



# Analytical study of Roman red slip ware from ancient Tripolis (Denizli, Turkey)



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## ABSTRACT

Roman red slip ware uncovered at Tripolis, an ancient city of Lydia region in modern Denizli province, Turkey, was analyzed for geochemical and mineralogical properties in order to clarify their manufacturing technology. Samples were examined by optical microscopy, X-ray powder diffraction, and X-ray fluorescence. Results thus obtained indicate that the analyzed red slip wares can be divided into three groups based on the inclusion types, and grain sizes. Mineralogical compositions also reflect differences in production technology. The firing temperatures are estimated from the phase assemblages as < 800 °C for the Group 1 and 2 samples and about 900 °C for Group 3 samples. Group 1 was probably produced from local clays (Lykos Valley) in Denizli region. Group 2 shows clear similarity with local clay but it is from different origin (probably from Meander Valley (Menderes Massif clays). Whereas Group 3 does not seem to be a local production of Tripolis, rather wares imported from possibly Sagalassos in ancient Pisidia of Turkey.

## 1. Introduction

In recent years, interdisciplinary works on the findings (ceramic, metal, bone, marble fragments, etc.) from archaeological sites have shown that the chemical, geological and physical analysis techniques yield beneficial results [1–8]. The chemical, mineralogical and structural characteristics of ancient artifacts can help to identify the source area of the raw material used in ceramic production and to identify the technological processes associated with pottery production. In addition, knowing the mineralogical composition can shed light on the firing temperature and time of the raw material. Why it is important to 'identify technological processes' and 'firing temperature'? Because, technological processes can be used to design any series of operations aimed transforming a raw material into a finished product. These include the geological properties of the local environment, the nature of the raw material, meteorological changes, the nature of the fuel and fluctuations in firing temperatures [9]. Firing temperature is also the most important step in the production of pottery. These can be used with caution to infer the details of ancient firing such as the regime, apparatus and fuel types used [10]. Pottery production technologies give us important information how changing social structures impacted the material culture in general and the production of pottery in particular.

There are many archaeological sites (Laodikeia, Hierapolis, and

Tripolis etc.) currently under excavation in Denizli province of southwestern Turkey (Fig. 1a). The ancient city of Tripolis is located in Yenicekent town of Buldan district in Denizli Province. In the Hellenistic period, the city of Tripolis was at the crossroads of Phrygia, Caria and Lydia regions [11]. Archaeological excavations at Tripolis has intensified since 2012. In the present study, Roman red slip ware samples from the late Roman period uncovered at Tripolis were investigated by archaeometric methods.

Imported red slipped ceramics were found at Ancient City of Tripolis where is located on the banks of Maiandros during the excavation works between 2012 and 2017. Among these findings, red slipped ceramics were defined which date Early Roman Imperial Period and Late Roman Period red slipped ware. Located in the Pisidia Region, Sagalassos was home to red slip pottery production that started in the 1st century BCE and 1st century CE, and continued in different forms until the 7th century CE [12,13]. Another group identified in excavations in Tripolis during the years is the Lycos valley red ceramics [14]. About 4–7th century CE findings on regional production group were identified in Laodikeia and also in two metropolises which are Tripolis and Hierapolis of the valley, the most distinctive feature of this group is that it has a reddish yellow liner. Except for the first two groups, a small group of late red ceramics with little darker red slip in the ancient cities of the Menderes Valley are generally found in 6–7th century CE layers for this reason they are named as “Sigillata from the Meander valley”

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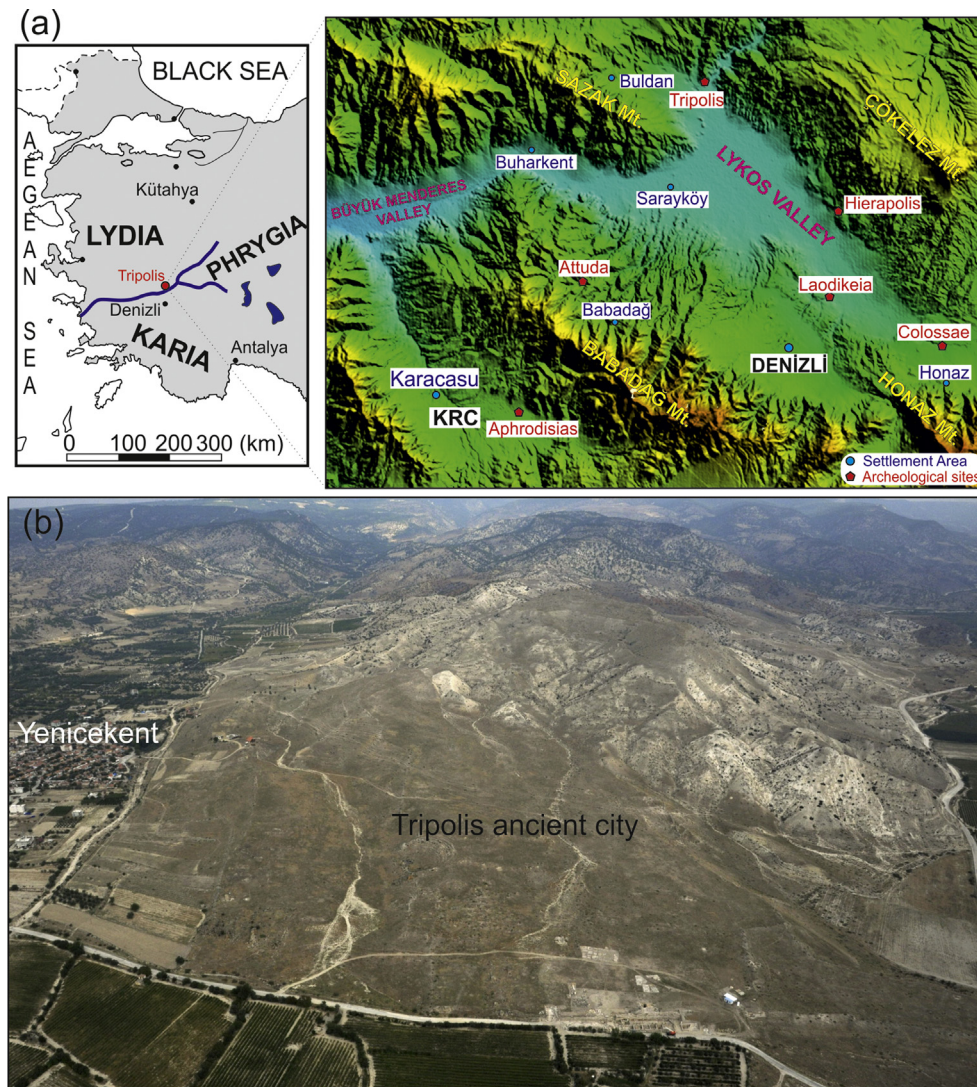


