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From Hellenistic slipped tableware to Roman Imperial Sagalassos Red Slip Ware: A petrographic and geochemical study

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ABSTRACT

This paper offers new insights from the petrographic and geochemical characterisation of 92 pottery samples from the archaeological site of Sagalassos in SW Anatolia (modern-day Turkey). The sampled table wares form part of the Hellenistic to Roman Imperial local pottery production lines. The aim of this study is to reconstruct in more detail the tableware production at the site and examine Sagalassos Red Slip Ware (SRSW) in comparison with the pre-existing Hellenistic tradition in slipped pottery. The results suggest that Hellenistic Colour Coated Ware (CCW) and Gray Ware with Black Slip (GWBS) were locally produced at the site using the same raw materials as the ones used for the subsequent mass-produced Sagalassos Red Slip Ware (SRSW), namely clays from the nearby NW parts of the valley of Çanaklı. SRSW appears thus as a continuation of the Hellenistic tradition in slipped pottery at Sagalassos, at least as far as some choices for clay raw materials are concerned. At the same time, this study provides for the first time evidence of regional production of a type of eastern sigillata that appears macroscopically similar to SRSW, while the number of identified imported wares to the *polis* of Sagalassos contributes new evidence to the discussion on the production of GWBS in the wider region of Anatolia and the origin of Eastern Sigillata A (ESA). Using the site of Sagalassos as a case-study, this research aims to demonstrate the importance of the analytical examination of pottery in a *longue durée* perspective in order to reconstruct ceramic traditions and better understand the local and regional sociocultural mechanisms behind them.

1. Introduction

The ancient urban community of Sagalassos, located in the historical region of Pisidia (southwest Anatolia) (Fig. 1), was involved in a long tradition of the production of tablewares going back to late Achaemenid times (5th – 4th centuries BCE) (Braekmans et al., 2017; Daems et al., 2019; Daems and Poblome, 2022, 2017; Poblome, 2016, 1999). From the later Hellenistic period onwards, Sagalassos underwent extensive urban development (Daems and Poblome, 2022, p.607, 2016, p.99; Daems and Talloen, 2022, pp. 181-184). Possibly associated with these changes, the already existing potter's craft extended its reach and gradually became the main ceramic production centre in the wider study region. In a next step, during the second half of the 1st c. BCE a new production line was initiated, the so-called Sagalassos Red Slip Ware (hereafter SRSW) as a regional variety of the style and tradition of eastern sigillata (Poblome, 1999).

Since 1986, research at the archaeological site of Sagalassos is being coordinated by KU Leuven, offering the opportunity to examine these long-term traditions of local ceramic production (Degryse and Waelkens, 2008; Waelkens, 1993; Waelkens and Loots, 2000; Waelkens and Poblome, 1997, 1995, 1993). Archaeological evidence regarding the Late Hellenistic workshops at the site is limited. Some kiln remains

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associated with Hellenistic pottery have been discovered, by excavations and geophysical prospections in the area of the Roman Odeon (Poblome et al., 2013). Most evidence of tableware production at Sagalassos comes from the Roman Imperial to Late Antique periods, when large-scale production of SRSW was taking place. The potters' workshops of this ware have been uncovered in the eastern parts of the ancient city where other crafts were also active (Eastern Suburbium, of which the Potters' Quarter forms part) (Poblome et al., 2002b, Poblome et al., 2000b). Across an area of around 6–7 ha, overfired waster sherds, broken moulds, kiln spacers and kiln remains have been discovered (Murphy and Poblome, 2017, p. 62), while geophysical surveys in the area revealed the presence of at least 80 strong magnetic anomalies associated with kiln structures (Murphy and Poblome, 2017, p. 66).

Typological, chronological, technological and archaeometric studies of the ancient pottery production lines from Sagalassos were initiated by the Sagalassos Archaeological Research Project from the start (Viaene et al., 1991), while the focus was primarily given to SRSW among the region's tablewares. Our knowledge regarding how this ware developed and how it relates to the pre-existing tradition of slipped pottery has been explored to some degree in the past (van der Enden et al., 2014). Building upon previous archaeometric research on both ceramics and clay sources from the site and study region (Braekmans et al., 2011; Degryse et al., 2003; Degryse and Poblome, 2008; Neyt et al., 2012; Ottenburgs et al., 1993a; Ottenburgs et al., 1993b; Poblome et al., 2002a; Poblome et al., 1997), this paper presents the results of the first systematic analytical study of a large and significant number of Hellenistic tablewares from the site. The aim is the detailed characterization, both mineralogical and geochemical (major, minor & trace elements), of the local production of Hellenistic (333 – 25 BCE) tableware in the territory of Sagalassos, while a number of SRSW samples from the Early to Middle Roman Imperial centuries (second half of the 1st century BCE – c. 150 CE) were also analysed in order to investigate the early stages of SRSW in comparison to the pre-existing tradition in slipped pottery. By reconstructing the ceramic technology of these wares, this study aims to examine ceramic production at the site in the *longue durée*. The results will be discussed within their socio-economic context and the ceramic trends of the wider region in order to understand the mechanisms behind any attested changes in ceramic technologies.

2. Materials

A total of 92 ceramic samples dating to the Hellenistic to Middle Roman Imperial periods excavated at the site of Sagalassos have been selected, after macroscopic assessment of the material and examination of the archaeological contexts. The material was initially sampled during the excavation seasons from 1992 to 2003, and made available for research at the Geology Division of KU Leuven. The focus is given on tablewares which are defined as fine(-grained) ceramics that are used for food and beverage consumption as well as serving (Bes, 2015, pp. 1–2) and can have some kind of surface treatment (i.e., slip). The sampling strategy was designed in such a way to include representative types of fine pottery attested at the site during the Hellenistic period (333 – 25 BCE) as well as from the first couple of centuries of SRSW (second half of the 1st century BCE – c. 150 CE; from initiation to developed mass production of SRSW; SRSW phase 1–3, see Poblome, 1999) when Sagalassos formed part of the Roman Empire. The samples selected derive from stratified consumption contexts from different excavation areas representing different locations across the ancient city, while a small number of samples originate from the nearby site of Kozluca and Ören. In addition to these, a small number of Eastern Sigillata A samples was also included in order to investigate the local and regional production characteristics in comparison to these imported ceramics. A description of all the samples analysed in this study along with their archaeological context, ware classification and periodization is given in Table 1.The Hellenistic tableware repertoire sampled from the site follows the stylistic and morphological trends of the wider Eastern Mediterranean region (Daems et al., 2019; Daems and Poblome, 2022; Poblome et al., 2013). ***Colour-Coated Ware*** (hereafter CCW) constitutes the main component of the Hellenistic tableware identified at Sagalassos. Being a common form of material culture in the Eastern Mediterranean region, this ware was first identified and named by John W. Hayes (1991) in his study of Hellenistic and Roman pottery from the House of Dionysos in Nea Paphos, Cyprus. Ceramics of this ware were produced from the 5th c. BCE into the 1st c. CE at different sites in the Eastern Mediterranean (Berlin et al., 2014; Kögler, 2014; Marzec et al., 2019; Moore and Brandon, 2014). At the site of Sagalassos, sherds of these wares have been found in archaeological contexts dating from the 3rd c. until the late 1st BCE (Daems and Poblome, 2017, p. 56; van der Enden et al., 2014, p. 87). They are characterised by a matt, semi-lustrous slip of variable colour – orange, red, dark red or black even on the same vessel (Lund, 2005, pp. 194–195; Marzec et al., 2019, p. 4103). The slip covers the interior and fully or partially the exterior surface of bowls (Poblome et al., 2013, p. 196). 39 samples of this ware have been selected for analysis.

Fig. 1. Map showing the location of the archaeological site of Sagalassos.

Table 1
Description of ceramic samples.

