mineralogical characteristics of fabric 1 are compatible with the geology of the area of Mytilene on Lesbos. The bay of Mytilene is covered with Quaternary alluvia consisting of both gray and red clays; at Aklidiou and Varia farther to the south are loose sediment deposits containing gravels of serpentinite, limestone, basalt, and phyllite, which probably derive from the disintegration of the peridotite and serpentinized peridotite outcrops that dominate the southern tip of the Amali peninsula.[192] The hills surrounding the bay of Mytilene are composed of partly anchimetamorphic marbles and schists from the Permian and Carboniferous periods, with chiefly greenschist facies and intercalations of phyllites, meta-argillaceous shales, and meta-sandstone. Pliocene basalt and intermediate lavas forming cones and summits are also observed on the hill slopes toward Mytilene, and Pliocene limestones form the rock basement of the ancient city's acropolis.[193]

Another indication of a local provenance is provided by a sample at the Fitch Laboratory of the British School at Athens, labeled "Mytilini, Tenedos Ware": it has the same petrographic characteristics as fabric 1. A Lesbian amphora from Corinth sampled by Ian Whitbread displays the same fabric as well.[194]

Based on these observations, and given the stylistic homogeneity of our sampled assemblage, a local provenance seems highly probable for the analyzed lead-glazed pottery fragments from the Sanctuary of Demeter at Mytilene.

Fabric 1 shares limited petrographic characteristics with Late Hellenistic pottery found at Ephesos, ca. 200 km south of Mytilene on the western coast of Asia Minor.[195] More generally, however, an Asia Minor provenance for fabric 1 is not supported by petrographic data so far published.[196]

CENTRAL ITALY: FABRICS 2 AND 3

Petrographic Description

Fabric 2 displays buff colors under crossed polars, ranging from ocher orange through greenish ocher to gray. It contains sparse coarse (sub-) angular sandy fragments of granitic rocks as well as their derivative

192. Giannetakis 1972.
193. Giannetakis 1972.
194. C-1937-2766; Corinth sample 84/33.
195. A published sample of appliqué ware from Ephesos displays a fine reddish fabric packed with muscovite micas, mica schists, quartz, calcareous inclusions, and (to a minor extent) opaque particles (Peloschek and Lätzer-Lasar 2014, pp. 60–61). Nonetheless, metamorphic rock fragments seem to be absent from this fabric. A similar observation can be made for Hellenistic moldmade lamps from Ephesos; see Fragnoli et al. 2022, pp. 11–18, table 2, figs. 4, 5 ("major group" and "minor groups 1 and 2").
196. At Priene, for instance, Late Hellenistic moldmade wares are characterized by a very fine fabric with an extremely high amount of mica alongside sparse quartz silts and shell fragments (Fenn 2011, p. 526). Hellenistic fabrics from Ephesos differ from fabric 1 in the lack of metamorphic content and the more common quartz and carbonate inclusions.

minerals, including white and biotite mica laths, feldspar, and quartz crystals, often unaltered. Other aplastic constituents include few to common angular inclusions of basalt, occasional pyroxene, and very rare chert. The calcareous nature of this fabric (CaO ca. 12% wt) has been confirmed by SEM-EDS. Rare depleted microfossils with calcareous skeletons are visible in most samples.

Fabric 3 is ocher brown under crossed polars. It stands out by its higher calcium content measured by EDS (CaO ca. 20 wt%), and it is mineralogically related to fabric 2, except for the more common occurrence of microfossils (with either calcareous or iron-rich skeletons) and the apparent absence of basaltic inclusions. The main aplastic content of this fabric consists of fine quartz crystals, feldspars, and depleted biotite, as well as some fresh white mica laths and biotite flakes, alongside some sparse fragments of siliceous rock, possibly a meta-arenite or a gneiss. This composition indicates a connection with a granitic-metamorphic environment.

