Looking for Ephesian workshops: an integrated petrographic, geochemical, and chrono-typological approach to Late Hellenistic Ephesos lamps

Pamela Fragnoli¹ · Marina Ugarković² · Johannes H. Sterba³ · Roman Sauer⁴

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Abstract

In this pilot study, Late Hellenistic mold-made lamps from Ephesos are investigated by combining chrono-morphological and stylistic features with thin-section petrography and neutron activation analysis. Coeval wares of Ephesian production and clay samples collected around the site as well as published data from the Bonn database are considered local reference material. The results point to a network of local/regional workshops sharing facilities and/or a labor force dedicated to distinct tasks. The whole evidence is consistent with the very beginning of a nucleated workshop industry able to optimize the productivity of mold-made wares and fill the demand of an increased regional and supra-regional market. The typological and compositional variability of the latest phases could suggest a gradual transfer of potting activities towards areas providing better-suited clay sources.

Keywords Ephesos · Late Hellenistic mold-made lamps · workshops · craft organization · petrography · NAA

Introduction

Ephesos is one of the great Ionian Greek cities established along the coastal area of Asia Minor, near the mouth of the Menderes River (today Selçuk, south of Izmir, western Turkey). Despite the regional political upheavals, during the Hellenistic period and especially when it became the capital of the Roman Asia Minor province in 133 BCE, the city of

Ephesos ascended to one of the most important ancient metropolises and one of the most vital hubs in the eastern Mediterranean seascape (Ladstätter 2016).

An economic upturn visible in the 2nd c. BCE embedded within its sociopolitical development was also marked by the strengthening of local crafts, including the notable ceramic production of finewares (Ladstätter 2016: 265). Ephesos lamps and mold-made relief bowls as well as plates and tablets of the so-called Ephesian Grey Ware (hereafter EGW) were, along with black- and red-gloss ware plates and bowls, the most important ceramic products attributable to the region of Ephesos in the period of the 2nd and 1st c. BCE (Ladstätter and Waldner *in press*). Even though particularities of the export of Late Hellenistic pottery from Ephesos are still under study, this was indeed the first time that ceramic wares manufactured in the workshops of Ephesos were used not only locally but also within regional and supra-regional circuits (Ladstätter 2007: 206; Ladstätter 2016: 265).

Ever since H. B. Walters introduced the term “Ephesus type” in his 1914 catalogue about Greek and Roman lamps kept at the British Museum (Walters 1914: 46–50), its slightly modified version, “Ephesos lamps,” has been extensively used for specific types of Late Hellenistic mold-made lamps thought to have been created and produced in Ephesos and occasionally imitated elsewhere (on the terminology, see also Chrzanovski 2020). Though the term was simply motivated

✉ Pamela Fragnoli
pamela.fragnoli@oeaw.ac.at

Marina Ugarković
marina.ugarkovic@iarh.hr

Johannes H. Sterba
johannes.sterba@tuwien.ac.at

Roman Sauer
roman.rosa@aon.at

¹ Research Group “Object Itineraries”, Department of Historical Archaeology of the Austrian Archaeological Institute, Austrian Academy of Science, Vienna, Austria

² Institute of Archaeology, Jurjevska ulica 15, 10 000 Zagreb, Croatia

³ Center for Labelling and Isotope Production, TRIGA Center Atominstitut, TU Wien, Vienna, Austria

⁴ Independent Researcher, Vienna, Austria

by the origin of the lamps stored in the British Museum (Walters 1914), its widely accepted use has also produced some ambiguities ever since. In this paper, the term “Ephesos lamps” is understood as defined by Anita Giuliani for different types of mold-made Late Hellenistic ceramic lamps produced in Ephesos and imitated elsewhere (Giuliani 2005b).

A great number of Ephesos lamps along with several molds for their manufacture that were discovered in different parts of this ancient city already testified to their local production (e.g., Walters 1914: 46–50; Miltner 1937: taf. XI, 7–21; Bailey 1975: 89–93; Gassner 1997: 192–194, 253, 254; Giuliani 2001 and 2005b; Mitsopoulos-Leon 2007; on mold finds: Miltner 1937: 200, nos. 1–2, Pl. 14; Bailey 1975: 90, 91, Q 181, Q 182, Pl. 1, 34, Q 203, Pl. 1, 38; Mitsopoulos-Leon 1985: 247, Pl. 27, 28; Giuliani 2001; Mitsopoulos-Leon 2007: L 68. L 76. L 77). Although Ephesos seems not only to be one of the major production centers but also a birthplace of the different types and sub-types of Ephesos lamps, these latter have been also attested, though in significantly lower amounts, at various other Eastern Aegean and Asia Minor sites, such as Delos, Pergamon, Miletus, Priene, Knidos, Metropolis, Tralles, Aphrodisias, Kibyra, Assos, and Sardis (Bailey 1975; Chrzanowski 2020). It is assumed that the Pergamene workshops participated in this production and local copies are reported for Sardis, Metropolis, Tralles, Aphrodisias, Kibyra, and Assos as well. Numerous examples have also been found throughout the Mediterranean and Black Sea, with reported imitations of the latest and most famous type—known as the Howland 49 type—on several localities, such as Nea Paphos on Cyprus, Corinth, Athens, and Thessaloniki as well as the Pontic sites of Myrmekion, Pantikapaion, Chersonesos, and Olbia (e.g., Broneer 1930: 66–70; Howland 1958; Bruneau 1965: pl. 16–18; Bailey 1975: 91; Drougou 2012; Kajzer 2013; Zhuravlev and Zhuravleva 2014; Ugarković 2016: 12–14; Chrzanowski 2020; James 2020; Sheiko 2020). So far, local imitations have been mainly hypothesized on the basis of macroscopic criteria (e.g., typology and macro-fabrics), while archaeometric data and evidence of in situ primary productions (e.g., kilns, molds, or wasters) are almost totally lacking both in Asia Minor and beyond with the exception of Nea Paphos on Cyprus (Kajzer 2013, 2016, 2017).

Whether the dispersal of Ephesos lamps is the result of regular trade or should be regarded as evidence of secondary cargo and/or souvenirs, the Ephesos lamps are in any case among the most widely distributed ceramic products of Ephesian Late Hellenistic ceramic workshops and, as such, they can be considered an archaeological marker for the upsurge in mobility that took place during the advanced/late 2nd and especially the 1st c. BCE (Giuliani 2005b and 2008; Ladstätter 2007: 206). Through the modes of appropriation and imitation in various Mediterranean-wide communities

and beyond (Chrzanowski 2020), Ephesos lamps can be also viewed in the light of choices maintained through multicultural interaction and cultural transfer. Such a phenomenon was not achieved with any other type of Hellenistic lamps, certainly not to such an extent.

The present paper employs a multi-proxy approach that combines morphological, stylistic, petrographic, and geochemical analyses. Previous petrographic and geochemical analyses conducted by Roman Sauer and Gerwulf Schneider suggested a local and/or regional production showing similarities with mold-made relief bowls and EGW (Sauer 1995a and 1995b; Zabełlicky-Scheffenecker et al. 1996; Ladstätter 2007; Hintermann 2016). Although pottery workshops of the Hellenistic period have still not been discovered in Ephesos, this argument is supported by the association of mold-made relief bowls and the molds for their manufacturing (c. 70 fragments that belonged to the main production of Ephesian mold-made relief bowls, i.e., the so-called IIAP-workshop), Ephesos lamps, EGW, and other Late Hellenistic fine tablewares discovered in the Magnesians Gate (Seiterle 1982; Rogl 2001; Giuliani and Rogl 2002; Rogl 2014). Even though these were found in a secondary deposition of the early 1st c. CE, the existence of the potter's quarter in the vicinity has been assumed (Seiterle 1982: 149; Sokolicek 2009: 341; Waldner personal communication). The above-mentioned archaeological evidence and archeometric analysis made on limited samples clearly supported the local production of Ephesos lamps in Ephesos; however, how these were really made was never a subject of any in-depth study. By enlarging the previous set of analyses with new samples and analytical methods and integrating the results with archaeological criteria, we aim at further defining how the local production was organized. In particular, we intend to clarify whether there were a few or many workshops producing Ephesos lamps in the region, what the distinctive features of these workshops were, and to what extent they were specialized and connected to the production of other coeval fine wares. Achieving these objectives is the necessary prerequisite to properly investigating the Mediterranean-wide dispersal of Ephesos lamps in terms of imports, imitations, and adaptations.

Archaeological context and ceramic repertoire

The Ephesian production of Late Hellenistic lamps is typically obtained through reducing firing atmospheres, which lends them the typical grey color of the fabric and the dark grey-black to grey, dully shining coating. Nevertheless, examples fired in an oxidizing atmosphere occur as well (Fig. 2d), though less commonly (Bussière and Lindros Wohl 2017: 30, 37). A distinctive micaceous fabric, with small quartz

and calcareous inclusions, can be recognized with the naked eye. Furthermore, Ephesos lamps are characterized by specific morphological traits and an eye-catching relief decoration that combines a wide range of different motifs. Morphological and stylistic studies conducted by Giuliani have identified six main groups of Hellenistic mold-made lamps thought to have originated in the workshops of Ephesos, each with several specific (sub-)types produced and used from the middle of the 2nd c. BCE until the first decades of the 1st c. AD (Giuliani 2001, 2004, 2005a, b, 2011). The study of the motifs' appearance and the preserved signatures has indicated that Ephesos lamps were produced by various craftspeople in different workshops (Giuliani 2001). One of the oldest, largest, and possibly most long-lived workshop was that of Asklepiades, whose products were exported from the early onset of their production, as evidenced by more than 50 pieces bearing this signature that are attested in Ephesos and around the Mediterranean (Giuliani 2005 b: 140, 141 and 2008: 92, n. 112).