Fig. 1. a. Simplified map of Western Anatolia and Digital Elevation Model (DEM) of Tripolis archeological site and Lykos Valley; b. Overview photograph of the landscape of the valley with Tripolis.

[15].

The main aim of this analytical study is to distinguish the ceramics of local production from wares imported from nearby regions or islands and to elucidate the manufacturing process and the firing techniques. Therefore, red slip wares were correlated to well-documented characteristics of red slip ware around Turkey [5,16,17].

## 2. Archeological and geological background

### 2.1. Historical-Archeological background

The ancient city of Tripolis is located within the territory of Yenicekent neighborhood of Buldan district in Denizli province in inner western Anatolia (Fig. 1). Remains of public and civilian architecture of the city located in the northwestern tip of the Lykos (Çürüksu) Valley spread across an area of about 3 sq.km. on the southern slope of a hill dominating the valley.

Earliest information on the location of the city is given by ancient historians and geographers (Strabo XIII.4.4, 169; Pliny, NH, V, XXIX; Hierokles, Synekdemosis, 669, 4; Ptolemy V.2.18; Oracles Sibylline V, 321). The area where the city is located was considered part of Lydia as noted by Herodotus (VII.30). Pliny the Elder (NH V.29) also places the city within Lydia. Another ancient author placing the city within Lydia

was Hierokles (Synek. 669.4). As a different opinion there are also some other ancient authors that placed the city within Karia, e.g. Ptol.Geogr. V.2.18. Sibylline Oracles mention the city as “Tripolis by Maiandros” (Orac. Sibyl. V.321). Tripolis has been placed within Lydia, Karia or Phrygia by different sources and this confusion is due to its location at the junction of all three regions. The most important reason for the differences in localization should be the changes in the borders through time. Nevertheless, Tripolis was part of the conventus of Sardeis for a while but then in another document it is cited within the conventus of Apameia. Considering the fact that various geographic formations such as rivers, mountains, and lakes were determinative in settling of borders will lead us to think that Tripolis on the northern bank of River Maiandros was actually part of Lydia. The phrase of “Μαιονίη Τρίπολις” in a Roman period inscription is the most important written evidence for placing Tripolis in Lydia.

The first identification and scientific remarks on the ancient city came from travelers as early as the mid-seventeenth century [18–22], however, these works contain only limited information on visible remains of antiquity. Denizli Museum Directorate conducted short-term excavations and surveys in 1993, 2007–2009 [23–26] and in 2012 the authors of this article initiated excavations, which still continue [11,27,28]. The most important evidence indicating the strategical and geopolitical location of Tripolis rises from its location on trade routes.

The trade route coming from Pergamon and Germe extends via Thyateira, Sardeis and Philadelphia to Tripolis, Hierapolis and Laodikeia. Although most of scholars date the origins of Tripolis as a city back to the Hellenistic period, archaeological materials obtained in the course of surveys at Hamam Bükü and Yenice Höyük located to the east and southeast of the city indicate human settlement in this area since the Late Neolithic – Early Chalcolithic period. The city was founded in the Hellenistic period under the name of Apollonia [29–35]. Then for a short period of time, she was called Antoniopolis after the visit of Marcus Antonius to Asia Minor in 41 BC; however, as the First Triumvirate was dissolved in 36 BC and Marcus Antonius left it the city's name should have changed in due course. Starting with the reign of Augustus, as inferred from the autonomous coins struck here, the city was then called Tripolis. The Çürüksu Valley, where Tripolis is located, housed independent cities until the Battle of Magnesia between Seleucid and the Pergamene Kingdoms in 190 BCE. Pergamene Kingdom won this battle with the support of Rome and with the Apameia Treaty signed in 188 BCE the region came under the Pergamene rule. When Attalos III, the last king of Pergamon, bequeathed his kingdom to Rome in 133 BCE the region came under the Roman rule. During the Roman Imperial period the city was part of the Conventus of Sardeis for a while; then, she became part of the Conventus of Apameia during Flavian period [22,36].

The city had high times during the Roman period. In the first century AD, the city had a main east-west street (decumanus maximus) of 9-m-width and alleys intersecting with it at right angles. The main street was flanked by houses and shops, according to evidence available at hand for the time being, from the first century BC through the mid-seventh century AD. The second main street (cardo) intersects with the east-west Colonnaded Street in the city center and it is called the Hierapolis Street. Around these two main streets are the public structures such as Arched Building, Agora, Nymphaeum and Bouleuterion as well as civilian structures (Fig. 2).