Provenance Ascription

Fabrics 2 and 3 can be related to a range of ancient lead-glazed pottery fabrics identified by Pauline Gohier and her colleagues as originating from the region of Rome, and described as fossiliferous fabrics with quartz, feldspar, mica, pyroxene, and occasionally volcanic rock inclusions (leucite lavas, basalt, trachyte).[197] Likewise, the analysis of lead-glazed pottery and associated wasters from the Janiculum revealed the dominance of a fine brownish-buff fabric with feldspar, white and colored micas, altered olivine, quartz and rare arenite, and sparse pyroxene.[198] Similar fabrics have been identified among the lead-glazed ceramics collected at Monte Testaccio, where the existence of a local workshop is suspected. These fabrics are usually coarser than those from the Janiculum, with the exception of those used in inkwells.[199]

This composition is not specific to lead-glazed pottery: similar pastes were used for utilitarian coarse wares in the Late Republican and Early Imperial periods in Rome and Latium.[200] The mineral fingerprint of these fabrics is compatible with the Pliocene marine clays attested in different locations along the Tiber valley, in upper Latium and Umbria, as well as near Rome and in southern Tuscany, and, with volcanic rock intercalations, on the Tyrrhenian coastline between Tarquinia and Cerveteri.[201]

When compared with other petrographic analyses carried out on ceramic material from Ostia, fabric 2 is compatible with a large fabric group that has been identified among Republican black-gloss pottery and labeled "Ostia/*Ager Portuensis,*" highlighting the probably local or regional provenance

197. Gohier, Cappelli, and Cabella 2016, pp. 590–591.

198. Giardino and Trosji 2008, pp. 318–319, table 1.

199. See Gohier, Cappelli, and Cabella 2016, pp. 590–591. De Vito et al. (2017, pp. 1781–1783, fig. 2) analyzed fragments of inkwells from the Nuovo Mercato di Testaccio that are deemed to represent a local "campano-laziale" production. Their fabric is very fine and brownish under crossed polars, and contains fine quartz crystals along with common iron oxide concentrations, feldspars, rare biotite and sedimentary rocks, and very rare muscovite. The presence of volcanic rock fragments is not reported by the authors.

200. Olcese and Coletti 2016, p. 54, fig. 5.

201. See Olcese 2003, pp. 55–60 (esp. p. 55, with a description of the "typische römische Produktion"); Gohier, Cappelli, and Cabella 2016, p. 591, n. 15; Olcese and Coletti 2016, p. 56.

of this pottery.[202] Moreover, the results of another archaeometric research program, targeting lead-glazed pottery fragments found in leveling works of the Antonine period at the Terme del Nuotatore in Ostia, supports the hypothesis of a local or regional provenance for fabric 3.[203] Petrographic analysis of selected fragments identified two related fabrics consisting of a marly clay with micaceous particles, augite, and calcareous inclusions. Archer Martin suggests that these fabrics derive from the exploitation of clays found in the middle Tiber valley north of Rome, in which case the raw materials could easily have been transported by boat to workshops located in or immediately outside the city.[204] Other suggested explanations of the origin of these fabrics involve the disintegration of travertine outcrops around Ostia.[205]

Lead-glazed pottery continued to be made in similar calcareous fabrics with igneous rock inclusions during the Late Antique and Early Medieval periods. These have also been identified as products of central Italy, and more particularly the wider region of Rome. For instance, pottery in a marly brown fabric with white and colored micas, feldspars, isolated microfossils, and calcimudstones, as well as angular fragments of gneiss, sedimentary siliceous rock (arenite), basalt and lava rock, and their constitutive minerals, has been linked with Tyrrhenian volcanism documented between southern Tuscany and Campania.[206] Others have linked a similar fabric, which also contains inclusions of chert, volcanic, and granitic rocks (but apparently lacks the metamorphic pattern), to the Pliocene clays and flysch-derived sands with intercalations of igneous formations that are characteristic of the area of upper Latium (for example, Civita Castellana, Civita di Bagnoregio, Orvieto).[207]

ATTICA: FABRICS 5 AND 6

Petrographic Description

Fabrics 5 and 6 are two related calcareous fabrics characterized by the presence of white and (fewer) colored micas, as well as inclusions of white mica schists and mica-rich quartzite grading into each other. The calcareous content of these fabrics was confirmed by SEM-EDS (Table 3).