Despite numerous hints at the existence of workshops in Ephesos associated with the production of Late Hellenistic tableware and lamps, such workshops have not been discovered yet (Ladstätter 2007: 206; Rogl 2014: 116; Ladstätter 2016: 265). However, several studies could cast light on many aspects of this production and the related socio-cultural phenomena (Mitsopoulos-Leon 1985; Giuliani and Rogl 2002; Rogl 2014; Ladstätter and Waldner *in press*). Besides the Ephesos lamps, typical locally produced tableware included cups with relief decoration (mold-made relief bowls), black- and red-gloss ware, Ephesian Grey Ware (EGW), and thin-walled pottery. Notwithstanding the typo-chronological groundwork, Ephesian pottery studies have in the last decades taken a turn towards a more contextual and interdisciplinary approach. Moreover, several important contexts have recently emerged in Ephesos that have benefited the study of Ephesos lamps as well. Over the years the comparison between the mold-made relief bowls and lamps has been of particular interest, also due to noticeable similarities of the decorative motifs (Giuliani and Rogl 2002). The current evidence suggests that the production of mold-made relief bowls in Ephesos (the so-called Süd-Atelier) started in the first half of the 2nd c. BCE and more probably in its second quarter, as none have been recovered from the fill of the western stoas (the so-called Störgraben), which is dated to 190 BCE (Rogl 2014: 132). Thus, the first mold-made relief bowls are slightly older than the first type of Ephesos lamps (group 1, see below) in the Lower Agora, dated to around the middle of the 2nd c. BCE or shortly after (Giuliani 2008: 90, 91). The published assemblages from Terrace House 2 show that the latest and most famous type of Ephesos lamps, known also as Howland 49A (here group 6, see below), appears at the end of the 2nd/beginning of the 1st c. BCE and is mostly widespread during the 1st c. BCE, when such lamps are frequently found together with

mold-made relief bowls and black- and red-gloss wares (e.g., WE 7, Waldner 2016: 337, 361). Their presence is further observed in the layers dated to the first decades of the 1st c. BCE, namely Late Augustan to Tiberian times, again in association with mold-made relief bowls and black- and red-gloss wares, but now also with thin-walled pottery, Eastern Sigillata A (ESA), Eastern Sigillata B (ESB), EGW and white-ground lagynoi (e.g., WE 7, Raum 41ain Waldner 2016: 334; also Waldner and Ladstätter 2014, WE 6, complex H/3; H-BI/1; WE 1, A-BI/1 and A-BI/4 in Ladstätter 2010: 174, 175, 177; WE 2, B-H/4 in Ladstätter 2010: 531). The presence of mold-made relief bowls in the latter contexts is, however, considered residual, since mid-1st c. BCE (or the third quarter of the 1st c. BCE?) is treated as the time around which the manufacture of mold-made relief bowls in Ephesos had come to an end (Rogl 2014: 135). The Howland 49 A type of Ephesos lamps remained the predominant lighting device until the Augustan times, and after its latest appearance in the Late Augustan to Tiberian contexts, it was replaced by local lamps in the Italian style and the locally-regionally produced Red-on-White lamps (see Waldner 2016: 367, n. 113, p. 370, and the diagram 1b on p. 371 for a comparison of the presence of lamp types in the Augustan and Late Augustan second half of 1st c. CE contexts; WE 4, Fundkomplex BI/1, BIV/2 Ladstätter 2005: 236, 241; Ladstätter and Waldner *in press*).

Geological setting

Ephesos is located in the Küçük Menderes valley at the point of contact between the Cycladic Metamorphic Complex to the west and the Menderes Massif to the east, both primarily defined by the presence of high-pressure metamorphic rocks (Okay 2001; Koralay et al. 2011). Çakmakoğlu's geological map reported in Figure 1 provides us with an exhaustive illustration of the different units exposed around the ancient city: the southeastern and eastern surroundings are dominated by the formations of Şirince Metaflysh, while the outcrops to the southwest, west, and north mostly relate to Efes Nappe (Çakmakoğlu 2007). The latter is in turn comprised of the Late Palaeozoic to Early Triassic Meryemana formation at the bottom and the Mesozoic Ayricadağ formation at the top. The Meryemana formation crops out to the southwest and is dominated by mica-schists, quartz-schists, phyllites, and marbles. At the upper levels of this formation metavolcanics and gneissose schist lenses often occur (Çakmakoğlu 2007). The Ayricadağ formation—which is broadly exposed to the north but shows dispersed lenses to the west and southwest as well—contains marbles and metacarbonates. The Şirince Metaflysh has instead a pelitic matrix composed of phyllites, garnet-schists, and mica-quartz-schists (Çakmakoğlu 2007). On specific locations within this matrix, tectonic slices or blocks of basic and

ultrabasic rocks can occur, such as metadiabases, serpentinized dunites, and peridotites.

Materials and methods

For the purpose of this paper, 45 samples of Ephesos lamps (Table 1) were examined through thin-section petrography, and 20 of these samples were further analyzed through neutron activation analysis (NAA). The analyzed lamps were sampled by different scholars over the course of time: older samples are referred to as EPHL1-22 and EPH240-244, the most recent ones as EPHLAM1-20. Due to the lack of remaining material, NAA could not be applied to older samples, most of which are lacking a precise chrono-typological attribution as well. Given these limitations the present paper does not intend to offer an exhaustive scenario for Ephesos lamps but rather to (1) make use of unpublished samples and data collected in the last three decades of research in Ephesos; (2) provide one of the first systematic and integrated reference data for an area and period that played a significant role in ceramic production and trade; (3) perform an explorative pilot study to guide future samplings and analyses as well as to test the hypotheses so far supported on the basis of the archaeological evidence.

The analyzed materials mainly originate from different contexts of the Lower Agora (known also as the Tetragnonos Agora) and Terrace House 2, while a few come from older excavations of the Basilica (Figs. 2 and 3). The samples incorporate several sub-types from the four main groups of Ephesos lamps (groups 1, 2, 5, and 6), based on the typology proposed by Giuliani. Lamps of group 1 have a small body with a sharp biconvex profile, high filling hole, flat or slightly curved shoulder, and mostly triangular nozzle and no handle (Fig. 2a and Fig. 3a–e). On the basis of the contextual analysis of Lower Agora assemblages, the limited series of sub-type 1 of group 1 (samples EPHL011, EPHLAM5, and EPHLAM12; Fig. 3b), with its specific motif variations, can be chronologically placed at the very beginning of the mold-made lamp production in Ephesos, around the middle of the 2nd c. BCE or shortly after (Giuliani 2008: 90, 91). The sub-type was already dispersed around the Aegean and it was possibly already connected with the Asklepiades workshop (Giuliani 2008: 92, n. 112). Sub-types 2 (samples EPHLAM1, EPHLAM14, and EPHLAM15; Fig. 3c, d) and 3 (samples EPHLAM2 and EPHLAM3; Fig. 3a, d) of the group 1 have a similar date; they morphologically differentiate themselves by a slightly higher body and a different treatment of the area around the filling hole, as well as in the motif repertoire.

A series of lamps described as group 2 (sample EPHLAM16, from the Asklepiades workshop; Fig. 3f) are

chronologically similar to group 1, but they present a somewhat different body outline, most notably a collar around the whole lamp. Such lamps were still in use in the early 1st c. BCE, as evident from an example found in Dwelling Unit 2 of Terrace House 2 (Ladstätter 2010: 533, B-K 339).

Group 5 (Fig. 3g–j) is morphologically different from group 1 mainly due to a wider ring around the disk, while several types, with a variety of motifs, are identified by a different treatment of the area surrounding the filling hole (samples EPHLAM4, EPHLAM7, and EPHLAM13 belong to sub-type 5.2; sample EPHLAM8 belongs to sub-type 5.3). These have been dated to the third quarter of the 2nd c. BCE and some to the later 2nd and (early?) 1st c. BCE, the latter also being corroborated by an example of an ATP monogram among our samples, contextually dated to the 1st c. BCE (EPHLAM7); whereas sub-type 5.3 has been seen as a direct prototype for the last and most known group of Ephesos lamps (group 6).

The samples of group 6 (Fig. 3k–n) typically refer to the youngest and most widespread type of Ephesos lamps, known also as Howland 49A type, which is characterized by a biconical body, flaring collar around the disk, ribbon handle, and obligatory oil-holes (samples EPH15, EPH19, EPH21, EPH241–243, EPHLAM9–11, EPHLAM18, and EPHLAM19). As noted above, their manufacture commenced in the late 2nd/1st BC, and lasted until the Late Augustan (early Tiberian?) times, and during this time they were the most common lamp type (Giuliani 2005: 140, 141, abb. 2, 2,3, and 2008: 92). Such lamps were undoubtedly produced in a number of workshops and were the first type to be clearly imitated outside Ephesos as well. Even though precise typological attributions were in many cases not possible, especially for old samples, significant information could be drawn from the decorative motifs, signatures, and even firing procedures. For instance, EPHLAM6 is decorated with a lanceolate-shaped leaf, which is generally associated with earliest types such as those represented by EPHLAM2. By contrast, EPHL022 decorated with Eros and grapes might be contemporary to lamps of group 6, though belonging to a distinct type. Typical of later types as well is either the association of rounded nozzles and oxidizing firing atmospheres (e.g., EPHL015 and EPHL019) or a row of double spirals (e.g., EPHL015), which respectively characterize the unattributed samples EPHLAM20 and EPH240. More generally, oxidizing firings like in EPHL013 and EPHL020 are known to occur mostly in later phases as a transition towards the Sigillata production. Finally, the small preserved base of EPHLAM17 did not enable any chrono-typological attributions but provided the signature of the Asklepiades workshop.