Production activities continued through ages as the city is positioned on trade routes. Hair pins and clips of bone, which have been uncovered in high quantities, indicate that animal husbandry was one of the important income items of the city. Another important item of production is pottery vessels. Mold examples uncovered indicate that the Tripolitan production did not target local consumption only but also marketed its products to the cities in the vicinity [37,38]. A significant part of the market activities should have taken place at the two agorae identified to date. Numerous coins uncovered at the Agora reveal information regarding the dimension of trade and commercial activities in the city including the origins of the traders. Some of the cities trading at Tripolis attested from coin finds include Pergamon, Smyrna, Ephesos, Tralleis, Aphrodisias, Thyateira, Philadelphia, Prymnessos, Antiochia ad Maeandrum, Kolossai, Laodikeia, Hierapolis, Pisidian Antioch, Herakleia Salbake and Stratonikeia. Other important public structures are city gates, baths, stadium, theatre and nymphaea built according to the needs of the city, increasing in parallel to the increasing population. Not only for the pagan Roman period but also for the times of Christianity the city offers important clues. At the First Ecumenical Council held at Nikaia in AD 325, Tripolis was represented at bishopric level [21,22].

Archaeological excavations conducted in the recent years have shown that Tripolis was also affected from the earthquake in AD 60 during the reign of Nero alongside Hierapolis, Laodikeia and Kolossai, which are mentioned in the epigraphic sources. Following the concerned earthquake new construction started in the city and Tripolis also made use of the funds sent by Nero for the rebuilding of the devastated cities in the region. The second big devastation by earthquakes took place in the second half of the third century and along with the cities in West Anatolia Tripolis was also razed to ground. This earthquake led to the formation of closed contexts that facilitate dating in archaeological excavations. Another earthquake attested in the course of excavations must have taken place in the fourth century AD; skulls and bones of two

adults from this catastrophe were uncovered in the debris of the Arched Building. According to the epigraphic sources Tripolis was also devastated from the earthquake of AD 494 like all the other cities in the region [32]. Another important historic clue attested at Tripolis is the evidence for the Sassanian raids of the late sixth – early seventh century AD, which are known from Aphrodisias, Sardeis and Ephesos [39].

As a result of the abovementioned earthquakes and raids, the life in the city declined starting in the seventh century AD. In this process, like in the rest of Anatolia, ruralization was at high levels at Tripolis. In the eighth-ninth centuries AD Tripolis was perhaps only a *kome* with a small population. The revival of the city in the tenth century may be attested from the frescoes depicting saints on the walls of the church, daily use wares and coins of the same period uncovered in various trenches [40]. Tripolis changed hands a few times between the Turks and the Byzantines in the first half of the thirteenth century. Turkish hegemony over Tripolis/Yenice and environs started in 1304–1306 with the Germiyan Emirate [41].

## 2.2. Geological background

The Denizli Basin is located in WNW–ESE trending graben and very rich in archaeological sites (Attuda, Colossae, Tripolis, Laodikea, Hierapolis, etc.) of different periods (Fig. 3). The basement rocks of the basin are represented by Paleozoic–Mesozoic aged metamorphic rocks of the autochthonous Menderes massif and Lycian nappes [42]. The Menderes Massif covers a large area in western Turkey, and composes of various metamorphic rocks, which are mostly composed of schist and marble, occasionally amphibolite and quartzite. Middle Eocene Lycian nappes are characterized by ophiolitic units which consist of serpentized mafic-ultramafic rocks and allochthonous carbonate rocks. Both of these units are found on the northern and southern flanks of the Denizli Graben. The basement rocks are overlain unconformably by Bayıralan formation consisting the conglomerate and gravelly sandstone. This formation is overlain conformably by the Denizli Group, which includes Kızılburun, Sazak, and Kolankaya sedimentary formations. [43,44]. The Neogene aged Denizli Group is unconformably overlain by the recent Quaternary units (Fig. 3).

The Kızılburun Formation (Early-Middle Miocene) unconformably overlies the basement and passes upwards through the Sazak Formation. The formation consists of conglomerates alternating with reddish mudstones and clast-supported conglomerates. The Sazak Formation (Middle Miocene) conformably overlies the Kızılburun formation and consists of limestone, marl, claystone, and clayey limestone. The Kolankaya Formation (Middle-Late Miocene) conformably overlies the bottom formations and consists of laminated mudstone–siltstone and marls, alternating marl–claystone, mudstone, sandstone, and clayey limestone [45–47]. Ulubey formation (Late Miocene – Late Pliocene), which is present in the northern part of Denizli basin, is composed of lacustrine limestone with claystone and marl intercalations. Asartepe Formation (Quaternary) overlies the Neogene aged units with an angular unconformity.

## 3. Material and methods

### 3.1. Material

Arched building, located on the northern end of the columnar street, extends in east-west direction and has a rectangular form. There are entrances from the porch (Columned gallery) in the west and the tabernals in the south. Arched building, built in the Late Hellenistic-Early Roman Period, has 10.6x 36.35 m area (Fig. 2). The 20 arches rising on 14 columns form two corridors. 1861 pieces of coins, 1081 pieces of bone spindles (needles, medical instruments, dice, hair pins), 289 pieces of metal works, 251 pieces of terracotta pieces, 38 pieces of marble pieces, 44 pieces of inscriptions, 15 pieces of glass pieces fabric pieces were found. The dates of the ceramic found in the structure are