Fabric 5 displays a fine greenish-ocher groundmass with few reddish clay pellets and well-sorted quartz silts, white mica silts, and fewer depleted biotite silts. Rock inclusions are relatively rare; they consist of white mica schist alongside gneiss and quartzite, rare quartzic metasiltstone, and depleted limestone.

Fabric 6 has a silty reddish-orange groundmass with red clay pellets, plentiful white mica laths (among which are rare muscovite), and oxidized biotite, alongside fine quartz, feldspars, and micrite. Fine sandy rock fragments are scattered throughout the fabric. They consist of meta-arenite, white mica schist, colored mica schist, and shale. Differences have been observed between samples with a stronger sedimentary or metamorphic fingerprint, which remains difficult to interpret in terms of paste recipes, workshop output, or natural variation in the clay sediment resource.

202. Olcese and Capelli 2011, pp. 129–130.

203. Martin 1992, pp. 323–324, 326; 1994, pp. 63–64.

204. Martin 1992, p. 324.

205. Arthur 1979, p. 394.

206. Lazzarini et al. 1980; Sfrecola 1992, groups 1–9; Paroli et al. 2003, pp. 487–488.

207. Aurisicchio, Lazzarini, and Mariottini 1994, pp. 92–93, 100. These marine clayey formations from the Pliocene and lower Pleistocene have been described in the area of Monte Mario, in the Tiber valley, at Monte di Roma, and farther north at Capena and Orte, Orvieto, Chiusi and Val di Chiana, Terni, and Perugia; the formation also appears on the Tyrrhenian coast near Cerveteri and Tarquinia (see Picon's analysis in Olcese 2003, pp. 52–53, fig. 33).

Provenance Ascription

Although the presence of fresh muscovite laths is reminiscent of several fine fabrics of the Early Roman period in western Asia Minor,[208] this characteristic is also found in several productions of various periods in Attica; it is considered to derive from the alteration of the local white micaschist formations.[209] Attic fine wares are also known for their elusive petrographic characteristics, notably in terms of groundmass texture and color, which correspond to our observations on fabrics 5 and 6.[210]

Fabric 5 is found in fine wares from the Athenian Agora, including two Hellenistic moldmade bowls sampled for reference.[211] Various samples collected by Marie Farnsworth at the site display the same type of fabric, notably a krater from the Hellenistic period.[212] The same fabric also appears among 15th-century Maiolica wares found in the Mazi plain in northern Attica, and preliminarily identified as regional products on stylistic grounds.[213]

One Hellenistic moldmade bowl from the Athenian Agora sampled for reference displays petrographic characteristics that are similar to fabric 6.[214] Comparisons can also be made with 5th- and 4th-century BCE black-glazed wares that have been attributed to Attic workshops based on their chemical composition, as well as some pseudo-Maiolica wares found in Attica.[215]

Geologically speaking, the presence of white mica schist, phyllite shale inclusions, and their detrital products can be related to the geological setting of the Mesogeia; this region is characterized by the widespread occurrence of autochthonous and allochthone formations of white mica–rich phyllosilicate. Different kinds of white mica schist occur more particularly in the vicinity of Athens. Calcitic and chloritic schists in alternation with quartzite are reported in the autochthonous "Kaisariani schists" and in a lower Cretaceous formation around Mt. Hymettos, east of the modern city center. These formations also occur in the adjacent area of Kaisariani and Koropi.[216] In addition, serricitic and chloritic schist alternating with shale and sandstone are present in a Maestrichtian–Eocene "Athenian schist" on the eastern border of the modern city.[217] An Upper Cretaceous formation of chloritic schists and phyllites also crops out in eastern Attica,

208. See below, fabric 8 (although that fabric contains fragments of biotite micaschist, which are absent from fabric 6). For muscovite silts in fine pottery fabrics from the western coast of Asia Minor, see also Peloschek and Lätzer-Lasar 2014, p. 61 (Ephesos); Liard et al. 2022, pp. 518–520 (Pergamon).