Sample no.	Sample export no.	Archaeological Context	Excavation sector, layer or locus	Ware	Periodization
SA21CK024	SA99JP13	99B3-194	–	Hellenistic Black Gloss	Hellenistic
SA21CK025	–	96UAN108	sector LXXV-W, layer 2S	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK026	–	96AG6	sector 5325/4775–6, layer 4	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK027	SA00JP62	00TSW2-17	layer 5	Hellenistic Black Gloss (with West Slope decoration)	Hellenistic
SA21CK028	SA97JP23	97H309	sector 5295–4980, layer 4	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK029	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK030	SA99JP9	99LA121	sector 2385–2320, layer 4	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK031	SA00JP60	00TSW1-23	layer 5	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK032	Sag 550	96S28 (Kozluca)	–	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK033	Sag 548	96S28 (Kozluca)	–	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK034	SA98JP75	98LA155	sector 2375/2320, layer 3	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK035	Sag 549	96S28 (Kozluca)	–	Hellenistic Gray Ware with Black Slip	Hellenistic
SA21CK036	SA00JP55	00TSW2-08	layer 2	Colour-Coated Ware	Hellenistic
SA21CK037	SA99JP10	99TSN15	sector 1720–2665, layer 4	Colour-Coated Ware	Hellenistic
SA21CK038	SA99JP12	99TSN27	–	Colour-Coated Ware	Hellenistic
SA21CK039	SA99JP2	99RB2-169	–	Colour-Coated Ware	Hellenistic
SA21CK040	SA99JP2	99RB2-169	–	Colour-Coated Ware	Hellenistic
SA21CK041	SA00JP56	00TSW2-08	layer 2	Colour-Coated Ware	Hellenistic
SA21CK042	SA00JP56	00TSW2-08	layer 2	Colour-Coated Ware	Hellenistic
SA21CK043	–	96 N50	layer 7	Colour-Coated Ware	Hellenistic
SA21CK044	–	96 N50	layer 7	Colour-Coated Ware	Hellenistic
SA21CK045	–	96 N50	layer 7	Colour-Coated Ware	Hellenistic
SA21CK046	SA00JP61	00TSW2-08	layer 2	SRSW Phase 1	Early Imperial (Phase 1–2)
SA21CK047	SA97JP22	94UAN110	sector 5305–4980, layer 7	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK048	Sag 380	94L115.SJ4	sector LVII, layer 13 N	SRSW Phase 1	Early Imperial (Phase 1–2)
SA21CK049	–	96 N50	layer 7, 1B170	Colour-Coated Ware	Hellenistic
SA21CK050	SA99JP8	99RB2-169	–	Colour-Coated Ware	Middle/Late Hellenistic (2nd - mid. 1st c. BC)
SA21CK051	SA99JP8	99RB2-169	–	Colour-Coated Ware	Hellenistic
SA21CK052	SA98JP78	98LA35	sector 2375/2315, layer 3	Colour-Coated Ware	Hellenistic
SA21CK053	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK054	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK055	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK056	SA00JP51	00B3-342	layer 7	Colour-Coated Ware	Middle/Late Hellenistic (2nd c. – 1st c. BC)
SA21CK057	SA00JP57	00TSW2-13	layer 3	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK058	SA99JP8	99RB2-169	–	Colour-Coated Ware	Hellenistic
SA21CK059	SA00JP61	00TSW2-08	layer 2	Colour-Coated Ware	Hellenistic
SA21CK060	SA00JP52	00PQ86	Aug. kiln 2	Colour-Coated Ware	Hellenistic
SA21CK061	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK062	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK063	SA98JP77	98SSC1/40	sector 2295/2325, layer 7	Colour-Coated Ware	Hellenistic
SA21CK064	SA99JP8	99RB2-169	–	Colour-Coated Ware	Hellenistic
SA21CK065	SJ8	94L161.SJ8	sector LVII-LIX, layer 15S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK066	SJ7	94L161.SJ7	sector LVII-LIX, layer 15S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK067	Sag 383	94L167.SJ12	sector LVII-LIX, layer 16S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK068	Sag 381	94L98-7.SJ6	sector LVII, layer 12 N	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK069	Sag 378	94L115.SJ1	sector LVII, layer 13 N	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK070	Sag 379	94L115.SJ3	sector LVII, layer 13 N	Colour-Coated Ware	Hellenistic
SA21CK071	Sag 382	94L167.SJ10	sector LVII-LIX, layer 16S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK072	SJ11	94L167.SJ11	sector LVII-LIX, layer 16S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK073	Sag 384	94L167.SJ14	sector LVII-LIX, layer 16S	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK074	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK075	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK076	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK077	–	96 N54	layer 8	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK078	–	96 N54	layer 8	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK079	SA97JP23	97H309	sector 5295–4980, layer 4	Colour-Coated Ware	Hellenistic
SA21CK080	SA97JP23	97H309	sector 5295–4980, layer 4	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK081	SA97JP23	97H309	sector 5295–4980, layer 4	Colour-Coated Ware	Hellenistic
SA21CK082	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK083	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK084	–	96 N44	layer 6	Colour-Coated Ware	Hellenistic
SA21CK085	SA00JP61	00TSW2-08	layer 2	Colour-Coated Ware	Hellenistic
SA21CK086	SA00JP57	00TSW2-13	layer 3	Colour-Coated Ware	Hellenistic
SA21CK087	SA00JP57	00TSW2-13	layer 3	Colour-Coated Ware	Hellenistic
SA21CK088	SA00JP57	00TSW2-13	layer 3	Colour-Coated Ware	Hellenistic
SA21CK091	–	96S68 (Ören)	–	Colour-Coated Ware	Hellenistic
SA21CK092	–	96S68 (Ören)	–	Colour-Coated Ware	Late Hellenistic
SA21CK093	SJ2	94L115.SJ 2	sector LVII, layer 13 N	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK094	–	96 N44	layer 6	SRSW Phase 1–2	Early Imperial (Phase 1–2)
SA21CK099	SA98JP76	98SSC1/25	sector 2295/2325, layer 5	Colour-Coated Ware	Hellenistic

(*continued on next page*)

Table 1 (*continued*)

Sample no.	Sample export no.	Archaeological Context	Excavation sector, layer or locus	Ware	Periodization
SA21CK100	SA98JP76	98SSC1/25	sector 2295/2325, layer 5	Colour-Coated Ware	Hellenistic
SA21CK101	SA98JP76	98SSC1/25	sector 2295/2325, layer 5	Colour-Coated Ware	Hellenistic
SA21CK102	SA03JP79	03AP228, trench 2, layer 20	–	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK103	SA03JP74	03AP201, trench 3, layer 11	–	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK104	SA00JP54	00TSW-13	layer 3	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK105	–	96S28 (Kozluca)	–	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK106	Sag 393	93L104 –4S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK107	Sag 322	93L127-6S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK108	Sag 303	93L462-11S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK109	Sag 313	93L104-4S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK111	Sag 276	93L127-6S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK112	Sag314	93L104-4S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK113	Sag 312	93L104-4S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK114	Sag 271	93L104-4S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK115	Sag 267	93L55-3S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK116	Sag 281	93L127-6S	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK117	Sag 245	92 N228 - East 5′	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK118	Sag 389	92 N148 - East 11′	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK119	Sag 180	92 N218 - East 12′	–	SRSW Phase 2–3	Early-Middle Imperial (Phase 2–3)
SA21CK178	Sag 557	96 N44	layer 6	Colour-Coated Ware	Hellenistic
SA21CK179	SA05PB/3	02LA144	–	Eastern Sigillata A	Late Hellenistic/Early Imperial
SA21CK180	SA05PB/2	00TSW2-13	layer 3	Eastern Sigillata A	Late Hellenistic/Early Imperial

Hellenistic Gray Ware with Black Slip (GWBS) is another category identified in the pottery materials from the site. As suggested by its name, this ware is characterised by a black slip and a gray-coloured fabric, produced by firing in a reducing atmosphere (Hayes, 1991, p. 8; Jones, 1950, pp. 184–185; Rotroff, 1997, p. 232; Rotroff and Olivier, 2003, p. 31; Schäfer, 1968, pp. 29–30). GWBS appears between the late 3rd c. BCE and 1st c. CE in different parts of the Eastern Mediterranean including Anatolia (e.g., Pergamon, Tarsus, Priene, Sardis, Ephesus) (Fenn, 2016; Heberdey, 1906, pp. 175-176; Jones, 1950, pp. 184-185; Laflı and Kan Şahin, 2014, pp. 98-99; Rotroff and Olivier, 2003, pp. 31–37; Schäfer, 1968, pp. 29–30; Zahn, 1904, pp. 398–399, nos.11–13). A total of 10 samples that exhibit the same characteristics of this described ware have been selected.

For reasons of comparison and analytical verification, 2 samples of ***Black gloss***[1] (BG) pottery were selected for analysis. This is another common type of pottery in the Eastern Mediterranean from the 5th until the 3rd c. BCE (for fully slipped) and the 1st c. BCE (for partially slipped), and it is characterised by a lustrous black slip and an oxidised fabric (Lund, 2005, pp. 186-187; Rotroff, 1997; Sparkes et al., 1970). Its origins are typically placed in 5th c. BCE Athens, while a range of imitation productions is found across Asia Minor as well (Cook, 1965). One example selected is characterised by incised and white painted decoration following the so-called *West Slope* tradition (Kögler, 2014, pp. 162–163; Lund, 2005, p. 187; Rotroff, 2002, 1997).

In terms of shapes, the most common types of Hellenistic pottery at Sagalassos include the mastoid cup which is a drinking cup of parabolic shape (A130), the Achaemenid cup which constitutes a handle-less cup with a hollowed base, a rounded body, a carination at the shoulder and a slightly splayed rim (A120), the plain rim bowl (B150), the incurving rim bowl (B170), the rounded rim dish (C170), the krater with protruding rim (F150) and the almond rim jar (H140) (Daems et al., 2019; Daems and Poblome, 2022) (Fig. 2).

Initiated during the second half of the 1st century BCE, the main type of tableware attested at Sagalassos from the Early Roman Imperial period onwards would become ***Sagalassos Red Slip Ware*** **(SRSW)**. Production of this ware starts at some point during the second half of the 1st c. BCE and is aligned with general ceramic trends of the period as represented by eastern sigillata which started appearing in the Eastern Mediterranean around the middle of the 2nd c. BCE (Bes, 2015; Poblome et al., 2000a, p. 280; Poblome and Zelle, 2002). Gradually this ware becomes the most common table ware replacing its Hellenistic predecessors (Poblome et al., 2001, p. 143). A reference study by Jeroen Poblome (1999) established a typo-chronological sequence of SRSW taking into account the stratigraphy of the site. Phases 1 and 2 are dated to the Early Roman Imperial period and are characterised predominantly by cups and bowls showing a continuation of some shapes already attested during the Hellenistic period, such as the mastoid cup (A130) and Achaemenid cup (A120) (Poblome et al., 2013; van der Enden et al., 2018). Ceramics of Phase 2–3 are dated to the Early-Middle Roman Imperial centuries and include mainly bowls and dishes (Poblome, 1999). A total of 20 samples of SRSW Phase 1–2 and 14 samples of SRSW Phase 2–3 were selected.

Finally, 7 samples of Late Hellenistic/Early Roman Imperial ***Eastern Sigillata A*** (ESA) were also analysed in order to be compared technologically to SRSW and to contribute to the discussion on the production of ESA. ESA was one of the first types of eastern sigillata produced in the Eastern Mediterranean from around the mid. 2nd c. BCE and soon after it became widely distributed gaining a supra-regional importance (Bes, 2015, pp. 12-16; Lund, 2015; Lund et al., 2006; Poblome et al., 2001, 2000a; Poblome and Zelle, 2002). No workshops associated with this ware have been discovered so far, but most archaeometrical evidence suggests that it was produced in the northeastern corner of the Mediterranean, in the region between Tarsos and Antioch-on-the-Orontes (Schneider, 1996a, 1996b).