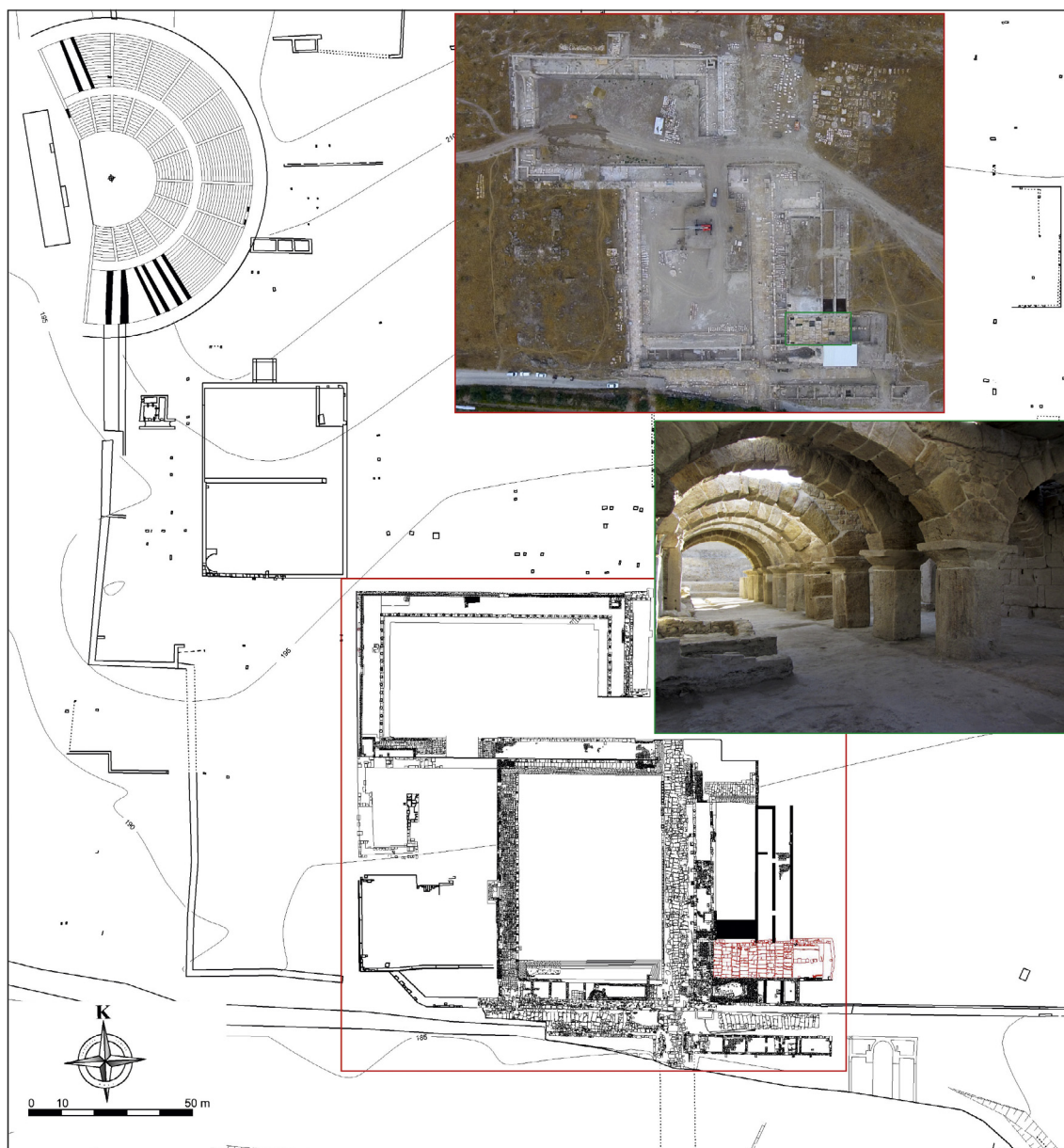


Fig. 2. A map of the Tripolis archeological site. The inset figures show the aerial photograph and the arched building from Tripolis.

from the Late Hellenistic Period to 7th century CE with no interruption. The presence of burned areas on the ground in the northern half of the structure suggests that dense amounts of iron slag, semi-worked or drafted bone artifacts, the use of baked earth molds, especially the northern corridor is used as storage space for materials produced in the southern corridor.

For this study eighteen samples were picked according to varying macroscopic properties (fabric, color, form etc.) in order to identify their structural, chemical and mineralogical properties. These samples are chosen based on dating data because the appearance of matrix and slips of the samples are close to each other. All the samples were uncovered between 187.27 m and 184.30 m levels between the northern arches of the Arched Building (Fig. 2) in 2013. Forms and photographs of all of the investigated samples are given in Table 1. Vast majority of the picked samples belong to open vessel forms such as plates and bowls and an amphora representing the closed vessels was incorporated with a single sample. The clay of the picked samples is usually pink and reddish yellow; their interior and exterior surfaces are red. Some samples distinguish themselves with their dark red slip fabric. Some

samples have blackened areas caused by firing. Sample KA8 may be considered a plate based on its broken base type; however, it was not included in any form group. Samples SA1 – 10 have a clay in reddish yellow and red but their slips have a shiny surface and light or dark red color [17]. Colors and fabrics of the samples do not display any clear distinction. Their clays are hard and firm, some samples have fine pores and fine lime temper. The samples assessed here correspond to forms 1B101, 1B190, 1B221, 1C140, 1C141, 1C142, 1C160, 1C182 of Sagalassos Red Slip Wares (Table 1) [13,47–51].

### 3.2. Method

Optical microscopy, powder X-Ray Diffraction analysis (XRD) and X-Ray Fluorescence (XRF) methods were used to investigate the production technology. Firstly, matrix and slip colors of ceramic samples were determined according to the Munsell Color Catalog, then thin sections for all samples were prepared from outer to inner layers and were investigated under optical microscope.