As an attempt to compensate for the limitations of the dataset, we also included data from other local fine wares as reference material. As already stated above, the two methods

Table 1 List of analyzed samples with associated archaeological context, chrono-typological features as well as petrographic and NAA groupings. Groups from the Bonn database fitting our NAA groups are also mentioned

Samples	Context; Inventory number	Petro-group	NAA group	Corresponding group in Bonn database	Typology	Chronology	Description of the lamp/fragment
EPHL001	Ephesos, Lower Agora; AG96/047	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL002	Ephesos, Lower Agora; AG96/029	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL003	Ephesos, Lower Agora; AG96/045	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL004	Ephesos, Lower Agora; AG93/023-2	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL005	Ephesos, Lower Agora; AG95/050-1	Minor group 1	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL006	Ephesos, Lower Agora; AG92/042-2	Minor group 1	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL007	Ephesos, Lower Agora; AG92/030-13	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL008	Ephesos, Lower Agora; AG87/079-1	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL009	Ephesos, Lower Agora; AG87/067-1	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL010	Ephesos, Lower Agora; AG87/067-2	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL011	Ephesos, Terrace House 2; HH2/99/679-1	Minor group 1	/	/	Ephesos lamp (group 1, type 1)	Mid 2 nd c. BCE or shortly after	Relief decoration: maple leaf and wine stalk
EPHL012	Ephesos, Terrace House; HH2/99/720-1	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL013	Ephesos, Basilica, Basilica N. 3	Minor group 2	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment; oxidized fired variant
EPHL015	Ephesos, Basilica; Basilica N. 1	Loner	/	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Almost whole lamp, rounded nozzle; relief shoulder decoration: double spirals flanked on both sides with small globules; oxidized fired variant
EPHL016	Ephesos, Lower Agora; AG96/080-3	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL017	Ephesos, Terrace House 2; HH2/99/702	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL018	Ephesos, Lower Agora; AG90/018	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment
EPHL019	Ephesos, Lower Agora; AG95/233-1	Minor group 2	/	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Half of the lamp, whole nozzle missing; relief shoulder decoration: tongues/petals, with triple berries towards the nozzle; oxidized fired variant
EPHL020	Ephesos, Terrace House 2; HH2/99/634	Loner	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body fragment; oxidized fired variant
EPHL021	Ephesos, Lower Agora; AG95/200-2	Minor group 2	/	/	Ephesos lamp (group 6)		

Table 1 (continued)

Samples	Context; Inventory number	Petro-group	NAA group	Corresponding group in Bonn database	Typology	Chronology	Description of the lamp/fragment
EPHL022	Ephesos, Basilica; HS-1	Major group	/	/	Ephesos lamp	Late 2 nd /early 1 st c. BCE–Late Augustan	Half of the lamp, relief shoulder decoration: so-called Ionian kyma; bridge toward the nozzle and small rosette; oxidized fired variant
EPH240	Ephesos	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Handle with a relief decoration, figural, Eros with grapes?
EPH241	Ephesos	Loner	/	/	Ephesos lamp (group 6)	Mid 2 nd –1 st c. BCE	Body, disk, shoulder, and nozzle fragment; relief shoulder decoration: row of double S spirals
EPH242	Ephesos	Major group	/	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Disk and shoulder fragment; relief shoulder decoration: row of rosettes
EPH243	Ephesos	Major group	/	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Disk and shoulder fragment; relief shoulder decoration: row of 8 petaled rosette
EPH244	Ephesos	Major group	/	/	Ephesos lamp	Mid 2 nd –1 st c. BCE	Body and base fragment
EPH/LAM1	Ephesos, Lower Agora; AG87/117-1	Major group	Group 05	/	Ephesos lamp (group 1, type 2)	Mid 2 nd c. BCE or shortly after	Shoulder/disk fragment; relief shoulder decoration: outer row of geometric pattern, inner elongated petals, so-called tongues; stylistically assigned to the Asklepiades workshop.
EPH/LAM2	Ephesos, Lower Agora; AG89/013-1	Major group	Group 03	Group I	Ephesos lamp (group 1, type 3)	Mid 2 nd c. BCE or shortly after	Shoulder fragment; relief decoration: lanceolate-shaped leaves; stylistically assigned to the Asklepiades workshop.
EPH/LAM3	Ephesos, Lower Agora; AG89/29-9	Major group	Group 03	Group I	Ephesos lamp (group 1, type 3)	Mid 2 nd c. BCE or shortly after	Nozzle fragment; relief decoration: heart-shaped leaf; stylistically assigned to the Asklepiades workshop.
EPH/LAM4	Ephesos, Lower Agora; AG89/37-2	Major group	Group 03	Group I	Ephesos lamp (group 5, type 2)	Advanced/late 2 nd c. BCE–(early?) 1 st c. BCE	Shoulder fragment; relief decoration: oval and elongated petals
EPH/LAM5	Ephesos, Lower Agora; AG89/78-2	/	Group 03	Group I	Ephesos lamp (group 1, type 1)	Mid 2 nd c. BCE or shortly after	Beveled nozzle fragment; relief decoration: head with a long beard, perhaps Silen
EPH/LAM6	Ephesos, Lower Agora; AG89/82-1	Major group	Group 03	Group I	Ephesos lamp	Mid 2 nd –1 st c. BCE	Shoulder/disk fragment; relief shoulder decoration: lanceolate-shaped leaf
EPH/LAM7	Ephesos, Lower Agora; AG90/18-4	Loner	Group 03	Group I	Ephesos lamp (group 5, type 2)	Late 2 nd /early 1 st c. BCE–Late Augustan	Almost whole lamp; relief shoulder decoration: outer row raised point and pointed arrow-shaped leaf, middle row three rows of raised darts pointed left, inner row calycinal flower, nozzle; palmette; workshop ATP-Monogram
EPH/LAM8	Ephesos, Lower Agora; AG90/18-7	Major group	Loner	/	Ephesos lamp (group 5, type 3)	Advanced/late 2 nd c. BCE–(early?) 1 st c. BCE	Shoulder/disk/nozzle fragment; without preserved decoration

Table 1 (continued)

Samples	Context; Inventory number	Petro-group	NAA group	Corresponding group in Bonn database	Typology	Chronology	Description of the lamp/fragment
EPH _L AM9	Ephesos, Lower Agora; AG90/21-34	Major group	Group 03	Group I	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Half of the lamp; without decoration
EPH _L AM10	Ephesos, Lower Agora; AG90/27-3	Major group	Group 03	Group I	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Shoulder fragment; relief decoration: ovoid leaf, raised points
EPH _L AM11	Ephesos, Lower Agora; AG90/27-7	Major group	Group 03	Group I	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Half of the lamp; relief shoulder decoration: oval leaves with a raised dot
EPH _L AM12	Ephesos, Lower Agora; AG90/41-2	Major group	Group 03	Group I	Ephesos lamp (group 1, type 1)	Mid 2 nd c. BCE or shortly after Augustan	Shoulder fragment; relief decoration: tendril and ellipsoid/lotus-shaped leaf; stylistically assigned to the Asklepiades workshop.
EPH _L AM13	Ephesos, Lower Agora; AG90/77-4	Major group	Group 03	Group I	Ephesos lamp (group 5, type 2)	Advanced/late 2 nd c. BCE–(early?) 1 st c. BCE	Shoulder fragment; alternation of oval and elongated leaves
EPH _L AM14	Ephesos, Lower Agora; AG91/3-1	Major group	Group 03	Group I	Ephesos lamp (group 1, type 2)	Mid 2 nd c. BCE or shortly after	Shoulder fragment; relief decoration: oak leaf and another feathered leaf; stylistically assigned to the Asklepiades workshop.
EPH _L AM15	Ephesos, Lower Agora; AG92/2	Major group	Group 03	Group I	Ephesos lamp (group 1, type 2)	Mid 2 nd c. BCE or shortly after	Whole lamp, relief shoulder decoration: oak leaf, lotus, tendril, maple leaf; nozzle: leaf in the shape of a heart; stylistically assigned to the Asklepiades workshop.
EPH _L AM16	Ephesos, Lower Agora; AG92/42-1	Major group	Group 03	Group I	Ephesos lamp (group 2)	Second half of the 2 nd –early 1 st c. BCE	Almost whole lamp, relief shoulder decoration: elongated and rounded petals; nozzle: heart-shaped leaf; signature: A (----)IIIA/ΔOY, Asklepiades workshop
EPH _L AM17	Ephesos, Lower Agora; AG92/50-2	Major group	Group 03	Group I	Ephesos lamp	Mid 2 nd –1 st c. BCE	Low base, mildly concave bottom, part of a signature, AC-/AHIL-/AΔ--, Asklepiades workshop
EPH _L AM18	Ephesos, Lower Agora; AG93/32-5	Major group	Loner /	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Shoulder fragment; relief decoration: geometric pattern, palmette, palmette with sepal
EPH _L AM19	Ephesos, Lower Agora; AG96/19A-2	Loner	Loner /	/	Ephesos lamp (group 6)	Late 2 nd /early 1 st c. BCE–Late Augustan	Shoulder fragment; relief decoration: rosette; oxidized fired variant
EPH _L AM20	Ephesos, Lower Agora; HH299/069	Loner	Group 04	Group H	Ephesos lamp	1 st c. BCE	Nozzle fragment; rounded tip; oxidized fired variant

Fig. 2 Pictures of types and variants of Ephesos lamps represented in this study: **(a)** group 1, sub-type 1 (shoulder decoration: maple leaf, wine stalk, and lotus); **(b)** group 1, sub-type 2 (shoulder decoration: ovules with three arches with rhomboids in between, triple row of cable pattern, four raised nozzle ridges from which the outer turn into a volute on each side of the shoulder with a mask towards the nozzle); **(c)** group 2 (shoulder decoration: raised oval leaves; three raised nozzle ridges from which the outer turn into a volute on each side of shoulder;

triple berries between the volute and leaves); **(d)** group 6 (shoulder decoration: vertical cable pattern); **(e)** group 6 (shoulder decoration: double S spiral); **(f)** group 1, sub-type 2 (shoulder decoration: so-called Ionian kyma, two rows of cable pattern, four raised nozzle ridges from which the outer turn into a volute on each side of shoulder); **(g)** group 6; **(h)** group 6 (shoulder decoration: tongues/pointed-oval leaves, triple berries towards the nozzle). Photos by: Niki Gail, OeAW-OeAI

applied here do not fully overlap; this reflects the compromises in our efforts to integrate old and new data and make the most efficient use of the remaining materials to be analyzed.