3. Methodology

Before the analytical investigation of the samples, the macroscopic characteristics of the sherds were documented following a system proposed by Orton and Hughes (2014) and can be found in **Supplementary Material 1**. In particular, these characteristics include: the colour of the fresh break recorded using Munsell Soil Chart (2000 revised edition) as well as the colour, relative size and frequency of the visible inclusions and voids. The colour and texture of the slip present was also recorded. The description of inclusions and voids was based on the examination of the fresh break using a Dino-Lite Premier Digital Microscope (AM4113ZT) at x30 magnification. An image of the macro-fabric of each sample was also taken using the aforementioned Dino-Lite microscope.

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[1] This ware is also known as Black glazed but this term is less accurate from a technological perspective and therefore it is not preferred.

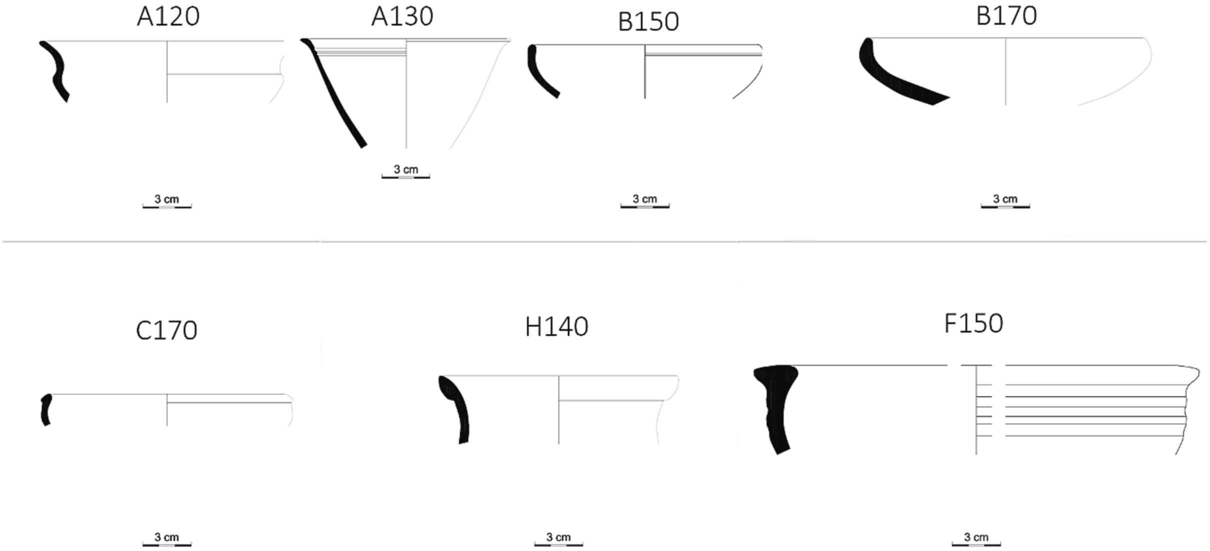

Fig. 2. Drawings of the main shapes of the Hellenistic pottery from Sagalassos.

Thin-section ceramic petrography was used as the primary method for characterizing the mineralogical composition of samples and classifying ceramic sherds into different fabrics. For that purpose, thin sections of all samples were made and studied at the Department of Earth and Environmental Sciences at KU Leuven using a Leica DM750P polarizing microscope. Fabrics were described by the petrology, distribution and texture of their main inclusions as well as their matrix properties using the modification of the Whitbread’s descriptive system (Whitbread, 1995, 1989), as proposed by Quinn (2022, 2013).

In addition, ‘bulk’ chemical analysis was carried out on all samples with the aim to investigate further their provenance. Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES) was employed for major and minor oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for trace elements (As, Ba, Be, Bi, Ce, Co, Cr, Cs, Dy, Eu, Ga, Gd, Hf, Ho, La, Lu, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Sm, Sn, Sr, Ta, Tb, Th, U, V, W, Y, Yb, Zn, Zr). The analyses were carried out at the Department of Earth and Environmental Sciences, KU Leuven, using a Varian 720ES and an Agilent 7700x series instruments. Prior to the analyses, the layer of slip from the exterior surfaces of all samples as well as any surface contamination were removed. The samples were then crushed and finely powdered using a porcelain mortar and a stainless steel ball mill. The lithium metaborate fusion procedure was followed to prepare the sample solutions. In particular, 0.1 g of ceramic powder was mixed with 0.5 g of $LiBO_2$ and fused in the graphite crucible in the muffle furnace at 1000 °C for 10 min. The melt was then poured in 50 ml of HNO_3. The Li fusion sample solutions were diluted 10 times with HNO_3 3 % for ICP-OES and 20 times with HNO_3 5 % for ICP-MS. Loss on Ignition (LOI) was determined separately by heating up around 0.5 g of ceramic powder in the furnace at 1000 °C for 1 h. It was not possible to measure the LOI for 5 samples due to the unavailability of sufficient material. The major and minor oxide values (ICP-OES) were converted to wt% according to the stoichiometric element to oxide conversion factors, while the ICP-MS data were converted to parts per million (ppm).

Eight Certified Reference Materials (SPS-SW2, NW-TM-24.4, SO-1, SO-2, GBW 7311, GBW 7411, MRG-1, G-2) as well as quality control mixtures and replicates of ceramic samples were measured repeatedly to monitor the instruments. The precision of both ICP-OES and ICP-MS is estimated as relative standard deviation (RSD%=STDEV/Average*100 %) and the accuracy is calculated as (Certified – Measured value) / Measured x 100. Precision of ICP-OES is generally below 1.5 %, with the exception of P_2O_5 which is below 3.79 %, and of ICP-MS below 5–10 %. Accuracy is mainly below 5 % for ICP-OES and below 10 % for ICP-MS with the exception of very low compositions that approach the detection limits of the instruments.

The geochemical data were processed using descriptive and multivariate statistical analysis in order to identify groups patterns in the dataset, interpret the variability and better visualize the data. Petrographically unique samples as well as samples related to Fabric groups were excluded from the dataset before applying any statistical analysis. Major and minor elements were recalculated on a LOI-free basis and to a constant sum of 100 wt% in order to counteract variations due to differences in analytical totals (Quinn, 2022, p. 358). Elements related to contamination because of sample preparation or post-depositional processes as well as elements with low concentrations close to the detection limits or extreme natural variability are excluded from the statistical analysis (P, As, Ba, Be, Bi, Ho, Sn, Sb, Tb, W, Mo) (Buxeda i Garrigós, 1999; Marzec et al., 2019). All data were then transformed to logarithms of base 10 in order to account for any departures from normality (Baxter, 2003, pp. 76–77, 2015, pp. 40–42, 73–77; Reimann et al., 2008, pp. 169–170; Varmuza and Filzmoser, 2009, p. 34). After transformation, the data were standardized so that all variables have the same weight and to account for differences in measuring scales (Baxter, 2015, p. 45; Carlson, 2017, p. 334; Reimann et al., 2008, p. 167; Varmuza and Filzmoser, 2009, p. 35). Scatterplots of different elements as well as Principal Component Analysis (PCA) were carried out in the R Studio software version 2022.7.2.576 (RStudio Team, 2022) using ggplot2 (Wickham, 2016) and stats (R Core Team, 2022) packages.

4. Geological background and clay sources

The archaeological site of Sagalassos is situated in the Western Taurus Mountain range, near the modern village of Ağlasun and in the Burdur province in modern-day Turkey. Built at an altitude of 1450–1600 m., the ancient city is overlooking the fertile valleys of Çanaklı and Ağlasun (Poblome et al., 2000b, p.39) (Fig. 3). Geologically, Sagalassos is located in the northwestern part of the Isparta Angle which is characterised by the presence of Mesozoic autochthonous carbonate platforms of the Bey Dağları Massif, which were overlain by the Lycian Nappe Complex and Cenozoic flysch and molasse deposits (Degryse et al., 2008, p. 17-18). The rocks found in the area of the ancient city can be subdivided into the autochthonous and allochthonous group.

The autochthonous group is composed of Mesozoic carbonates, siliciclastics, Cenozoic flysch (shale, sandstone, conglomerate) and Quaternary volcanic tuff, lake and river sediments (Degryse et al., 2008; Muchez et al., 2008). The allochthonous group on the other hand, forms

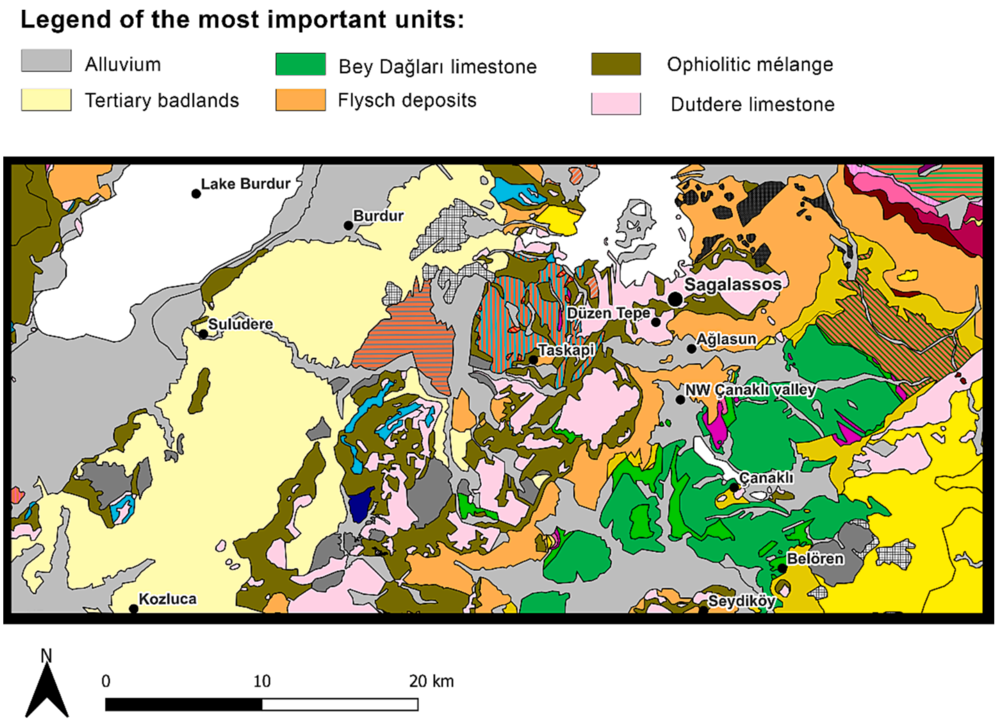

Fig. 3. Geological map of the region of Sagalassos showing the most important geological units and the main locations mentioned in the text (after Neyt et al., 2012).

part of the Lycian Nappe Complex which is composed of an ophiolitic mélange (Muchez et al., 2008, p. 25). It is found to the north of the valley of Yeşilbaşköy and consists of sedimentary and magmatic rocks (Degryse et al., 2008, p. 19). The allochthonous carbonates are part of the Domuz Dağ unit and are found to the north of the ancient city (Degryse et al., 2008, p. 20). Apart from these two units, other more recent deposits are also found in Sagalassos. These include volcanic, alluvial and lacustrine deposits and are found in the upper strata (Degryse et al., 2008, p. 20).