The mineralogical composition of the red slip ware was determined

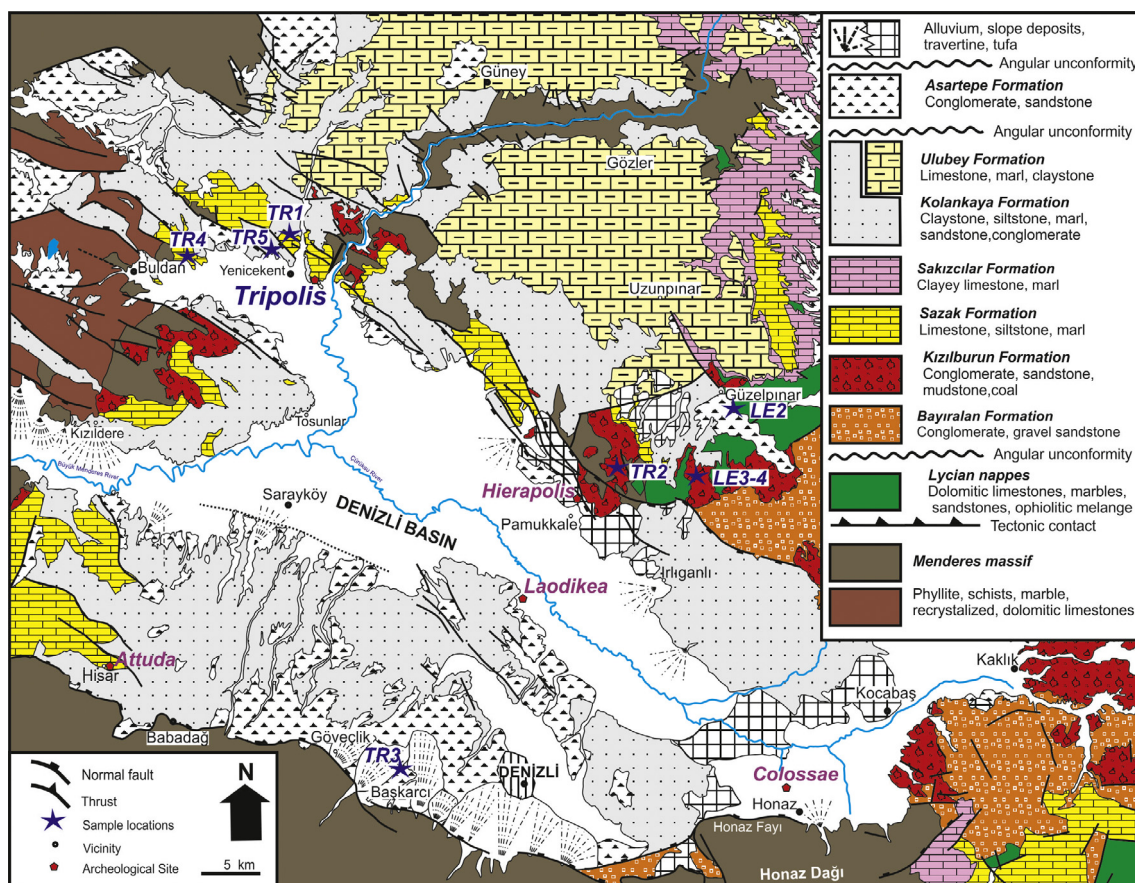


Fig. 3. Geological map of the Denizli Graben [46].

by XRD using GNR APD 2000 PRO with  $\text{CuK}\alpha$  ( $\lambda = 1.5418 \text{ \AA}$ ) radiation in the Department of Geological Engineering at Pamukkale University. The XRD method is applied for the determination of all mineral phases in the samples, especially those small enough to be inspectable in the microscope. The samples were ground in an agate mortar to a particle size of less than  $50 \mu\text{m}$  and undirected plaques were prepared. X-ray diffractograms were run at 40 kV and 30 mA condition in the  $5\text{--}45^\circ 2\theta$ , (with step = 0.05, integration time = 2 s). As a result of XRD analyses, semi-quantitative percentages were estimated based on the external standard method [52]. The mineral intensity factors in XRD- bulk fraction estimations and the reflections were measured in mm.

The chemical composition was determined at the Department of Geological Engineering at Pamukkale University using Spectro XEPOS Polarized Energy Dispersive X-Ray Fluorescence spectrometer (PEDXRF) for major and some trace elements. The instrumentation was equipped with a 50 W Pd end window X-ray tube and the spectral resolution was 160 eV (1000 cps Mn K $\alpha$ ). During the measurement the sample chamber is flushed with Helium. United States Geological Survey (USGS) standards, which are referred as GEOL, GBW-7109 and GBW-7309 were used for XRF analysis. Red slip ware samples were crushed in a tungsten carbide crushing vessel, and 6.25 g of powdered sample was mixed with 1.4 g of wax (M-HWC). The mixture was pressed at 18 N in an automatic press to obtain a pressed disc. Dilution factor (0.8169) is calculated from the mass of the sample and total dilution mass. The total organic matter and inorganic carbon amount were determined by Loss-On-Ignition at 550 °C for 4 h and at 950 °C for 2 h [53].

## 4. Results and discussion

### 4.1. Optical microscopy analysis

Petrographic investigations of thin sections constitute a crucial tool for the study of archaeological ceramics. On the basis of the inclusion types according to optical microscopy, all red slip wares could be divided into three petrographic groups. The first is dominated by biotite, feldspar and pyroxene grains (Group 1), the second dominated by muscovite and with carbonate matrix (Group 2) and the third dominated by fine silicate crystals (Group 3).