Thin-section petrography

The inclusions, clay matrix, and porosity of 45 thin sections were examined under a standard polarizing microscope, i.e., LEICA DM 2700P. The aim was to group the ceramic thin sections according to common strategies in the procurement and manipulation of raw materials. The resulting petro-groups were described and documented through photomicrographs at different magnifications. Comparative charts were used to quantify the main components (Rice 1987: 348).

The obtained results were interpreted within a wider reference database including 192 thin sections of other more and less coeval local wares — i.e., EGW, mold-made relief bowls and ESB — and clay samples collected around Ephesos and in the Meander Valley. Through an extensive survey, more than 200 clay deposits—some of which provided evidence of ancient or modern exploitation—were sampled in 1991 by R. Sauer, R. Jindra, M. J. Haiden and U. Outschar, in 2002 by S.

Ladstätter, R. Sauer, and B. Pichler, as well as in 2014 by L. Peloschek (Peloschek 2015). Samples collected in the close surroundings of the ancient city include Neogene alluvial or continental freshwater deposits, red lateritic weathering loams developed on carbonates or crystalline schists, soils developed on crystalline rocks available close to the Magnesian Gate in the Agora, as well as silty clays near the Artemision and harbor basin. The samples taken in the Küçük Meander Valley consist of Quaternary alluvial deposits. The petrographic, mineralogical and chemical analyses applied to these samples are the object of a separate publication in preparation and thus will not be discussed here in detail.

Neutron activation analysis

Twenty samples of Ephesos lamps were subjected to the standard analytical protocols for NAA of ceramics at the Atominstitut in Vienna (Sterba 2018). Sample size was approximately 100 mg per sample; irradiation time was 35 hours at a neutron flux density of $1 \cdot 10^{13} \text{ cm}^{-2} \text{ s}^{-1}$. For quantification, internationally certified reference materials (CANMET reference soil SO1, NIST SRM 1633b Coal Fly Ash, Light Sandy Soil BCR No. 142, NIST SRM 2702 Inorganics in Marine

Fig. 3 Drawings of selected lamps analyzed in this paper: **(a)** EPHLAM3 (group 1, sub-type 3); **(b)** EPHLAM12 (group 1, sub-type 1); **(c)** EPHLAM1 (group 1, sub-type 2); **(d)** EPHLAM14 (group 1, sub-type 2); **(e)** EPHLAM2 (group 1, sub-type 3); **(f)** EPHLAM16 (group 2); **(g)**

EPHLAM4 (group 5, sub-type 2); **(h)** EPHLAM13 (group 5, sub-type 2); **(i)** EPHLAM7 (group 5, sub-type 2); **(j)** EPHLAM8 (group 5, sub-type 3); **(k)** EPHLAM11 (group 6); **(l)** EPHLAM18 (group 6); **(m)** EPHLAM19 (group 6); **(n)** EPHLAM10 (group 6)

Sediment, and MC Rhyolite GBW 07113) as well as the Bonn reference material (Mommensen and Sjöberg 2007) were irradiated and measured together with the samples. With data from two measurements of 1,800 s and 10,000 s after decay times of 4 days and 4 weeks, respectively, the concentrations of the elements sodium (Na), potassium (K), scandium (Sc), chromium (Cr), iron (Fe), cobalt (Co), nickel (Ni), zinc (Zn), arsenic (As), rubidium (Rb), strontium (Sr), zirconium (Zr), antimony (Sb), caesium (Cs), barium (Ba), lanthanum (La), cerium (Ce), neodymium (Nd), samarium (Sm), europium (Eu),

terbium (Tb), ytterbium (Yb), lutetium (Lu), hafnium (Hf), tantalum (Ta), tungsten (W), thorium (Th), and uranium (U) were calculated.

Statistical analysis of the raw data was done by applying the best relative-fit factor calculations (i.e., dilution correction) as established in Bonn (Beier and Mommensen 1994), grouping the samples according to their modified Mahalanobis distance. In this process, a distance measure—which factors in the individual measurement errors—is calculated for each pair of samples. This distance is then minimized under consideration

of a possible dilution of the samples. This overcomes the potential statistical spread that results from the different content of water, silicon, or organic matter. Following this primary calculation, the distances are then used in an iterative process to find groups of samples.

The results were compared with 70 EGW and ESB previously analyzed in Vienna as well as published data from the Bonn database (Kerschner et al. 2002; Akurgal et al. 2002; Kerschner 2007). From this latter database, two reference groups interpreted as local and named Groups H and I have been used for comparison. Although these groups mainly relate to the Ephesian ceramic workshop tradition during the 7th and 6th c. BCE, they also include vessels from the original Hellenistic fills and molds of Hellenistic mold-made relief bowls found in the Magnesian gate.

Results

Thin-Section Petrography

The components mostly recurring in ceramic thin sections are quartz (generally monocrystalline and more rarely polycrystalline), muscovite, biotite, carbonate grains, K-feldspars, plagioclase, iron oxides, and quartz-schists (with both muscovite and biotite). The samples differ in optical activity, color, the calcareous or micaceous nature of the matrix, the grain-size distribution of inclusions, and the presence of slipping layers covering the vessel surfaces. Based on these differences the thin sections were divided into one major and two minor groups plus a small number of loners. The former includes 33 samples, while the two minor groups are each represented by three samples (Tables 1 and 2).

The major group (Fig. 4A–H) shows a calcareous, brown (both in PPL and XP), and isotropic clay matrix. Variation in color and grain-size distribution often occurs across the matrix, which indicates both different degrees of carbonate recrystallization after a high firing temperature and mixing procedures not sufficiently homogenized by working. Inclusions exhibit a unimodal distribution between 0.15 and 0.4 mm and a percentage abundance of 10%. The altered absorption colors of biotite inclusions in plane polarized light (Fig. 4C) are due to firing temperatures reaching at least 900°C. The high firing temperatures also determined the dissociation of carbonates, which significantly increased the porosity of the clay matrix characterized by typical yellowish pores.¹ Besides the most recurrent minerals and rocks mentioned above, some samples also contain a few sandstones with carbonate cements (Fig. 4B) and very few marbles. Though only in traces, altered

volcanic rocks with alkali feldspars (Fig. 4D), chert, and epidote appear in isolated samples.

The surfaces of most of the samples were covered with a clay slip layer, which strongly varies in terms of color, compactness, thickness, grain-size distribution, and optical activity (Fig. 4E–H). Some slip layers are optically more active than the underlying ceramic body, which is presumably due to the use of distinct raw materials, namely with different sintering degrees. Cases of double-layered slips have been observed as well (e.g., EPHL017, Fig. 4G). Similar evidence is known for the black-glaze Campana A vessels from south Tyrrhenian, Italy, and has been interpreted as a means to obtain the typical metallic shine of this ware (De Bonis et al. 2017). Differences in the slip layers inevitably affect the functional and aesthetic features of the end products. Non-vitrified slips have an increased permeability, shine, and scratch resistance. A higher permeability is in turn responsible for an increased seepage of oil into the porous clay body. However, in all cases, the slip adheres well and has similar dilatometric behaviors as the ceramic body.

The samples of the first minor group (Fig. 5A, B; Table 2) differ by the more frequent occurrence of muscovite, the higher incidence of inclusions (15–20%), as well as the lack of sandstones. EPHL011 differs by the presence in trace of mica-schists, epidotes, and marble altered by firing. Trace of altered volcanic rocks is only present in EPHL006. As in the major group, carbonate-rich components were dissociated through the firing process.

The second minor petro-group (Fig. 5C, D; Table 2) is distinguished by the features of the clay matrix, which is micaceous, non-calcareous, slightly to moderately active, and brown-reddish colored (both in PPL and XP). The lamps of this group were thus produced with different clay raw materials and fired at lower temperatures and under different conditions, i.e., oxidizing atmospheres. The variety of inclusions also differs, comprising gneisses² and amphiboles besides the minerals and rocks mentioned above (muscovite, quartz, quartz-schists, feldspars, plagioclase, and biotite). In contrast to the major and first minor groups, biotite minerals were not altered by the firing process and carbonate grains are lacking. Moreover, inclusions display angular shapes, cloudy spatial arrangements, and a bimodal grain-size distribution, which might indicate a tempering action by potters. The surface treatments also differ from the other groups since slipping layers occur only very rarely.

Six samples (i.e., 13.3% of the total assemblage) could not be assigned to the above-mentioned petro-groups and are to be

¹ The observations of firing and finishing procedures made under the polarizing microscope evidenced initial differences that need to be further investigated through additional methods (e.g., SEM).

² Though the fabrics are relatively fine, gneisses could be distinguished from quartz-schists based on the lack of a distinct schistosity, the more coarse-grained texture, and the lower amount of platy micaceous minerals.

Table 2 Main features for each identified petro-group. The types of inclusions are listed in decreasing order of importance and are italicized in case they are not present in each sample. Abbreviations: *qu*, quartz; *ca*, carbonate grains; *bt*, biotite; *mu*, muscovite; *kfs*, K-feldspar; *pl*, plagioclase; *ox*, iron oxides; *ep*, epidote; *amph*, amphibole

Petro-groups	Clay matrix					
	Inclusions	Type	Incidence	Grain-size distribution	Maximal diameter	Composition
Textural heterogeneities						
Optical activity						
Color XP						
Color PPL						
Major group	qu, ca, bt, mu, kfs, qu-schists, pl, ox, sandstones, volcanics, marble, chert, ep	10%	Unimodal	1.2 mm	Calcareous	Clay pellets, lenses, and recrystallized areas
Minor group 1	mu, qu, ca, bt, kfs, qu-schists, pl, ox, mu-schists, volcanics, ep, marble, chert	15–20%	Unimodal	0.4 mm	Calcareous	/
Minor group 2	mu, qu, qu-schists, gneiss, pl, kfs, ox, amph, bt	10–15%	Bimodal	0.8 mm	Micaceous	/

considered as loners (Fig. 5E–H, Table 3). These latter differ in the optical activity, nature, and color of the clay matrix as well as in the grain-size distribution rather than in the type of inclusions. Clay pastes with the most pronounced optical activity, micaceous nature, and yellow-orange-reddish colors (both in PPL and XP) as well as finest texture have been observed among the loners. The sample EPH241 (Fig. 5G, H) shows peculiar firing and finishing procedures, as suggested by the sandwich structure with dark core and reddish margins, the smaller grain size, and stronger orientation of inclusions towards the surfaces, as well as the slip layer with bloated pores. Color and structure variation from the core to the margins indicate an uneven distribution of heat within the ceramic body, which mostly occurs in cases of fast heating rates and short soaking times (Buxeda I Garrigós et al., 2003). According to the experimental work by Thér (2014), these are peculiar to a one-space firing structure where vessels are put in contact with the fuel, such as in a pit fire or bonfire. Furthermore, the finer layer under the surfaces suggests a strong burnishing action before the application of the clay slip. Some of the above-mentioned characteristics could be the result of a firing accident; however, their association with peculiar finishing procedures and paste recipes reveals a certain degree of intentionality, even though attested only in one sample.