Geological surveys conducted in the past have located several clay deposits in the wider area around Sagalassos (ca. 15 km around the ancient city) (Degryse and Poblome, 2008; Neyt, 2012; Ottenburgs et al., 1993a). These deposits have been extensively characterised in terms of both their mineralogy and geochemistry allowing us to investigate further the provenance of the raw materials used for the ceramics under study. Within the ancient town and around the area of Eastern Suburbium, primary clays are present which resulted from the weathering of the ophiolitic bedrock. Apart from clay minerals which are mostly smectite, these soils consist mainly of feldspars, pyroxenes and amphiboles as well as minor amounts of basalt fragments. Trace amounts of mica, magnetite and occasionally sand/siltstone are also present (Neyt, 2012, p. 84). These deposits are characterised by a good plasticity because of their high content in clay minerals, but have the disadvantage of being coarser in nature and thus require further refining in order to be used for fine tableware (Degryse and Poblome, 2008, p. 237).

Secondary clays deriving from the weathering of flysch deposits are present in different locations around the territory of Sagalassos, namely in the Ağlasun valley, in the area of Köyünü, Yazır and to the north of the Çanaklı valley. Illite is the main mineral present in these deposits which contain also quartz and K-feldspars as well as small quantities of amphiboles and biotite (Degryse and Poblome, 2008, pp. 237–238). The northern and central part of the Çanaklı valley is characterised by lacustrine detrital clays consisting mainly of illite and chlorite clay minerals (Braekmans et al., 2011, p. 2104). These clays contain high amounts of quartz, plagioclase and K-feldspars (Degryse and Poblome, 2008, p. 238; Neyt, 2012, pp. 57–58), while calcite content varies between the samples analysed (Neyt, 2012, p. 58). Along the shores of Lake Burdur, deposits associated with the weathering of previous lake deposits were also identified (Degryse and Poblome, 2008, p. 234). These clays contain mainly fragments of limestone and shells, while quartz and feldspar contents are low. The main clay minerals present are smectite and illite (Neyt et al., 2012, p. 1301).

Clays around Düzen Tepe were also characterised in the past and they mainly derive from the weathering of flysch deposits. These clays contain mainly K-feldspars, quartz and pyroxenes and the main clay mineral present is illite (Braekmans et al., 2011, p. 2104). Finally, other clay deposits were identified at the valley of Taşkapı and they are smectite-rich (Degryse and Poblome, 2008, p. 238; Neyt et al., 2012, p. 1301).

5. Results

5.1. The results of thin section ceramic petrography

The petrographic study of the samples revealed and identified the presence of 8 Fabrics as well as a number of unique samples. A detailed petrographic description of the fabrics can be found in **Supplementary Material 2**. The frequency categories described below are estimated using a percentage comparative chart and following the system proposed by Quinn (2022, p. 108): Predominant (>70 %), Dominant (50–70 %), Frequent (30–50 %), Common (15–30 %), Few (5–15 %), Very Few (2–5 %), Rare (0.5–2 %), Very Rare (<0.5 %).

The majority of the samples belong to Fabric A (n = 43) which is a fine-grained fabric characterised by the presence of monocrystalline quartz and muscovite mica, set in a moderately calcareous matrix (Fig. 4**a, b**). It is worth noting that this fabric has high variability in terms of the frequency of the inclusions present. The matrix of most of the samples is characterised by fine microcrystalline calcite. Limestone fragments are also present but in variable frequencies, ranging from Common to Very Few. Very Few plagioclase feldspars are identified, while a range of other inclusions, such as opaques, biotite mica, and the so-called Textural Concentration Features (TFs), most likely iron rich clay pellets (Whitbread, 1986), are documented as Very Few to Very Rare. The fine nature and size of the inclusions suggests that the clay used for this fabric has been refined. Some samples have matrices with

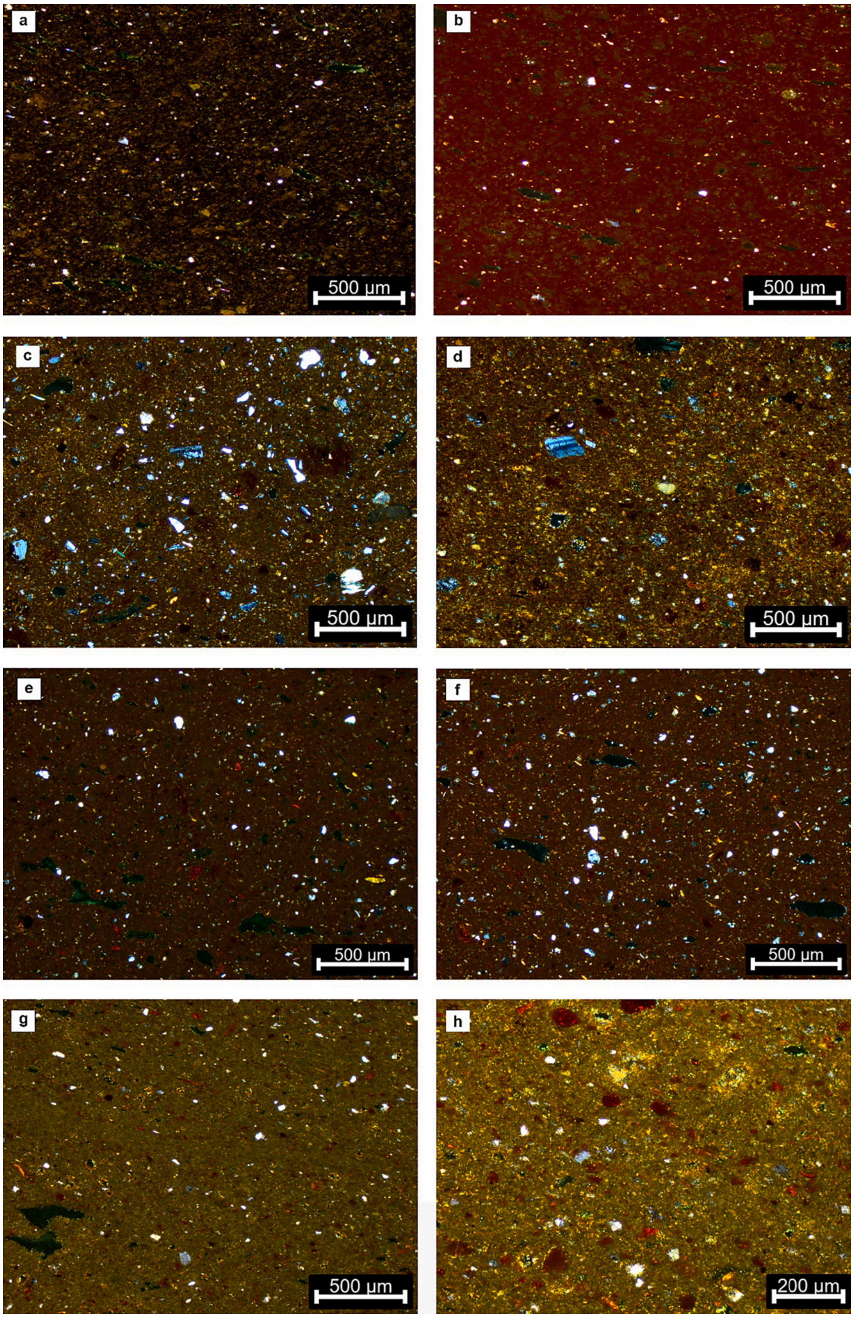

Fig. 4. Photomicrographs of representative samples of the Major petrographic fabrics taken in XP. Fabric A: (a) SA21CK026, (b) SA21CK070; Fabric B: (c) SA21CK076, (d) SA21CK078; Fabric C: (e) SA21CK064, (f) SA21CK067; Fabric D: (g) SA21CK105, (h) SA21CK057.

high to moderate optical activity (SA21CK026, SA21CK030, SA21CK031, SA21CK036, SA21CK038, SA21CK039, SA21CK040, SA21CK041, SA21CK046, SA21CK047, SA21CK052, SA21CK053, SA21CK062, SA21CK065, SA21CK080, SA21CK093, SA21CK101, SA21CK115), while the rest have weakly optically active to inactive matrices (SA21CK030, SA21CK037, SA21CK042, SA21CK055, SA21CK059, SA21CK060, SA21CK061, SA21CK066, SA21CK070, SA21CK075, SA21CK079, SA21CK084, SA21CK085, SA21CK087, SA21CK099, SA21CK100, SA21CK106, SA21CK107, SA21CK109, SA21CK111, SA21CK112, SA21CK113, SA21CK114, SA21CK117, SA21CK118, SA21CK119). Variability is also recorded in terms of the firing conditions. Some samples were fired in a reducing atmosphere as suggested by the dark brown colour of the matrix, others in an incomplete oxidising atmosphere or in a reducing atmosphere with an oxidation period at the end, and others in a completely oxidising atmosphere. Most samples are characterised by core/margin colour differentiation suggesting uneven firing conditions. This fabric includes samples dated to both the Hellenistic and Early to Middle Roman Imperial periods. Classification-wise, they belong to CCW, GWBS and SRSW (Phase 1–3) (Fig. 5).