*Group 1* (KA1, KA4, KA5, KA7) is characterized by abundant biotite and quartz contents. In some of the samples, feldspar and pyroxene minerals were encountered in small amounts and sizes. Biotite minerals are also observed in sizes ranging from 0.5 to 1 mm (Fig. 4a). Feldspar is a rarely inclusion type present, appearing as fine clasts in the matrix. These clasts are usually angular, with an average grain size of 0.1–0.3 mm. Very fine elongated mica laths are abundant. When the matrix texture was examined it was determined that they were very well oriented during the preparation of the samples. The current orientations are interpreted as samples were fired before the ceramic matrix not completely dry. In KA5 sample, very abundant biotite minerals were observed, but these minerals were found to be opaque. Furthermore, in mineralogical point of view, KA5 sample showed similar chemical properties with group 1.



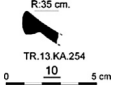

*Group 2* (KA2, KA6, KA9) is easily recognizable due to the abundance of muscovite minerals present (Fig. 4b). Muscovite minerals are up to 0.7 mm in size. Generally, in the matrix, minor amounts of small quartz grains were also observed. They are usually in the form of angular and semi-angular grains. These particles are distributed in the matrix and are in the ratio of 5%. Quartzite (1 mm) pebbles are also

**Table 1**  
Macroscopic descriptions of the red slip ware [13, 48–51].

Sample Number	The red slip ware forms	Sample photograph	Form of the red slip ware	Clay Colour	Surface Colour
KA1			tableware	7.5YR 7/4 very pale brown	10R 5/6 red 5YR 4/1 dark gray
KA2			tableware	5YR 6/6 reddish yellow	10R 4/6 red
KA4			tableware	7.5YR 7/4 very pale brown	10R 5/6 red 7.5YR 5/2 brown
KA5			tableware	7.5YR 7/4 very pale brown	7.5YR 4/1 dark gray 5YR 4/3 reddish brown
KA6			amphora	5YR 7/4 pink	10R 5/6 red
KA7			tableware	7.5YR 7/6 reddish yellow	7.5YR 3/1 very dark gray 10R 5/6 red
KA8			tableware	2.5YR 5/6 red	10R 4/6 red 2.5YR 5/6 red
KA9			tableware	7.5YR 6/6 reddish yellow	10R 4/6 red
SA1			FORM 1C 160	5YR 6/6 reddish yellow	2.5YR 4/8 red 10R 3/3
SA2			FORM 1B 190	5YR 6/6 reddish yellow	2.5YR 4/8 red
SA3			FORM 1B 221	5YR 6/6 reddish yellow	2.5YR 4/8 red 10R 3/3 dusky red
SA4			FORM 1B 101	5YR 6/6 reddish yellow	2.5YR 4/8 red
SA5			FORM 1C 182	5YR 6/6 reddish yellow	2.5YR 4/8 red
SA6			FORM 1C 160	5YR 6/6 reddish yellow	2.5YR 6/6 light red 10R 3/3 dusky red
SA7			FORM 1C 142	2.5YR 6/6 light red	2.5YR 4/8 red 2.5YR 3/2 dusky red
SA8			FORM 1C 141	2.5YR 6/6 light red	2.5YR 4/8 red

(continued on next page)

Table 1 (continued)

Sample Number	The red slip ware forms	Sample photograph	Form of the red slip ware	Clay Colour	Surface Colour
SA9			FORM 1C 140	5YR 6/6 reddish yellow	2.5YR 5/8 red10R 4/4 weak red
SA10			FORM 1C 140	5YR 6/6 reddish yellow	2.5YR 4/8 red10R 4/4 weak red

observed in the sample. The pore structure was detected in small quantity and size.

Group 3 (SA1-10) is predominantly defined as very fine silicate crystal (Fig. 4c). All samples have similar mineralogical compositions and differ according to the amount of some minerals. It is characterized by its quartz, biotite and pyroxene contents. In the samples, pyroxenes and opaque minerals are observed in small and little amounts. In addition, small calcite minerals are also observed. Generally, rounded quartz grains are usually monocrystalline and partially polycrystalline grains. The dimensions of the quartz grains are up to a maximum of 0.25 mm and correspond to the fine sand size. The pyroxene mineral observed in a small amount is apparent with oblique angle of incidence. In the specimens examined, a small number of oriented voids of about 0.09 mm in diameter are observed. In most cases, elongated voids are more prominent. The long axis of these gaps is measured as about 0.5 mm. The current orientations are interpreted as firing the ceramic matrix to be completely dry. KA8 sample subdivided into subgroup 3a (Fig. 4d). This sample contains abundant quartz, muscovite, and crystallized calcite and pyroxene minerals in lesser amounts. Crystallized calcite observed as small grains in the matrix, which are probably derived from marble, was added to the clay as temper. Calcite was often preferred as a temper over quartz, especially when manufacturing tableware due to the flexibility provided to create smaller vessels of various shapes and wall thicknesses [7,54–56]. In addition,

metamorphic rock fragments were identified in the sample. It was determined that the metamorphic rock fragment is a muscovite quartz schist with a size of about 2.2 mm.

#### 4.2. Mineralogical (XRD) analysis

Results of X-ray powder diffraction are in general agreement with mineralogical–petrographic observations. Fig. 5. The semi-quantitative mineralogical results of red slip ware samples, summarized in Table 2, were calculated based on mineralogical analyses. The three petrographic groups defined according to optical microscopy findings also have different mineralogical composition.