Ephesos lamps show affinities with other coeval wares (Fig. 6A, D) in terms of raw materials and paste recipes. The vast majority—represented by the major petro-group and the first minor petro-group (36 out of 45 samples representing 80% of the analyzed assemblage)—share the same recipes with mold-made relief bowls (Fig. 6A, B). The few oxidizing fired variants—such as those classified into the second minor petro-group (= 6.6%)—correlate instead with EGW (Fig. 6C). Among loners, the finest oxidizing fired exemplars (e.g., EPHL015) are similar to some ESB (Fig. 6D).

The minero-petrographic associations of all thin sections (Tables 3 and 4) suggest the exploitation of local Neogene and Quaternary deposits, which formed from the weathering and/or transport of pelitic and carbonate metamorphic rocks. In particular, the weathering products of the Şirince Metaflysch and Meryemana formations located immediately east and south of the site—Kş and Pzm on the geological map in Fig. 1—and dominated by muscovite-biotite-quartz-schists were presumably exploited. The thin sections of clays collected around Ephesos and within the Küçük Menderes Valley further corroborate the local origin of raw materials (Fig. 6E–H). Besides frequent inclusions of quartz, feldspars, micas, carbonates, gneisses, and schists, local-fired clay occasionally include sandstones, volcanics, marbles, chert, hornblendes, and epidotes. However, based on the petrographic affinity of a very few lamps (e.g., EPH0L15) with ESB exemplars, a sporadic more distant sourcing beyond the Küçük Menderes Valley is not to be

Fig. 4 Thin-section microphotographs under XP (A, B, and E) and PPL (C, D, F, G, and H) of Ephesos lamps representative of the major group: (A) EPHLAM2; (B) EPHLAM4; (C) EPHLAM9; (D) EPHL003; (E) EPHLAM14; (F) EPHL008; (G) EPHL017; (H) EPHLAM2

excluded. Indeed, the ESB is assumed to have mainly been produced around Aydın—i.e., the ancient city of Tralles in the Büyük Menderes Valley—on the basis of both archaeological and geochemical evidence (Sauer 1995a: 36–64; Schneider 2000; Ladstätter 2007: 208–209).

Neutron activation analysis

The 20 samples of Ephesos lamps were grouped and compared to 23 EGW and 47 ESB previously analyzed at the Atominstut in Vienna as well as the data available from the

Fig. 5 Thin-section microphotographs under XP of Ephesos lamps representative of the first—(A) EPHL006 and (B) EHPL011—and second minor groups—(C) EPHL013 and (D) EPHL019—as well as petrologers EPHL015 (E), EPHL020 (F), and EPH241 (G, H)

Bonn database on Ephesian ceramic productions (Kerschner et al. 2002; Akurgal et al. 2002; Kerschner 2007).

Statistical investigation of the full dataset performed to establish a grouping for the lamps showed that there is no chemical relation between the lamps and the ESB and that one large group containing both lamps and EGW could be established

(the green circle on Fig. 7). This group is named Group03 and corresponds well with the so-called Group I published by Kerschner et al. (2002) and further refined in Kerschner (2007). Data from those publications—15 samples represented by green squares on Fig. 7—clearly groups together with 15 lamps (green triangles) and 16 EGW (green dots) analyzed

Table 3 Main features for each identified petro-group. The types of inclusions are listed in decreasing order of abundance. Abbreviations: *mu*, muscovite; *qu*, quartz; *bt*, biotite; *ca*, carbonate grains; *kfds*, K-feldspar; *ox*, iron oxides; *pl*, plagioclase; *kya*, kyanite; *ep*, epidote

Petro-loners	Inclusions	Clay matrix						
		Type	Incidence	Grain-size distribution	Maximal diameter	Composition	Optical activity	Color XP
EPH241	gneiss, qu, pl, kfds, bt	15–20%	Bimodal	0.84mm	/	Inactive	Brown-reddish margins + brown core	Brown margins + dark brown core
EPHL015	qu, mu, ox, bt, kfds, chert	5–7%	Unimodal	0.12mm	/	Very active	Orange	Orange
EPHL020	qu, mu, bt, ox, chert	7–10%	Unimodal	0.28mm	/	Slightly-intermediately active	Brown-orange	Brown-orange
EPHΛAM7	qu, ca, kfds, pl, mu, bt, ox	7–10%	Unimodal	0.25mm	Calcareous	Inactive-slightly active	Brown-light brown	Brown-light brown
EPHΛAM20	mu, qu, ox, bt, kfds	5%	Unimodal	0.2mm	/	Very-intermediately active	Reddish-brown	Brown-orange
EPHΛAM19	mu, ca, qu, ox, kfds, bt, sandstone, chert, kya, ep	10–15%	Bimodal	0.25mm	Micaceous+ calcareous	Very active	Beige-yellowish	Beige-yellowish

in Vienna and belonging to the most represented group among lamps, i.e., our Group03. The largest green square on Figure 7 represents the mean of Bonn “Group I,” which also remarkably fits our Group03.

Further data from the above-mentioned publications and from Akurgal et al. (2002) was used to add an unclassified Ephesos lamp (EPHΛAM20) to a large group of 27 samples belonging to Bonn “Group H” (blue squares on Fig. 7). Both groups, “Group I” and “Group H,” represent the local fingerprint of Ephesos (Kerschner 2007). While “Group I” includes both archaic and Hellenistic vessels as well as molds for the production of mold-made relief bowls that Rogl assigned to IIAP workshop, “Group H” only contains archaic vessels (Kerschner et al. 2002: 193–198). Group03 (i.e., Group I) is distinguished by the lower and higher values of lanthanides—i.e., La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu—and Rb and Ta, respectively. Though this still needs to be clarified in future publications, the low content of lanthanides is not surprising, since heavy minerals enriched in those elements—e.g., monazite, xenotime, allanite—rarely occur in the geological environment around Ephesos (Sauer 1995a and 1995b). The high values of alkali metals such as Rb could be instead related to the abundance of micas and/or feldspars as observed under the polarizing microscope. Table 1 reports the correspondence between Viennese and Bonn reference groups.

One lamp (EPHΛAM1) and one EGW are chemically similar to each other but different from the above-mentioned groups and fall into our Group05 (pink dot and triangle on Fig. 7). The remaining three lamps (EPHΛAM8, EPHΛAM18, and EPHΛAM19) could not be grouped at all and are thus to be considered as chemical loners. Analytical data for the 20 Ephesos lamp samples as well as the group means for the three groups containing Ephesos lamps can be found in Tables 4 and 5.

Although not coeval with Ephesos lamps, we also compare our NAA data with those obtained from Late Roman lamps from Rhodes, which were attributed to different areas of the western coast of Asia Minor, i.e., southern Aeolis, northern Ionia, and southern Ionia (Hein and Kilikoglou 2017: 651–657). No match has been found with our local groups 03, 04, and 05. This also pertains to Hein and Kilikoglou’s group A1, which fits with Klazomenai—i.e., group SMYR-E in Akurgal et al. 2002 and Kerschner and Mommsen 2009—but shows affinities with Ephesos according to Katsioti (2017: 662).

Discussion of the results

Although this remains to be further investigated on a larger set of samples, both thin-section and NAA analyses point to similar trends, namely the occurrence of a predominant local group shared with other coeval wares and the presence of a few loners (Table 1). Apart from a very few exceptions (i.e., 3

Fig. 6 Thin-section microphotographs under XP of mold-made relief bowls (A, B), EGW (C), ESB (D) fired clay samples within the Küçük Menderes Valley (E–H)

out of 17 cases), the NAA and petrographic predominant group—respectively mentioned as NAA Group03 and major group—widely match each other, as they include the same samples. The correlation between NAA and petrographic results decreases when considering loners: two NAA loners (EPHLM8, EPHLM18) belong to the major petro-group,

while NAA Group03 includes one petrographic loner (EPHLM7). Among petro-loners, EPHLM7 is the most akin to the major petrographic group, from which it differs only by the prevalence of feldspars over micas (Tables 2 and 3). As the dilution approach applied to NAA data strongly reduces the signal of inclusions, we can assume that

Table 4 Compositional data (concentration values) and measurement error for the samples measured by NAA. All values are in $\mu\text{g/g}$