Fabric B (n = 6) is a fine-grained fabric characterised by the presence of plagioclase feldspar and biotite mica, all set in a moderately calcareous matrix (Fig. 4**c, d**). Inclusions of sedimentary origin are represented only by limestone which appears as Common to Few. Angular and subangular inclusions of monocrystalline quartz, pyroxene, alkali feldspar, muscovite, serpentine, amphibole and volcanic rock fragments are related to an igneous geology. TFs of type 1 appear as Few and have ovoid shape, clear to diffuse boundaries and high optical density. They can be identified as clay pellets. Another type of TFs (type 2) found only in two samples might be evidence of clay mixing or clay processing.

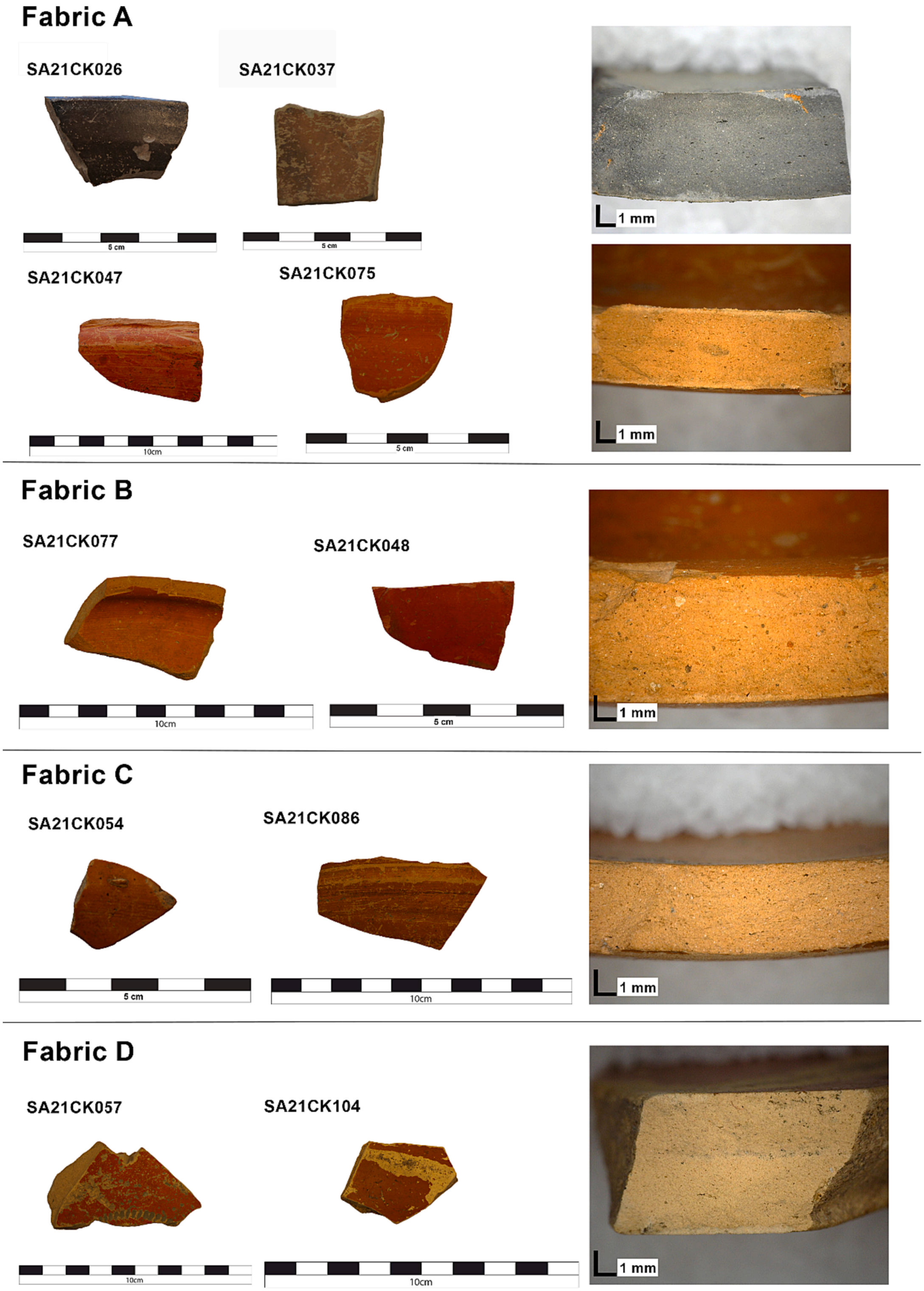

Fig. 5. Photos of representative samples of the Major petrographic fabrics and their fabric photo taken using a Dino-Lite Premier Digital Microscope (AM4113ZT) at x30 magnification. The samples belong to the main wares attested: GWBS (SA21CK026), CCW (SA21CK037, SA21CK054, SA21CK086), SRSW (SA21CK047, SA21CK048, SA21CK075, SA21CK077), ESA (SA21CK057, SA21CK104).

These clay pellets and striations appear similar to the surrounding matrix but contain no inclusions and have neutral optical density. The samples have low to moderate optical activity and were fired in an oxidising atmosphere. Fabric B is dated to both the Hellenistic and Early Roman Imperial periods and includes CCW as well as SRSW (Phase 1–2) (Fig. 5).

Fabric C (n = 8) is a fine-grained fabric characterised by the presence of plagioclase feldspar, muscovite and biotite mica, as well as monocrystalline quartz, all set in a moderately to highly calcareous matrix (Fig. 4**e, f**). Angular and sub-angular inclusions of mica, quartz and feldspar along with serpentine are probably related to an igneous geological environment. Volcanic rock fragments are also recorded in most samples. Inclusions of sedimentary origin are limited and include: limestone (Common to Few), calcite (Very Rare to Absent) and a sandstone fragment (Very Rare to Absent). The fine nature of the inclusions present suggests that the clay has been refined. The matrices of the samples show low to moderate optical activity, and have a red brown to brown colour which suggests an oxidising firing atmosphere. Fabric C represents materials that are dated to the Hellenistic period and associated with CCW, with the exception of only one sample of SRSW dated to the Early Roman Imperial period (Phase 1–2) (Fig. 5).

Finally, Fabric D (n = 5) is a fine-grained homogeneous fabric that has a very different texture from the rest of the fabrics identified in the assemblage (Fig. 4**g, h**). It is characterised by serpentine inclusions and monocrystalline quartz, all set in a highly calcareous matrix. Clay pellets appear as Few, while muscovite mica is also present as Few to Very Few. Sedimentary rocks are represented only by limestone which appears as Common to Few, while a volcanic rock fragment is only recorded in one sample. The matrices of the samples are optically inactive, apart from the matrix of sample SA21CK103 that has moderate optical activity. The yellow to brown colour of the matrix suggests that the samples were fired in an oxidising atmosphere. Fabric D is dated to the Late Hellenistic to Early Roman Imperial periods and includes exclusively samples of Eastern Sigillata A (Fig. 5).

Four more fabrics appear as less common in the material under study and each includes only 2 samples (Minor Fabrics). Fabric E (SA21CK056, SA21CK082) is a medium to fine-grained fabric that is characterised by the presence of micritic limestone, mono- and polycrystalline quartz and biotite mica, all set in a highly calcareous matrix. The boundaries of quartz crystals appear sutured suggesting that they have been under some metamorphism. Volcanic mafic rock fragments that have started also to metamorphose appear as Few, while mica schist fragments are present as Few to Absent. Fabric F (SA21CK043, SA21CK094) is a medium to fine-grained fabric with inclusions of limestone, quartz and feldspar, set in a highly calcareous matrix. Shell fragments, muscovite mica and amphibole are present as Few to Very Few. Among metamorphic rocks, marble fragment is recorded as Very Rare to Absent. Fabric G (SA21CK068, SA21CK073) is a fine-grained fabric that contains mainly inclusions of quartz and limestone in a moderately calcareous matrix, while Fabric H (SA21CK071, SA21CK072) is a fine-grained

Table 2

Chemical composition of the chemical groups of the ceramics under study measured by ICP-OES and ICP-MS. The results are presented on a LOI-free basis and recalculated to 100 wt%. Major and minor oxides are reported as wt% and trace elements in ppm.