209. Farnsworth 1964, p. 223; 1970, p. 10; *Agora* XXXIII, pp. 16–28; Pentedeka, Georgakopoulou, and Kiriatzi 2012, pp. 125–128, 164.

210. *Agora* XXXIII, pp. 20 ("pinkish buff fabric"), 405–406.

211. Our petrographic analysis of three fragments of Hellenistic moldmade bowls with long-petal decoration from the Athenian Agora indicates that fragments P 27364 and P 20488 (*Agora* XXII, pp. 83–84, nos. 326, 334) are in fabric 5, and P 20204 (*Agora* XXII, p. 83, no. 325) is in fabric 6. Rotroff considered P 20488 (*Agora* XXII, p. 84, no. 334) a possible import.

212. Farnsworth petrographic collection, Wiener Laboratory, sample 41.

213. F. Kondyli, pers. comm. (July 2019); ongoing research by Liard on the petrographic characterization of glazed pottery of the Ottoman period from Attica.

214. See n. 211, above.

215. For black-glazed wares, see Pentedeka, Georgakopoulou, and Kiriatzi 2012, pp. 125–128. A lekane rim and several drinking vessels of the 5th century BCE sampled by Farnsworth from the Athenian Agora are also in this fine silty fabric (Farnworth petrographic collection, Wiener Laboratory, samples 3, 32, 45, 54). Pseudo-Maiolica is the subject of ongoing research by Liard. The compositional continuity of Athenian pottery through time was highlighted by Farnsworth (1964, p. 223).

216. Perissotaris 1992.

217. Bornovas 1982.

near Markopoulo, Keratea, and farther south.[218] Moreover, the coastal area around Piraeus, with Upper Miocene sands and silts, locally rich in clay, also contains the detritic fragments of these phyllosilicate and schist formations.[219] North of Athens, Pleistocene brown clayey loams contain dispersed cobbles and rubble from the disintegration of Neogene formations, and more rarely of Alpine formations, among which may be schists.[220] These clay deposits and loam could have provided the raw materials necessary for the production of pottery in fabrics 5 and 6 and other similar fabrics.

THE CORINTHIA: FABRICS 7 AND 8

Petrographic Description

Fabric 7, represented by three samples, is a silty fabric with plentiful quartz and feldspar crystals and fewer mica silts (chlorite, oxidized biotite, sparse muscovite), and with colors that range from reddish brown (no optical activity) to ocher yellow (with moderate activity). The low calcareous content of this fabric (ca. 8–12 wt% CaO) was confirmed by SEM-EDS and is evident in the uneven fabric colors and texture as well as the presence of few calcimudstones. Scattered sandy inclusions include graywacke and low-metamorphic quartz-mica rocks with colored and white mica subgrains, alongside occasional inclusions of litharenite sandstone, red mudstone, golden shale, and radiolarian chert, and very rare depletion products of igneous rocks (pyroxene, feldspars). The clay contains some sparse dark brown textural concentration features.

Fabric 8, also represented by three samples, is a very fine, silty, ocher-green fabric with occasional traces of depleted microfossils. It contains angular inclusions of quartz, alkali feldspar, plagioclase, and fine-grained sedimentary rock fragments (for example, arenite siltstone, chert, and radiolarian chert), alongside calcimudstone inclusions and sparse low-metamorphic rocks and sparse biotite flakes.