Sample	NAA-Group (dil. fact.)	Na	K	Sc	Cr	Fe	Co	Ni	Zn	As	Rb	Sr	Zr	Sb	Cs
EPHLAM1	Group 05 (0.97)	5070 ± 98.4	28600 ± 462	17.2 ± 0.359	207 ± 3.32	44200 ± 651	21.9 ± 0.516	157 ± 3.29	98.6 ± 2.15	32 ± 0.638	163 ± 2.97	174 ± 7.59	182 ± 9.72	2.86 ± 0.107	8 ± 0.0789
EPHLAM2	Group 03 (1.07)	6260 ± 121	27500 ± 444	16.2 ± 0.338	190 ± 3.13	47800 ± 703	17.9 ± 0.419	136 ± 2.85	106 ± 2.31	82.6 ± 1.64	171 ± 3.11	190 ± 8.27	185 ± 9.92	3.28 ± 0.123	7.69 ± 0.0758
EPHLAM3	Group 03 (1.09)	6240 ± 121	28300 ± 457	15.9 ± 0.331	200 ± 3.3	48200 ± 709	21.4 ± 0.503	147 ± 3.09	118 ± 2.56	125 ± 2.49	160 ± 2.9	182 ± 7.91	189 ± 10.1	2.8 ± 0.105	6.7 ± 0.0661
EPHLAM4	Group 03 (0.93)	4800 ± 93.2	30200 ± 487	20.2 ± 0.422	250 ± 4.11	51700 ± 761	26 ± 0.611	188 ± 3.95	136 ± 2.96	25.4 ± 0.506	194 ± 3.52	172 ± 7.47	226 ± 12.1	2.74 ± 0.103	8.92 ± 0.0879
EPHLAM5	Group 03 (1.01)	5150 ± 99.9	29000 ± 468	18.8 ± 0.393	231 ± 3.8	49800 ± 733	22.8 ± 0.536	186 ± 3.91	102 ± 2.23	35.2 ± 0.702	180 ± 3.27	144 ± 6.29	209 ± 11.2	3.53 ± 0.133	8.53 ± 0.0841
EPHLAM6	Group 03 (0.96)	5440 ± 106	32200 ± 520	19.2 ± 0.4	214 ± 3.53	53200 ± 782	23.7 ± 0.557	166 ± 3.49	118 ± 2.57	43.3 ± 0.863	219 ± 3.99	174 ± 7.58	224 ± 12	3.44 ± 0.129	10 ± 0.0989
EPHLAM7	Group 03 (1.26)	6310 ± 122	23000 ± 371	14 ± 0.292	164 ± 2.71	37000 ± 544	18.5 ± 0.435	118 ± 2.48	89.7 ± 1.95	53.6 ± 1.07	148 ± 2.7	199 ± 8.66	147 ± 7.84	3.19 ± 0.12	6.59 ± 0.065
EPHLAM8	Loner	6370 ± 124	23800 ± 384	21.5 ± 0.45	393 ± 6.48	55300 ± 813	31.9 ± 0.749	304 ± 6.39	111 ± 2.42	54.4 ± 1.08	117 ± 2.14	281 ± 12.2	192 ± 10.3	4.13 ± 0.155	7.43 ± 0.0733
EPHLAM9	Group 03 (0.92)	5930 ± 115	33600 ± 543	19.2 ± 0.401	235 ± 3.87	48300 ± 711	22.9 ± 0.537	158 ± 3.31	126 ± 2.74	16.2 ± 0.323	226 ± 4.12	154 ± 6.7	204 ± 10.9	2.94 ± 0.11	10 ± 0.0991
EPHLAM10	Group 03 (0.92)	7520 ± 146	33400 ± 539	18.6 ± 0.389	215 ± 3.55	47900 ± 705	22.3 ± 0.523	146 ± 3.07	120 ± 2.6	89 ± 1.77	213 ± 3.88	153 ± 6.66	210 ± 11.2	2.61 ± 0.098	9.16 ± 0.0904
EPHLAM11	Group 03 (0.95)	4760 ± 92.4	30800 ± 496	18.4 ± 0.384	227 ± 3.73	47400 ± 698	24.1 ± 0.566	173 ± 3.64	116 ± 2.54	80.3 ± 1.6	202 ± 3.68	165 ± 7.21	199 ± 10.6	3.44 ± 0.129	8.88 ± 0.0876
EPHLAM12	Group 03 (0.88)	4200 ± 81.6	32900 ± 531	19.5 ± 0.408	231 ± 3.8	54100 ± 797	26.4 ± 0.619	199 ± 4.18	139 ± 3.03	47.3 ± 0.942	213 ± 3.88	186 ± 8.1	216 ± 11.5	7.82 ± 0.294	9.25 ± 0.0912
EPHLAM13	Group 03 (0.80)	5640 ± 109	35500 ± 572	21.5 ± 0.448	238 ± 3.93	58000 ± 853	24.8 ± 0.583	178 ± 3.73	137 ± 2.97	17.8 ± 0.355	256 ± 4.65	151 ± 6.57	231 ± 12.3	3.33 ± 0.125	11.2 ± 0.11
EPHLAM14	Group 03 (0.97)	4610 ± 89.4	29800 ± 482	19 ± 0.398	236 ± 3.89	51900 ± 764	23.8 ± 0.56	174 ± 3.66	117 ± 2.54	43.1 ± 0.859	182 ± 3.31	174 ± 7.6	174 ± 9.33	3.33 ± 0.125	8.49 ± 0.0837
EPHLAM15	Group 03 (0.86)	3090 ± 59.9	30700 ± 495	20.8 ± 0.434	269 ± 4.44	59400 ± 874	25.7 ± 0.603	204 ± 4.29	131 ± 2.86	49.5 ± 0.985	200 ± 3.64	170 ± 7.40	211 ± 11.3	4.1 ± 0.154	10.1 ± 0.0994
EPHLAM16	Group 03 (0.93)	5620 ± 109	33200 ± 535	19.3 ± 0.403	226 ± 3.72	48400 ± 712	20.7 ± 0.487	174 ± 3.65	114 ± 2.48	40.1 ± 0.800	216 ± 3.93	148 ± 6.46	218 ± 11.7	3.58 ± 0.134	9.51 ± 0.0938
EPHLAM17	Group 03 (0.94)	7630 ± 148	32400 ± 523	18.9 ± 0.394	226 ± 3.72	49200 ± 724	22.8 ± 0.536	161 ± 3.39	116 ± 2.53	17.2 ± 0.342	203 ± 3.70	155 ± 6.73	239 ± 12.8	3.32 ± 0.125	9.29 ± 0.0917
EPHLAM18	Loner	4310 ± 83.7	31200 ± 503	18.8 ± 0.393	228 ± 3.76	49500 ± 728	23.6 ± 0.555	167 ± 3.51	125 ± 2.71	37.1 ± 0.74	179 ± 3.26	149 ± 6.5	254 ± 13.6	2.31 ± 0.0869	8.09 ± 0.0797
EPHLAM19	Loner	4870 ± 94.5	25800 ± 416	17 ± 0.354	218 ± 3.6	50700 ± 746	23.2 ± 0.546	195 ± 4.1	166 ± 3.61	94.3 ± 1.88	155 ± 2.82	169 ± 7.36	174 ± 9.3	3.59 ± 0.135	6.63 ± 0.0654
EPHLAM20	Group 04 (0.96)	8070 ± 157	28700 ± 464	26.4 ± 0.551	154 ± 2.54	77900 ± 1150	33.9 ± 0.795	96.3 ± 2.02	155 ± 3.38	40.6 ± 0.809	147 ± 2.68	188 ± 8.18	209 ± 11.2	4.37 ± 0.164	10.2 ± 0.101

Sample	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	W	Th	U
EPHLAM1	505 ± 10.2	38.5 ± 0.528	74.8 ± 1.18	38.1 ± 0.959	6.04 ± 0.114	1.31 ± 0.0211	0.763 ± 0.0178	3.27 ± 0.0392	0.496 ± 0.00962	5.05 ± 0.0662	1.27 ± 0.014	3.3 ± 0.103	15.5 ± 0.232	3.46 ± 0.115
EPHLAM2	517 ± 10.5	43 ± 0.59	81.3 ± 1.28	38.9 ± 0.977	6.42 ± 0.121	1.39 ± 0.0223	0.899 ± 0.0209	3.78 ± 0.0453	0.537 ± 0.0104	5.31 ± 0.0696	1.18 ± 0.0131	3.85 ± 0.12	18.8 ± 0.283	3.67 ± 0.122
EPHLAM3	750 ± 15.2	39 ± 0.536	78.4 ± 1.23	35.4 ± 0.894	6.22 ± 0.117	1.37 ± 0.022	0.784 ± 0.0182	3.66 ± 0.0439	0.505 ± 0.00979	5.07 ± 0.0665	1.18 ± 0.0131	0.541 ± 0.0176	17.7 ± 0.266	4.55 ± 0.151
EPHLAM4	608 ± 12.3	47.7 ± 0.654	93.5 ± 1.47	42.9 ± 1.07	7.3 ± 0.138	1.66 ± 0.0266	1 ± 0.0233	4.09 ± 0.0491	0.57 ± 0.011	5.14 ± 0.0675	1.34 ± 0.0148	2.98 ± 0.0926	20.6 ± 0.31	5.16 ± 0.172
EPHLAM5	463 ± 9.36	43 ± 0.591	83.7 ± 1.32	40.0 ± 1.0	6.76 ± 0.128	1.5 ± 0.024	1 ± 0.0233	3.83 ± 0.0458	0.497 ± 0.00963	5.35 ± 0.0702	1.23 ± 0.0136	2.47 ± 0.0769	17.6 ± 0.265	5.12 ± 0.17
EPHLAM6	479 ± 9.68	48.9 ± 0.671	96.8 ± 1.52	48.8 ± 1.23	7.74 ± 0.146	1.65 ± 0.0265	1.13 ± 0.0262	4.35 ± 0.0522	0.525 ± 0.0102	4.91 ± 0.0644	1.4 ± 0.0155	2.49 ± 0.0775	22.7 ± 0.34	5.24 ± 0.174
EPHLAM7	505 ± 10.2	35.2 ± 0.484	70.2 ± 1.11	28.9 ± 0.724	5.12 ± 0.0965	1.26 ± 0.0203	0.877 ± 0.0204	3.38 ± 0.0405	0.437 ± 0.00848	4.18 ± 0.0548	0.991 ± 0.011	3.1 ± 0.0963	14.9 ± 0.224	2.83 ± 0.0944
EPHLAM8	545 ± 11	35.6 ± 0.489	75.4 ± 1.19	34 ± 0.851	5.31 ± 0.10	1.33 ± 0.0213	0.564 ± 0.0131	2.99 ± 0.0359	0.45 ± 0.00872	5.86 ± 0.0768	0.953 ± 0.0106	2.52 ± 0.0785	12.5 ± 0.188	2.8 ± 0.0933