	Chemical Group 1		Chemical Group 2		Chemical Group 3		Chemical Group 4		Chemical Group 5	
	n = 45		n = 6		n = 10		n = 5		n = 4	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Al_2O_3	15.41	0.50	15.96	0.48	16.70	0.82	11.37	0.42	13.65	0.89
CaO	8.52	1.31	7.60	0.92	6.97	1.67	18.59	2.13	14.42	1.49
Fe_2O_3	8.97	0.68	8.18	0.28	8.14	0.69	7.54	0.49	7.44	0.24
K_2O	2.87	0.12	3.46	0.32	3.44	0.20	2.45	0.25	2.56	0.12
MgO	6.79	0.63	4.14	1.36	5.44	0.93	7.51	0.55	5.30	1.24
MnO	0.10	0.02	0.12	0.01	0.10	0.01	0.13	0.02	0.10	0.02
Na_2O	1.00	0.09	1.42	0.20	0.74	0.13	0.51	0.05	0.82	0.10
P_2O_5	0.35	0.18	0.37	0.15	0.34	0.12	0.57	0.21	0.52	0.11
SiO_2	55.12	0.96	57.87	1.42	57.22	1.30	50.69	1.15	54.38	0.75
TiO_2	0.88	0.03	0.87	0.01	0.91	0.03	0.64	0.01	0.80	0.02
As	6.71	2.20	9.78	1.68	6.74	2.10	3.88	1.63	7.99	1.53
Ba	1267	2614	1175	59	578	70	659	231	1251	1250
Be	2.10	0.54	5.01	1.21	2.16	0.78	1.36	0.38	1.68	0.54
Bi	0.21	0.11	0.32	0.22	0.10	0.18	0.21	0.03	0.15	0.08
Ce	50.1	4.39	154	10.9	69.0	7.00	34.9	0.85	57.0	11.6
Co	34.9	4.78	29.4	2.71	28.0	4.33	29.8	3.38	26.2	0.87
Cr	900	581	600	182	689	258	583	215	446	36.5
Cs	6.22	0.69	10.4	1.72	8.40	1.01	3.65	0.28	4.56	0.41
Dy	3.92	0.19	4.87	0.09	4.68	0.31	3.39	0.12	3.80	0.28
Eu	1.09	0.26	1.82	0.08	1.09	0.11	0.87	0.04	1.11	0.25
Ga	16.6	1.88	20.3	0.67	18.7	1.02	11.7	0.82	13.9	1.38
Gd	4.51	0.33	7.19	0.32	5.16	0.42	3.78	0.08	4.66	0.57
Hf	4.28	0.41	7.49	0.68	5.45	0.53	2.86	0.38	4.11	0.31
Ho	0.81	0.04	0.96	0.02	0.96	0.07	0.70	0.02	0.78	0.07
La	29.9	1.46	120	10.5	46.0	6.62	22.9	1.65	37.9	9.25
Lu	0.37	0.02	0.42	0.02	0.42	0.03	0.28	0.01	0.34	0.03
Mo	6.38	8.82	5.81	1.72	3.61	2.53	2.91	2.59	1.01	0.49
Nb	15.7	1.18	31.1	1.28	19.6	1.26	11.0	0.96	14.8	1.62
Nd	23.3	1.66	52.6	3.82	29.2	2.96	18.6	0.35	25.7	4.55
Ni	421	181	320	50.5	253	90.2	318	68.5	256	23.1
Pb	24.2	30.3	41.0	2.80	21.0	1.90	10.5	1.12	18.2	2.45
Pr	5.93	0.45	15.3	1.18	7.83	0.76	4.59	0.07	6.70	1.35
Rb	106	6.35	135	4.24	129	9.51	71.8	4.31	84.4	7.14
Sb	0.82	0.15	1.53	0.10	0.94	0.20	0.54	0.07	0.81	0.11
Sm	4.70	0.30	8.12	0.50	5.38	0.55	3.80	0.11	4.86	0.58
Sn	2.63	0.41	2.77	0.23	3.35	0.58	1.50	0.29	1.99	0.21
Sr	230	41.8	708	31.0	241	70.5	600	57.6	364	74.0
Ta	1.13	0.06	2.02	0.05	1.46	0.07	0.76	0.04	1.08	0.10
Tb	0.67	0.04	0.92	0.03	0.78	0.07	0.58	0.01	0.66	0.06
Th	10.7	0.48	28.5	2.83	14.7	1.64	6.45	0.42	11.3	2.09
U	2.75	0.27	6.79	0.48	3.77	0.25	1.69	0.15	2.83	0.12
V	124	11.7	119	5.98	126	15.5	77.5	9.50	98.3	11.4
W	39.6	53.4	35.9	31.4	26.0	28.8	12.6	24.0	18.4	19.7
Y	21.7	0.78	27.4	0.53	26.5	2.06	20.0	0.70	21.6	1.87
Yb	2.42	0.12	2.74	0.07	2.84	0.19	1.87	0.06	2.21	0.13
Zn	113	11.2	113	2.90	99.1	8.27	96.6	15.8	86.2	7.50
Zr	142	13.4	246	22.3	165	13.5	91.8	9.33	126	10.8

fabric characterised by the presence of limestone set in a highly calcareous matrix.

Regarding the samples with a unique petrography (n = 19) identified in the assemblage, these belong to both the Hellenistic and Roman Imperial periods. 6 samples belong to the Hellenistic Gray Ware with Black Slip, the majority of which are associated with inclusions of metamorphic origin which are not found locally in the region of Sagalassos. The Hellenistic Black Gloss samples (n = 2) also belong to different fabrics, as well as 4 CCW samples and 2 of the Eastern Sigillata A examples. Finally, 3 samples of SRSW from the Early Roman Imperial period and 2 samples of SRSW from the Early-Middle Roman Imperial period have a unique petrographic fabric.

5.2. The results of geochemical characterization: Descriptive and multivariate statistics

In addition to thin section petrography, all samples were analysed geochemically in order to investigate further any chemical variability present. The bulk elemental composition of the samples can be found in **Supplementary Material 3**, while the mean values of the chemical groups identified are given in Table 2 and **Supplementary Material 4**. The data are first examined using scatterplots in order to investigate any variability in the dataset and then further explored using Principal Component Analysis (PCA) after logarithmic transformation. The resulting plot of the first two principal components confirms the compositional variability of the different chemical groups as attested in the scatterplots (Fig. 6**a**,**b**). The chemical groups identified are consistent with the petrographic results, though some petrographic Fabrics join in one chemical group (see below).

Chemical Group 1 (CG1) is the largest chemical group identified in the dataset and it corresponds to all the samples from Fabric A and Fabric H. This group is distinguished because of its higher MgO values (4.67–8.40 wt%) compared to the rest of CGs (Fig. 7**a**). High MgO values are related to the high chlorite and smectite content in clay minerals or the presence of serpentinite (Degryse and Poblome, 2008, p. 234). CaO content of this group is variable as seen also in the petrographic study and it ranges from 5.95 to 11.25 wt%. Na_2O values range between 0.83 and 1.22 wt%, while K_2O values of this CG are between 2.64 and 3.13 wt % (Fig. 7**b**). Concerning trace elements, a distinct characteristic of CG1 is the fact that it contains higher Cr and Ni values compared to the rest of the groups with mean values of 900 ppm and 421 ppm respectively. It is interesting to note that Cr values can be exceptionally high for some samples reaching up to 2776 ppm. Cr and Ni are highly compatible elements and they are related to mafic rocks and their accessory minerals such as pyroxene, amphibole and micas (Braekmans et al., 2011, p. 2110; Degryse and Braekmans, 2013, p. 194). Rare Earth Element (REE) values of this group range between 111 and 146 ppm and High Field Strength Elements (HFSE) values are between 146 and 204 ppm. Sr values of this group are quite low compared to other CG identified ranging between 144 and 361 ppm (Fig. 7**c**). This CG forms also a clear cluster when looking at the PCA plot because of its higher MgO and Cr-Ni-Co values compared to the rest of the samples (Fig. 6).

Chemical Group 2 includes the samples of Fabric B. This group is characterised by lower MgO values (3.38–6.91 wt%) and higher Na_2O (1.03–1.57 wt%) and K_2O (2.84–3.71 wt%) values compared to CG1 (Fig. 7**b**). These high alkali values can be explained by the high presence of feldspars and micas in this fabric as suggested by the petrographic study. In terms of trace elements, this group is clearly distinguishable from the rest of the CGs. It has elevated REE, especially Light Rare Earth Elements (LREE) as seen in Fig. 7**c** and Fig. 7**d**. Large-ion Lithophile Elements (LILE) and HFSE values are also enriched for this group. In the Th vs Cr plot, it also appears separate because of its high Th content. Th values are usually associated with ferromagnesian minerals (Degryse and Braekmans, 2013, p. 195). Sr values are also very high compared to the rest of the CGs ranging between 669 and 747 ppm, likely substituting for Ca in the attested feldspars. This suggests that pottery of CG2 was made using clays that were exploited from a different geological environment than the clays used for CG1.

Chemical Group 3 includes samples of the Petrographic Fabric C as well as Minor Fabric G and it plots close to Chemical Group 1. The samples of this group however appear to have slightly lower values of MgO (4.23–6.41 %), higher values of Al_2O_3 (15.30–18.04 wt%) and higher K_2O values (3.14–3.68 wt%). CG3 has also slightly higher REE values (149–209 ppm) (Fig. 7**e**), HFSE (185–225 ppm) and Th values (12.9–17.5 ppm). Sr values are similar to those of CG1 ranging between 173 and 413 ppm. This close similarity of CG3 to CG1 might suggest that the clay sources exploited derive from the same area, but the higher REE values observed are related to clay preparation processes. The petrographic study showed that the ceramics of CG3 are characterised by a higher frequency of inclusions than those of CG1, and the clay used seems to have been processed differently and/or appears less refined.

Chemical Group 4 corresponds to the samples of imported Eastern Sigillata A wares which belong to Fabric D. This group is clearly distinguished because of its high CaO content (15.30–20.40 wt%) which is explained by the fact that this is a highly calcareous fabric as seen under the microscope (Fig. 5). Na_2O and Al_2O_3 values are lower than the rest of the CGs. More specifically, Na_2O values range between 0.45 and 0.57 wt%, while Al_2O_3 values are between 10.85 and 11.83 wt%. In

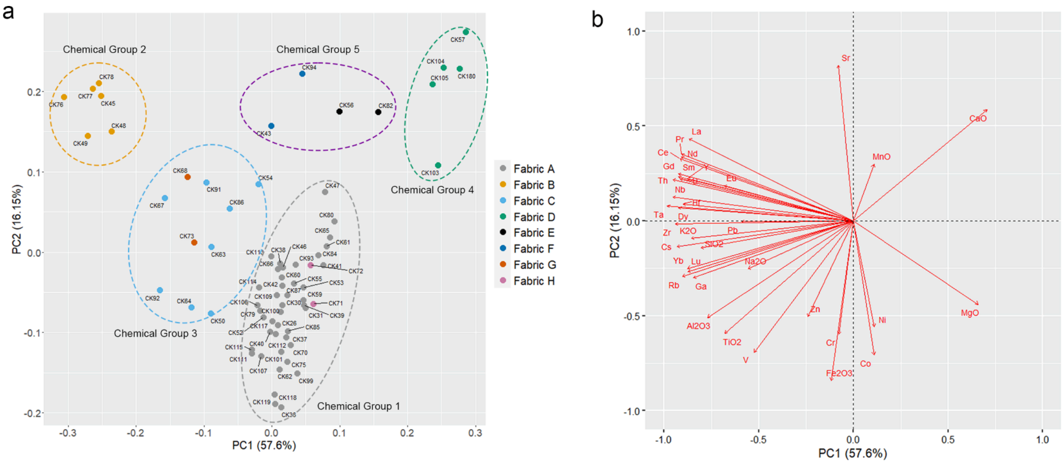

Fig. 6. Results of Principal Component Analysis (PCA) applied on the ICP-OES and ICP-MS chemical data of the ceramic samples under study, excluding petrographically unique samples: (a) scatterplot of principal component 1 versus principal component 2 showing the chemical groups and their corresponding petrographic fabrics and (b) plot of loadings explaining the variability observed in plot a.