Group 1 contains abundant illite/mica, followed by lesser amounts of feldspar and quartz and in some samples also calcite and pyroxene (Fig. 5a). Group 2 itself is characterized by the illite/muscovite and rarely feldspar and quartz (Fig. 5b). The presence of calcite indicates a parent carbonate clay. Because calcite is not detected by optical microscopy. In the XRD analyzes for Group 3, mineralogical features similar to quartz, feldspar, diopside, and hematite contents were determined predominantly. However, there are differences in the abundance of some minerals relative to each other. In most of the samples, quartz mineral is observed as dominant mineral. In the SA3 sample with carbonate content, it was found that it contained quartz and it contained more feldspar. But there is also a lack of diopside

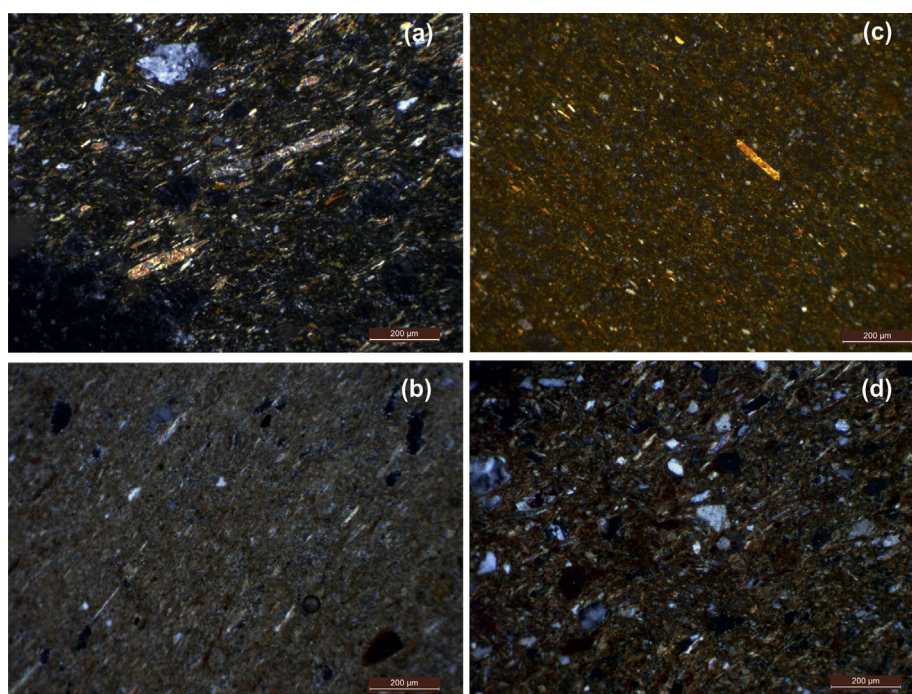


Fig. 4. Thin section photomicrographs (all in crossed Nicol) of the three main petrographic groups distinguished of the red slip ware: (a) Group 1 (sample KA1); (b) Group 2 (sample KA6); (c) Group 3 (sample SA3); (d) Subgroup 3a (sample KA8).

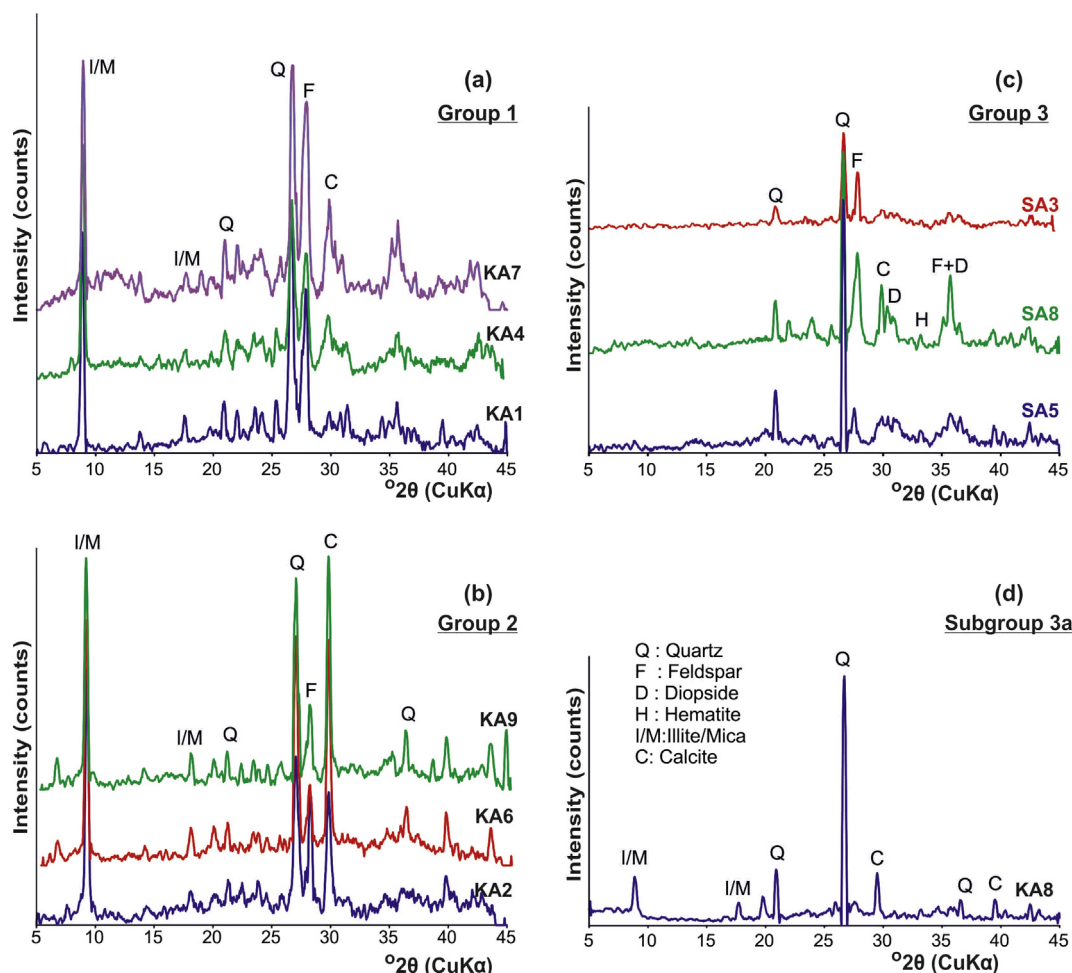


Fig. 5. X-ray powder diffraction patterns of red slip ware.