Table 4 (continued)

EPHLLAM9	510 ± 10.3	48.1 ± 0.66	97.4 ± 1.53	47.2 ± 1.19	7.58 ± 0.143	1.66 ± 0.0267	1.04 ± 0.0241	4 ± 0.0479	0.584 ± 0.0113	5.46 ± 0.0715	1.42 ± 0.0158	2.67 ± 0.0829	21.4 ± 0.322	5.15 ± 0.172
EPHLLAM10	555 ± 11.2	50 ± 0.687	101 ± 1.59	42.2 ± 1.06	7.83 ± 0.148	1.65 ± 0.0264	1.08 ± 0.0252	4.04 ± 0.0485	0.605 ± 0.0117	6.51 ± 0.0854	1.41 ± 0.0156	3.71 ± 0.115	21.2 ± 0.319	4.86 ± 0.162
EPHLLAM11	505 ± 10.2	48.1 ± 0.661	94.7 ± 1.49	42.3 ± 1.06	7.83 ± 0.148	1.61 ± 0.0259	1.02 ± 0.0238	4.18 ± 0.0501	0.616 ± 0.012	4.99 ± 0.0655	1.31 ± 0.0145	3.48 ± 0.108	20.8 ± 0.312	4.96 ± 0.165
EPHLLAM12	582 ± 11.8	50.1 ± 0.688	101 ± 1.59	49.8 ± 1.25	8.44 ± 0.159	1.68 ± 0.027	1.11 ± 0.0258	4.64 ± 0.0556	0.682 ± 0.0132	4.92 ± 0.0644	1.39 ± 0.0154	4.04 ± 0.126	21.8 ± 0.327	6.18 ± 0.206
EPHLLAM13	540 ± 10.9	56 ± 0.768	111 ± 1.74	51.1 ± 1.28	9.01 ± 0.17	1.86 ± 0.0299	1.33 ± 0.031	5.06 ± 0.0607	0.722 ± 0.014	5.41 ± 0.071	1.57 ± 0.0174	4.09 ± 0.127	26.0 ± 0.39	5.81 ± 0.193
EPHLLAM14	532 ± 10.8	46.9 ± 0.644	90.6 ± 1.43	43.5 ± 1.09	7.31 ± 0.138	1.58 ± 0.0254	1.04 ± 0.0243	4.03 ± 0.0482	0.565 ± 0.0109	4.79 ± 0.0628	1.24 ± 0.0137	3.29 ± 0.102	19.3 ± 0.29	5.10 ± 0.17
EPHLLAM15	578 ± 11.7	52.8 ± 0.725	106 ± 1.67	47.2 ± 1.19	8.6 ± 0.162	1.87 ± 0.0301	BDL	4.35 ± 0.0521	0.623 ± 0.0121	5.14 ± 0.0674	1.32 ± 0.0146	5.76 ± 0.179	22.2 ± 0.333	4.95 ± 0.165
EPHLLAM16	579 ± 11.7	47.1 ± 0.646	94.2 ± 1.48	40.0 ± 1.00	7.67 ± 0.145	1.59 ± 0.0256	1.01 ± 0.0236	4.2 ± 0.0504	0.598 ± 0.0116	5.50 ± 0.0721	1.41 ± 0.0157	4.25 ± 0.132	21.8 ± 0.327	5.01 ± 0.167
EPHLLAM17	560 ± 11.3	47.3 ± 0.65	94.3 ± 1.48	48.8 ± 1.23	7.26 ± 0.137	1.61 ± 0.0258	0.885 ± 0.0206	3.93 ± 0.0472	0.588 ± 0.0114	6.01 ± 0.0788	1.4 ± 0.0155	3.1 ± 0.0965	21.3 ± 0.32	4.97 ± 0.166
EPHLLAM18	634 ± 12.8	43.4 ± 0.596	83.9 ± 1.32	40.8 ± 1.02	6.65 ± 0.125	1.54 ± 0.0247	0.76 ± 0.0177	3.61 ± 0.0433	0.513 ± 0.00994	6.62 ± 0.0868	1.1 ± 0.0122	3.03 ± 0.0942	16.2 ± 0.243	3.79 ± 0.126
EPHLLAM19	627 ± 12.7	40.1 ± 0.55	79 ± 1.24	40.4 ± 1.02	6.68 ± 0.126	1.36 ± 0.0219	0.852 ± 0.0198	3.52 ± 0.0422	0.527 ± 0.0102	4.76 ± 0.0624	1.13 ± 0.0125	3.29 ± 0.102	15.8 ± 0.238	4.87 ± 0.162
EPHLLAM20	679 ± 13.7	73.9 ± 1.01	149 ± 2.34	70.2 ± 1.76	11.4 ± 0.216	2.77 ± 0.0445	1.59 ± 0.0371	5.39 ± 0.0646	0.741 ± 0.0144	5.33 ± 0.0699	0.984 ± 0.0109	3.13 ± 0.0973	21.7 ± 0.326	4.27 ± 0.142

EPHLLAM7 was produced with similar clay sources but different paste preparations compared to most of the lamps. By the same principle, the NAA loners EPHLLAM8 and EPHLLAM18 indicate instead the use of distinct clay sources, although their inclusions do not qualitatively and quantitatively differ from that observable in the majority of lamps. Nevertheless, both thin-section petrography and NAA concur in differentiating EPHLLAM19 and EPHLLAM20 from all the other lamps.

In general, thin-section petrography evidences a higher variability compared to NAA: nine recipes including three petrogroups and six petro-loners were identified under the microscope vs. the three groups and three loners that emerged from NAA. This is probably because technological aspects such as finishing and firing—which do not anyhow affect the concentration of trace elements—were considered as distinguishing criteria under the microscope. A further aspect that might have affected the variability is the number of samples, which is significantly higher for thin-section petrography (45 vs. 20 for NAA). In fact, if we look only at the 19 samples analyzed through both methods, the number of petrographic recipes decreases from nine to four and becomes thus less than those identified via NAA. However, as many other coeval wares petrographically akin to Ephesos lamps repeatedly fall into only two well-established NAA groupings, we would not expect an increased geochemical variability by adding new lamp samples. At any rate, the NAA results evidence a noticeable constancy and continuity in the exploitation of supply sources in Ephesos, which dates back at least to the Archaic times. A further result distinguishing thin-section petrography from NAA is the affinity of isolated oxidizing fired lamps with ESB. In order to interpret this mismatch in terms of raw material procurement and processing, further NAA analyses have to be applied to fine-grained oxidizing fired variants of lamps in the future. In order to establish a chronological sequence in the use and processing of raw materials, we designed a seriation table that relates petro- and NAA groupings with chrono-types (Fig. 8). The table also includes the information on decorative motifs, workshop attributions, and firing atmospheres as factors that can affect the nature of ceramic recipes as well. The predominant compositional group emerging both from petrographic and NAA analyses includes specimens from every typological group, though the earliest group 1 significantly predominates over the later groups 2, 5, and 6. All the exemplars belonging to this predominant compositional group were fired under reducing atmospheres and decorated with a wide spectrum of motifs, such as elongated petals and heart-shaped, lotus-shaped, lanceolate, ovoid, and oak leaves. All the lamps attributed to the Asklepiades workshop, whether on the basis of decorative style or signatures, fall into this predominant compositional group. The few remaining unattributed lamps (four out of 12 samples) belong to later types (5 and 6) and are generally decorated with oval and elongated

Fig. 7 Principal component analysis (PCA) of the dilution-corrected data. Group03 and Group05 contain both grey plates and lamps, while Group04 shows a single lamp that fits the data in the literature. Group means of “Group I” and “Group H” are taken from Kerschner (2007) to provide a visual reference point. Ellipses depict 95% confidence intervals for the groups; in case of Group03 and Group04 this includes literature data, thus providing our suggested grouping for “Group I” and “Group H,” respectively

leaves. As already stated, both methods could not be integrated on all the samples for a variety of reasons. Three samples could fall into the predominant NAA/petro-group once this integration occurs, as they belong either to the major petro-group (e.g., EPH242, EPH243) or to the major NAA group (e.g., EPHLAM5). EPHLAM5 belongs to the first typological group, bears a figural decoration depicting Silen and, like the samples classified into the predominant NAA/petro-group, was fired under reducing atmospheres. The same firing procedures characterize EPH242 and EPH243, which, however, belong to the latest type. EPH243 is in particular decorated with a row of petaled rosettes.

Petrographic and NAA loners are exclusively related to later types 5 and 6, usually fired under oxidizing atmospheres and decorated with palmettes, rosettes, or double spirals. In general, oxidizing fired variants are distinguished by a higher compositional variability: when they are not loners, they belong to small-sized reference groups, such as the second minor petro-group related to lamps of type 6 decorated with triple berries and the so-called Ionian Kyma. The first minor petro-group includes instead reducing fired variants of the earliest type decorated with maple leaves and wine stalks. Interestingly, the only exemplar with the ATP monogram here analyzed (EPHLAM7) shares the same NAA group—i.e., the same clay sources—with the exemplars of the Asklepiades workshop but exhibits distinct petrographic features—i.e., paste preparation—which make it a petro-loner.

The seriation table reported in Figure 8 evidences changes at the transition to type 5, i.e., between the third quarter of the 2nd c. BCE. and the early 1st c. BCE. These changes occurred at a compositional, stylistic, and technological level: new sources and recipes were used, leading to a higher compositional variability, which corresponds to the emergence of a wider spectrum of decorative motifs and the development of oxidizing fired variants.