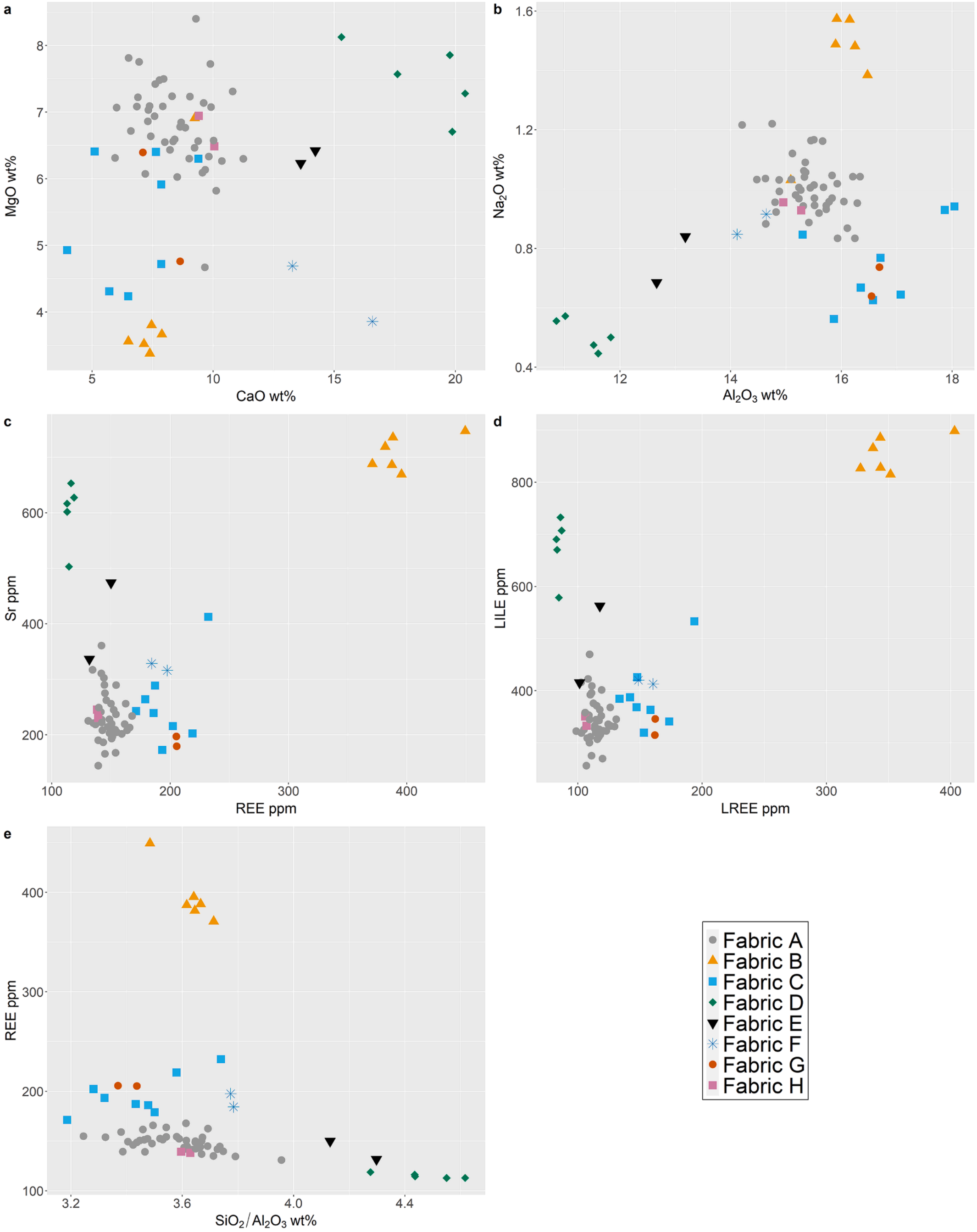

Fig. 7. Scatterplots of different elements measured by ICP-OES and ICP-MS. The values are recalculated to 100 wt% on a LOI-free basis. (a) MgO vs CaO wt%; (b) Na2O vs Al2O3 (wt%); (c) Sr vs REE (ppm); (d) LILE vs LREE (ppm); (e) REE (ppm) vs SiO2/Al2O3.

terms of trace elements, this group has lower REE (94.0–98.8 ppm) (Fig. 7**c**) and HFSE (102–128 ppm). Sr values are higher than CG1, 3 and 5 (503–653 ppm) (Fig. 7**c**). It should be noted that all the ceramics of this group were found to have consistently higher LOI, ranging between 7.6 and 12.9 wt%.

Finally, Chemical Group 5 includes samples of Fabric E and Fabric F. Although in some scatterplots this chemical group partially overlaps with CG1, it is distinguished because of its higher CaO (13.28–16.57 wt %), lower Al_2O_3 (12.66–14.64 wt%) and lower MgO (3.86–6.42 wt%) than CG1. This difference in geochemistry correlates with the petrographic results that suggest that these fabrics contain mainly quartz and inclusions of sedimentary origin, especially limestone. Cr and Ni values are also lower than CG1 (407–496 ppm and 226–282 ppm respectively), while Sr values are higher (316–474 ppm).

6. Discussion

6.1. Comparison with clay sources: Provenance of raw materials

The provenance of the different Chemical Groups is investigated by looking at the geology of the region of Sagalassos and by comparing the chemical composition of the ceramics with that of the clay sources in the study region. The data of the clay sources are taken from the most recent and detailed study conducted by Neyt et al. (2012, pp. 1303, table 6). This study collected clay samples from different sites across the study region of Sagalassos and analysed them chemically with the same analytical technique as this study, allowing us to make the comparison.

CG1 and CG3 which are characterised by high MgO and Cr-Ni-Co values and occasionally the presence of inclusions related to igneous geology such as opaques, volcanic rock fragments, serpentine and pyroxenes, reflect the Lycian geology which is found around Sagalassos and confirms the local origin of these groups. When looking at the chemical data of the clay sources, these two Chemical Groups show a close correspondence with the clays from the NW parts of the valley of Çanaklı. They are characterised by similar Na_2O and K_2O values as well as elevated content of MgO content as the Çanaklı clays. These clays contain large amounts of chlorite which explains their high MgO content (Degryse and Poblome, 2008, p. 245). In terms of trace elements, there is also a good correspondence between Çanaklı clays and CG1 and CG3. These clays contain high amounts of Cr and Ni and low levels of Sr as is the case with ceramics of CG1 and CG3. This result is in agreement with the previous archaeometric studies on SRSW that pinpointed the exploitation of clays in the NW parts of the Çanaklı valley for the production of SRSW (Degryse et al., 2003; Degryse and Poblome, 2008; Poblome et al., 2002a).

Concerning the ceramics of the rest of the CGs, it is not possible to make a direct link with any particular source that has been currently documented in the study region. Concerning the ceramics of CG2, their lower MgO content as well as their higher REE values, exclude a matching with Çanaklı clays which were used for the production of the majority of Hellenistic and Roman Imperial fine wares. Rather their values appear closer to the clays from the valley of Ağlasun with high REE and high Sr values. The samples of CG2 belong to Fabric B which is a fine-grained fabric characterised by the presence of rocks and minerals of sedimentary and volcanic origin that are consistent with the geology of the region under study. Limestone fragments as well as pyroxene, amphibole, mica and volcanic rock fragments are present in this Fabric. It is not possible to pinpoint the exact location for the clay raw materials used for this group but taking into account both the petrographic and geochemical results, a regional origin of these ceramics from the wider study region of Sagalassos is suggested.

The chemical composition of CG4 on the other hand, does not appear close to the composition of any of the clay sources from the region of Sagalassos. The samples of this chemical group belong to Fabric D which is a fine-grained fabric characterised by a highly calcareous matrix that contains only some inclusions of serpentine and quartz. The presence of serpentine fragments shows that the raw materials exploited are related with an igneous (ophiolitic) geological environment, but the texture and matrix characteristics of this Fabric are very different from the rest of the Fabrics identified suggesting its non-local origin. Although the processing of raw materials might have affected their chemical composition making a match with a particular source difficult, taking into account this systematic difference in petrographic fabric and the ware identification of the ceramics (ESA) it seems plausible to suggest that these ceramics were made at a workshop outside the region of Sagalassos. Finally, the petrographic study of ceramics of CG5 indicates their non-local origin. In particular, these ceramics contain inclusions of metamorphic origin such as mica schist and marble, suggesting that the raw materials used for the production of these wares were exploited in a geological environment with some metamorphism which is not found in the immediate vicinity of Sagalassos.