Provenance Ascription

The combination of sedimentary, low-metamorphic, basaltic, and ophiolitic rocks, as well as their derivative minerals, is a recurrent characteristic of pottery fabrics from the region of Corinth.[221] The overall lower mica content of the fabric, alongside inclusions of shale, chert, quartzic siltstone, and mudstone, helps to distinguish these fabrics from Attic fabrics, although the distinction is not always easy to make on an individual basis. Indeed, the clays of Corinth have been extensively researched by archaeometrists and are known for their elusive character.[222] Through the petrographic study of clays and ancient pottery samples, Farnsworth contributed to clarifying the difference between Corinthian and Attic pottery, but she also made clear that a series of reddish-orange micaceous fabrics with sandy inclusions of siliceous and clay-rich sedimentary, meta-sedimentary, and low-metamorphic rocks may have been produced in both regions.[223]

218. Perissotaris 1992.
219. Bornovas 1982.
220. Perissotaris 1992.
221. Joyner 2007 (coarse medieval cooking-pot fabrics); White 2009 (fine medieval lead-glazed table wares); Liard et al. 2022 (fine medieval and post-medieval lead-glazed table wares).
222. For a synthesis of work on Corinthian clays, see Whitbread 2003.
223. Farnsworth 1964, 1970.

Pottery samples exhibiting a clay fraction high in calcium carbonate and containing inclusions of feldspar, quartz, fine quartzite, fine schist, spotted shale, and mica are interpreted by Farnsworth as "Acrocorinth fabrics" on the basis of comparisons with clays that she sampled in the area, although a mineralogical diversity of the local clay resources seems plausible.[224] Such rock outcrops are also reported in the Geraneia mountains north of the Isthmus, and pottery fabrics with similar inclusions have been identified in later types of lead-glazed pottery at Corinth.[225] Red *terra rossa* clays from the hills of Penteskouphi (southwest of Corinth) and Anaploga (west of Corinth), on the other hand, contain silty to sandy inclusions of quartz and mica, limestone, sandstone, and mudstone with radiolaria and chert subgrains, and fewer serpentinite and igneous rock fragments.[226] Farther west, Hellenistic and Roman pottery as well as modern-day clay sources so far sampled around the ancient city of Sikyon and analyzed petrographically contain mainly calcite and silicate inclusions.[227] Therefore, these clay sources located west of Corinth are less likely to have provided the raw materials for the Roman lead-glazed pottery in fabrics 7 and 8.

Furthermore, a provenance from the immediate region of Acrocorinth is more confidently asserted for fabric 8. A comparative analysis of individual thin sections by the author revealed that the clay used is similar in texture, color, and apparent composition to a fragment of an Archaic kotyle from Corinth sampled by Farnsworth.[228] A further comparandum has been found with a fragment of a coarse fabric identified among local medieval cooking wares at Corinth.[229]

224. Farnsworth 1970, pp. 12, 19–20. Indeed, the fired briquettes made from Acrocorinth clays by Whitbread and housed at the Fitch Laboratory are clearly different in texture, calcareous content, and overall mineralogical composition. Only a Lakonian rooftile (Corinth sample 83/29) is similar to our fabric.

225. Liard et al. 2022, p. 511. Fabric 7 shares several compositional characteristics with medieval (Frankish) lead-glazed pottery from Corinth, although the sedimentary (quartzic) and low-metamorphic component seems more striking in the Early Roman pottery samples. Farther to the east, Late Hellenistic pottery with metamorphic rock inclusions is also reported by petrography around the ancient city of Sikyon, although without displaying a convincing match with our fabric 7.

226. Whitbread 1995, pp. 330–333. Whitbread (1995, 2003) has done substantial work to define the diversity, locations, and working properties of Corinthian clays used by ancient potters.

227. Trainor 2015, pp. 2–3, 34–35.

228. Farnsworth 1964, pp. 224, 227, no. 14, pl. 68.

229. Joyner 2007, pp. 196–197 (fabric 5).

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