Conclusions

The Ephesos lamps taken under consideration here were produced according to variable raw material procurement patterns, paste preparation modes, surface treatments, and firing procedures within the Küçük Menderes Valley. In combination with the variety of decorative motifs and preserved signatures (Giuliani 2001), this points to a network of local/regional workshops rather than to a single-unit production model. Nonetheless, one group clearly predominates when we compare petrographic and NAA data. This includes lamps related to different workshops, types, and decorative motifs as well as other coeval wares, such as EGW and mold-made relief bowls. In other words, a significant part of the Late Hellenistic ceramic production shared the same raw materials and paste preparation. Despite similarities in decorative motifs, previous studies have questioned the probability of a

Table 5 Means and spread for the three groups described in our paper with all values given in $\mu\text{g/g}$. Literature data available for groups I and H (Akurgal et al. 2002; Kerschner 2007) have been included in the calculations of our Group03 and Group04. Thus, group data for Group03 and Group04 that we present here include our suggestion for the new group values for group I and group H, respectively

	Na	K	Sc	Cr	Fe	Co	Ni	Zn	As	Rb	Sr	Zr	Sb	Cs
Group03 (Group I)	N = 4910 $\pm$ 1530 46	29800 $\pm$ 1430	18.0 $\pm$ 0.598	207 $\pm$ 14.1	48900 $\pm$ 1930	23.1 $\pm$ 5.15	160 $\pm$ 28.9	113 $\pm$ 7.78	27.1 $\pm$ 503	185 $\pm$ 10.1	173 $\pm$ 37.4	195 $\pm$ 36.9	3.52 $\pm$ 1.34	8.23 $\pm$ 0.522
Group04 (Group H)	N = 10100 $\pm$ 1660 27	30200 $\pm$ 1800	25.8 $\pm$ 0.664	168 $\pm$ 22	73100 $\pm$ 3520	34.4 $\pm$ 6.87	103 $\pm$ 44.4	150 $\pm$ 20.2	27.6 $\pm$ 11.6	151 $\pm$ 8.37	184 $\pm$ NA	239 $\pm$ 34.3	4.01 $\pm$ 0.525	10.3 $\pm$ 0.955
Group05	N = 2 4020 $\pm$ 986	28000 $\pm$ 321	16.6 $\pm$ 0.363	194 $\pm$ 5.01	43300 $\pm$ 452	21.6 $\pm$ 0.4	155 $\pm$ 2.73	97 $\pm$ 1.59	27.6 $\pm$ 4.31	154 $\pm$ 8.07	167 $\pm$ 6.9	184 $\pm$ 11.5	2.66 $\pm$ 0.182	7.27 $\pm$ 0.683

	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	W	Th	U
Group03 (Group I)	518 $\pm$ 74.2	44.2 $\pm$ 1.67	88.9 $\pm$ 2.45	40.5 $\pm$ 3.58	7.12 $\pm$ 0.359	1.54 $\pm$ 0.0515	0.995 $\pm$ 0.0941	3.94 $\pm$ 0.137	0.532 $\pm$ 0.035	5.05 $\pm$ 0.504	1.24 $\pm$ 0.0479	1.84 $\pm$ 0.642	18.8 $\pm$ 1.15	4.88 $\pm$ 0.746
Group04 (Group H)	759 $\pm$ 108	62.1 $\pm$ 3.12	135 $\pm$ 7.51	60.3 $\pm$ 5.21	11.3 $\pm$ 1.61	2.67 $\pm$ 0.142	1.51 $\pm$ 0.0893	5.16 $\pm$ 0.238	0.696 $\pm$ 0.0322	5.35 $\pm$ 0.818	0.997 $\pm$ 0.0824	2.57 $\pm$ 0.544	20.5 $\pm$ 0.756	3.9 $\pm$ 0.406
Group05	465 $\pm$ 36.4	37.5 $\pm$ 0.469	73 $\pm$ 0.857	36.4 $\pm$ 1.37	5.90 $\pm$ 0.0795	1.30 $\pm$ 0.0195	0.754 $\pm$ 0.0159	3.15 $\pm$ 0.075	0.477 $\pm$ 0.013	5.15 $\pm$ 0.311	1.08 $\pm$ 0.183	3.00 $\pm$ 0.28	14.4 $\pm$ 0.968	3.29 $\pm$ 0.151

production of relief mold-made bowls and Ephesos lamps in the same workshops due to technological (e.g., quality of the slip) and chronological criteria (Ladstätter and Waldner *in press*). Thus, the predominance of one compositional group across different wares would rather suggest a number of distinct production units using the same clay source and following more or less the same generic recipe. Advancing this interpretation, one can even imagine that the procurement and processing of raw materials were undertaken either communally through forms of co-operation—which could also include shared facilities such as large clay-processing basins—or by an additional labor force possibly operating beyond single workshops.

Though this needs to be further corroborated on a larger set of samples, the lower and higher variability of NAA and petrographic data could indicate that raw materials collected from the same sources were processed in different ways, which were sometimes workshop-specific such as in the case of the ATP workshop. Significantly more obvious is the higher variability of surface treatments (e.g., clay slipping) in comparison to other technical stages. These fluctuations in standardization along the manufacturing process might indicate a division of labor tasks within the chaîne opératoire of Ephesos lamps. As stressed by Cuomo di Caprio (2007: 324) for some Campana C plates from Morgantina, those who were in charge of shaping vessels did not necessarily deal with either the surface finishing and slipping or with the firing process. Concerning Ephesos lamps, it remains nonetheless unclear why in such a cultural *koine* the technical knowledge necessary to obtain vitrified slips and thus better-suited end products, both in functional and aesthetic terms, was not transmitted as widely as other parameters.

The centralized strategies of raw material procurement and the division of tasks along the chaîne opératoire fit well with the hypothesis of highly specialized workshops supported by the city to fill the demand of an increased local and regional market (Ladstätter 2007; Ladstätter and Waldner *in press*). The closest model of production assumable is an initial nucleated workshop industry, through which individual workshops cluster around shared facilities and labor force, also not specialized, in order to optimize the productivity of mold-made ware. A different picture clearly emerges from oxidizing fired variants despite the reduced number of samples analyzed so far. These variants differ from the more widespread reducing ones by the production modes, places, and organization. Distinct and quite variable strategies in raw materials procurement and modes of paste preparation, surface treatments, and firing were indeed employed. Unfortunately, the selection of samples from a limited number of contexts in such a huge city does not allow us to discuss our results in terms of customers' preferences. However, we would not expect significant differences in relation to distinct contexts of provenance, as types and sub-types invariably occur within the city and our

Fig. 8 Seriation table correlating chrono-typology, NAA, and petrographic groups as well as decorative motifs and signatures. Only samples with a clear typological attribution are reported: EPHL011 for the first minor petro-group; EPHLAM5 for the major NAA group; EPHLAM1, EPHLAM2, EPHLAM3, EPHLAM4, EPHLAM9, EPHLAM10, EPHLAM11, EPHLAM11, EPHLAM12, EPHLAM13, EPHLAM14, EPHLAM15, and EPHLAM16 for the predominant NAA/petro-group; EPHLAM 8, EPHLAM 18, and EPHLAM19 for

NAA loners; EPHL015, EPH241, and EPHLAM07 for petro-loners; EPH242 and EPH243 for the major petro-group; and EPHL19 and EPHL21 for the second minor petro-group. The samples for which the petrographic and NAA results did not coincide (e.g., EPHLAM7, EPHLAM8, and EPHLAM18) are not reported. The red vertical dashed line indicates changes by the late 2nd c. BCE in the raw material procurement and processing. The correlation with decorative motifs has to be taken as a general trend.

petrographic recipes, including loners, are represented in almost each context investigated here.

At a diachronic level, the correlations between chrono-typological and compositional groups evidence a general continuity in the raw material procurement patterns and paste preparation modes. The distribution of the main compositional group across the various types indicates a well-established tradition of at least 100 years ranging from the earliest exemplars of the mid 2nd c. BCE to the Howland 49A type produced until the Late Augustan times. Despite the general continuity, slight fluctuations are observable in the course of time. By the late 2nd c. BCE, the incidence of the predominant group decreases, while new supply sources and paste preparation are established. Intriguingly, in the latest phases, typologically unidentified lamps appear, i.e., typological singletons. The highest variability of the latest phases in terms of both typological and compositional features suggests that an increased number of workshops were producing lamps in the region. As this variability is partially related to oxidizing fired variants, the finest variants of which show petrographic affinities with the ESB, this change could also indicate a gradual transfer of potting activities towards areas providing better-suited clay sources such as the Büyük Menderes Valley.³

Though preliminary, our results shed new light on the organization of the pottery production at Ephesos in a period when local ceramics reached an unprecedented level in terms of quality and distribution (Ladstätter 2007; Ladstätter and Waldner in press). Furthermore, they represent an important step towards the systematization of compositional data aimed

at reconstructing the network of workshops and exchanges around Ephesos. Future aims consist in further characterizing some steps of the operational sequence, such as, for instance, surface finishing and firing, as well as enlarging the sampling to Ephesos lamps found across the Mediterranean in order to assess the distribution scale of the single local/regional workshops and to identify their Mediterranean-wide imitations.

Methodologically, this study further evidences the need to integrate different datasets for the identification of workshops. Separately, the characterization of raw materials and the classification of objects into typo-chronological and stylistic categories are not sufficiently reliable to support a workshop attribution. We showed that different workshops can share similar raw material procurement patterns, paste preparation modes, and decorative motifs, while other procedures like surface finishing might strongly vary within the same production unit. In this framework, even workshop signatures become a more fluid evidence hiding the underlying complex network of people and labor. If the identification of Late Hellenistic workshops still needs much investigation, the integration of NAA and thin-section petrography allowed us to establish a solid reference group, which will aid in clarifying the distribution radius of the Ephesian ceramic market at its apogee.

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³ The clay deposits around Aydın in the Büyük Menderes Valley are still widely exploited today for the production of ceramic vessels and bricks due to their excellent properties in terms of plasticity, workability and texture.

Author contribution All authors contributed to the study conception and design. PF secured the funds for this work through the Austrian Archaeological Institute; collected the samples in Ephesos; performed thin-section petrography; wrote the part related to the petrographic results and geological setting as well as a first draft of the discussion and conclusion, which all authors commented; and edited the final draft. MU selected the samples based on the typological and contextual study she performed for this work and wrote the introduction as well as the part related to the archaeological context and ceramic repertoire. All authors contributed to the part on materials and methods. NAA was performed by JHS who also processed and wrote up the results. RS provided expertise on the geological background and ceramic petrography.

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