6.2. From earth to pots: Reconstructing ceramic technology and spatial patterns

This analytical study allows us to reconstruct various steps involved in the production sequence of tableware from the site. Hellenistic Gray Wares with Black Slip, Colour Coated Wares as well as SRSW of the first centuries CE (phase 1–3) were produced locally using the same raw materials. The majority of the ceramics is characterised by a fine-grained fabric (Fabric A) that mainly contains inclusions of quartz and mica. Some CCW and one sample of SRSW (phase 1–2) belong also to Fabric C (Fine-grained with Feldspar, Muscovite mica, Biotite mica, and Quartz) including the samples from Ören, while 4 samples of SRSW (phase 1–2) belong to Minor Fabric G (Fine-grained with Quartz, Limestone and Feldspar) and Minor Fabric H (Fine-grained with Limestone). The fine nature and size of the inclusions suggest that the clay used for these ceramics has been refined which is in agreement with the archaeological evidence from the Roman Imperial workshops located in the Eastern Suburbium of Sagalassos where the production of SRSW was organized (Murphy and Poblome, 2017, p. 69). Ceramics of CG1 and CG3 were made using calcareous, Mg-rich clays from the NW parts of the valley of Çanaklı suggesting the continuous use of the same raw materials from Hellenistic into Roman Imperial times. The presence of large variability characterizing this fabric in terms of the frequency of inclusions might suggest different processing of raw materials during different periods or the exploitation of different horizons of this clay source, especially when taking into account the long-term use of the same raw materials. It is worth mentioning that these Çanaklı clay deposits are located at a relative distance (c. 8 km) from the ancient city. In contrast to table wares, local contemporary coarse pottery was made using clays from the weathering of ophiolitic or flysch deposits found near Sagalassos (Degryse et al., 2003). Thus, this preference of using Çanaklı clays for the production of tableware constitutes a deliberate technological choice made by Sagalassos' potters over the years, already from Hellenistic period, and can be linked to the special properties of the raw materials as well as the desired product qualities – fine pottery. In particular, Çanaklı clay deposits are characterised by high plasticity and they are silt-rich clays, with very few coarse inclusions. As such, they require less processing than the ophiolitic clays and in this way they are suitable for large-scale production of table wares (Degryse and Poblome, 2008, pp. 238, 245).

After forming the pottery on the wheel, a layer of slip was applied on the exterior surface of the ceramics and then the ceramics were fired at variable firing conditions and temperatures. During the Hellenistic period, a higher degree of variability is observed concerning the firing temperatures, while from the Early Imperial Roman period onwards samples were fired consistently at higher temperatures. In particular, high and moderate optical activity is observed almost exclusively for the matrices of CCW and GWBS samples dating to the Hellenistic period. Weakly optically active to inactive matrices are recorded for samples dating to both periods, namely Hellenistic CCW and Early-Middle Roman Imperial SRSW, suggesting that the approximate equivalent firing temperature was close to or above 850 °C (Quinn, 2022, p. 269, 2013, p. 191). In addition, the matrices of some samples appear to have a high degree of vitrification. Previous archaeometric studies have shown that the NW Çanaklı clay sources exhibit the highest elasticity modulus at around 850 °C, while above 900 °C they develop cracks (Ottenburgs et al., 1993b). In terms of firing conditions, the majority of the Hellenistic pottery is again characterised by a high degree of variability. Hellenistic GWBS were fired in a reducing atmosphere as suggested by the grey colour of their fabric macroscopically and dark brown colour under the microscope (in both PPL and XPL). Regarding Hellenistic CCW, some of them were fired in an incomplete oxidising atmosphere or in a reducing atmosphere with an oxidation period at the end, and others in a completely oxidising atmosphere. From the Early Roman Imperial period onwards, a more consistent pattern is observed and all the samples of SRSW were fired in an oxidising atmosphere.

Some ceramics that were identified macroscopically as SRSW as well as 2 Hellenistic CCW sherds were made using different raw materials than Fabric A and belonged to Fabric B and CG2. Fabric B is a fine-grained fabric characterised mainly by feldspar and biotite mica. Other inclusions of sedimentary and igneous origin are also present indicating that the raw materials used derive from a geological environment characterised by the intermixture of those rocks. The fact that these ceramics look similar to SRSW macroscopically but they are made using different raw materials from the standarised SRSW production suggests the presence of other regional workshop(s) producing fine pottery similar to SRSW. This comes as no surprise if we take into account that SRSW does not represent an isolated phenomenon. Apart from forming part of the eastern sigillata family, a case was built earlier on the phenomenon of *koine* of which SRSW was part (Poblome et al., 2017). Sagalassos and in general southwest Anatolia formed part of this sociocultural and socioeconomic sphere that shares a common vocabulary in terms of tableware production and consumption (Bes, 2015, pp. 29, 40; Lund, 2015, p. 230). The fact that ceramics which appear macroscopically similar to SRSW are in fact products of regional rather than local production, highlights the need to approach SRSW within a regional framework (Poblome et al., 2000a). The ceramics of these groups are also wheel-thrown and are characterised by a slip on their exterior surfaces. Most samples were fired in an oxidising atmosphere, while the core/margin colour differentiation suggests uneven firing conditions.

Concerning the Eastern Sigillata A samples included in this study, the majority of them appear to have a homogeneous composition and were made using the same raw materials (Fabric D). They are made using a highly calcareous clay which is highly processed so that it contains only very few inclusions of fine quartz and serpentine fragments. Previous archaeometric analyses on a number of ESA samples from different sites indicated that they are characterised by high CaO, MgO, Cr and Ni content (as well as high LOI) and contain inclusions of serpentine, similarly to the ESA samples of this study (Daskiewicz et al., 1995; Schneider, 1996a, pp.193-194, 1996b). These studies showed that the raw materials used for ESA derive from the weathering of ophiolitic rocks probably from the area between Tarsos and Laodikeia, even though the exact location of the related production centre(s) remains unknown (Schneider, 1996a, p. 194). The yellow to brown colour of the matrix suggests that the samples of this group were fired in an oxidising atmosphere.

A small number of CCW ($n = 2$) and SRSW ($n = 2$) appear different from the majority of the CCW and SRSW samples. They are made using a highly calcareous clay and are characterised by an intermixture of rocks and minerals of sedimentary, igneous and metamorphic origin (Fabric E, Fabric F). Although an exact matching with the clay sources is not possible, their petrographic and geochemical study has shown that these ceramics were made using clays from outside the study region of Sagalassos suggesting again a framework of regional production of tableware. The ceramics of this group were fired in an oxidising atmosphere.

Finally, it should be noted that a number of Hellenistic ceramics belonging to GWBS have a unique petrographic composition, suggesting the presence of other workshops in the wider region or further away. Most samples are characterised by inclusions of metamorphic origin which are not found in the region of Sagalassos but rather are more likely related to workshops in western Asia Minor (Betina, 2019; Bozkurt and Oberhänsli, 2001; Fragnoli et al., 2022; Ladstätter, 2013, p. 319; Okay, 2001). It is yet unclear how and to what extent the production and distribution of pottery at Sagalassos was integrated in wider patterns of exchange. Elucidating these exchanges would be a much needed scope for further research. At this point it should be also mentioned that all the GWBS samples from Kozluca are characterised by unique petrographic and chemical compositions. This is not unexpected as Kozluca can possibly be identified as ancient Kormasa (Hall, 1986, pp. 141–142), which was a *polis* independent of Sagalassos already in Hellenistic times. It is also interesting to observe that the samples from Ören fall squarely in the fabric groups linked to the clays from the northwestern Canakli valley characterizing the fineware production at Sagalassos, given that Ören is located in the northern parts of the Burdur plain at some distance from Sagalassos. Interestingly, Sagalassos, Kozluca and Ören are the only three sites in the study area where a banded pottery ware dated to the Hellenistic period has been observed (Daems and Poblome, In Review). At this point, there is still a lot of unclarity regarding the political and economic development of Sagalassos as a *polis* and its associated territorial expansion during the middle and late Hellenistic periods. However, these results corroborate ongoing macroscopic pottery studies and provide additional support for an earlier hypothesis that the territorial and economic expansion of the early city did not operate at the same speeds (Daems and Talloen, 2022). Still, more research is needed to explore these hypotheses to the fullest.

7. Conclusion

Although the Hellenistic pottery workshops of Sagalassos are only scantily known, this study provides evidence for the production of CCW as well as GWBS at the site using the same raw materials as the ones used in the subsequent period for the production of SRSW, namely the Çanaklı clays. SRSW appears thus as a continuation of the pre-existing Hellenistic tradition in slipped pottery following similar technological choices in terms of the raw materials used (Poblome et al., 2000a; Poblome and Zelle, 2002). Taking into account that the clays of Çanaklı are located c. 8 km away from the ancient site, questions arise in relation to the political and economic control over those deposits over the years and the organization of the transportation of clays to the site (Poblome, 2004, p. 500). Currently, the starting date of the production of SRSW is under review and might potentially move backward in time (towards the middle of the 1st c. BCE). A reasoned starting point for this production was proposed in the past, based on the history of incorporation of the region of Pisidia into the Roman empire (25 BCE) (Poblome, 1999). This implies the possibility that the production of CCW co-existed with the production of SRSW for some time and that the transition in production from one type of tableware to the other was a more gradual process. It is not possible to draw definitive conclusion at this stage, but the ongoing detailed re-examination of the relevant archaeological deposits should be revealing. What can be concluded from the results of this study, is that ceramic production at Sagalassos shows a high degree of conservatism and continuity in terms of the raw materials used. During both Hellenistic and Roman Imperial times, the same raw materials were exploited for the production of tableware despite the fact that the political and economic situation was different for each period, indicating also the quality and preference for these mineral resources. A similar pattern regarding the exploitation of the same raw materials over time for the production of tableware has been observed at Pergamon (Japp, 2013, p. 167; Schneider and Japp, 2009).

At the same time, the identification of additional fabrics in the assemblage which are made using different raw materials than the mass-produced SRSW, albeit their macroscopic-typological similarity to SRSW, suggests the possible presence of other eastern sigillata workshops in the wider region. In addition, the high number of petrographically unique samples identified indicates a higher variability is present among tablewares than previously thought. The results of this study highlight the need for further detailed archaeometric studies in order to be able to better understand the ceramic landscape of southwest Anatolia from Hellenistic to Roman Imperial times.

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CRediT authorship contribution statement

Christiana Kelepeshi: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Dennis Braekmans:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. **Dries Daems:** Data curation, Investigation, Writing – review & editing. **Jeroen Poblome:** Supervision, Validation, Writing – review & editing. **Elvira Vassilieva:** Formal analysis, Methodology, Writing – review & editing. **Patrick Degryse:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

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

Data availability

All data are available in the manuscript and the supplementary material.

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Appendix A. Supplementary data

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