**Table 2**  
Mineralogical composition percentages of the red slip ware samples.

Groups	Sample Number	Illite/Biotite (%)	Feldspar (%)	Quartz (%)	Pyroxene (%)	Calcite (%)	Hematite (%)
Group 1	KA1	65	23	10	–	2	–
	KA4	66	18	7	9	–	–
	KA5	–	57	4	36	2	–
	KA7	56	23	8	13	–	–
Group 2	KA2	63	28	5	–	4	–
	KA6	71	11	9	–	9	–
	KA9	70	13	9	–	9	–
Group 3	SA3	–	52	22	21	–	4
	SA5	–	25	41	24	–	10
	SA8	–	41	24	30	–	8
Group 3a	KA8	51	–	40	9	–	–

content. Feldspar mineral is more in SA8 but less in SA5. The SA8 sample, which was determined to be different from all samples, had the highest feldspar and diopside content and was found to be evident by the observation of the hematite mineral (Fig. 5c). Group 3a samples contains abundant illite/mica and quartz, followed by lesser amounts of pyroxene (Fig. 5d).

The maximum firing temperature is based on the presence or absence of special minerals detected within the analyzed samples. The most important mineralogical change during firing is the disappearance of clay minerals. Increases that reach about 700–800 °C at firing temperatures gradually degrade the peak density of the clay phase. Furthermore, the thermal degradation of calcite due to increased firing

conditions starts at about 600 °C and is completed at 800–850 °C. At these temperatures (above 800 °C), free CaO reacts with free silica and aluminum derived from the degradation of clay minerals and forms gehlenite at temperatures between 850 and 900 °C or 1050 °C [4,57].

Thin sections and XRD analyzes of red slip wares (groups 1 and 2) from Tripolis suggest that samples have similar compositions and the well-preserved illite mineral phase in samples indicates low firing temperature, (< 800 °C). Because Group 2 samples contain more calcite and illite/mica peak for this reason it has a lower firing temperatures than Group 1. The firing temperatures (Groups 1 and 2) could be low temperature (approximately 800 °C). The firing temperature of red slip wares (Group 3) is over 800 °C, which is not found in any significant



**Table 3**  
Major (in wt %) and some trace (ppm) elements concentration obtained through XRF.

Elements	Units	Group 1					Group 2					Group 3					Group 3a			
		KA01	KA04	KA05	KA07	KA09	KA02	KA06	KA09	SA01	SA02	SA03	SA04	SA05	SA06	SA07	SA08	SA09	SA10	KA08
SiO <sub>2</sub>	%	50.61	46.70	51.40	48.15	39.03	39.28	37.95	48.16	48.65	48.14	48.51	49.37	49.34	46.59	52.01	50.87	48.40	49.69	49.69
TiO <sub>2</sub>	%	1.05	1.04	1.09	1.13	0.73	0.73	0.69	0.89	0.89	0.81	0.91	0.90	0.86	0.88	0.90	0.87	0.87	0.91	0.91
Al <sub>2</sub> O <sub>3</sub>	%	17.66	16.69	18.55	17.79	12.08	12.62	11.98	14.51	14.70	13.38	15.35	14.91	14.55	14.51	15.43	14.51	14.27	16.33	16.33
Fe <sub>2</sub> O <sub>3</sub>	%	7.00	7.24	6.90	7.25	5.65	5.78	5.35	8.53	8.65	7.69	8.36	8.65	8.17	8.47	8.63	8.36	8.34	7.22	7.22
MnO	%	0.06	0.07	0.06	0.06	0.05	0.06	0.05	0.08	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.05	0.05
MgO	%	3.73	3.48	3.42	3.49	3.32	3.30	3.06	7.92	6.70	7.33	6.71	8.31	7.58	7.36	8.25	7.95	7.05	2.44	2.44
CaO	%	8.12	12.49	10.12	11.07	16.92	15.13	17.04	7.36	7.78	8.73	7.25	7.34	9.27	9.56	9.65	8.06	10.18	6.85	6.85
Na <sub>2</sub> O	%	1.80	1.54	2.54	1.60	1.37	1.18	1.11	1.32	1.25	1.30	1.22	1.40	1.57	1.37	1.59	1.35	1.46	0.98	0.98
K <sub>2</sub> O	%	4.38	4.02	3.76	4.12	3.49	3.25	2.83	3.03	2.95	2.81	3.14	3.00	2.63	2.81	2.59	2.86	2.97	3.17	3.17
P <sub>2</sub> O <sub>5</sub>	%	0.24	0.26	0.19	0.26	0.21	0.21	0.24	0.23	0.23	0.23	0.25	0.26	0.18	0.19	0.26	0.21	0.22	0.15	0.15
LOI	%	5.50	6.50	2.00	5.70	18.20	17.90	18.50	8.00	8.30	9.40	7.80	5.60	6.30	8.20	0.70	4.70	5.80	12.10	12.10
<b>TOTAL</b>		<b>100.15</b>	<b>100.02</b>	<b>100.02</b>	<b>100.62</b>	<b>100.05</b>	<b>99.43</b>	<b>98.80</b>	<b>100.04</b>	<b>100.20</b>	<b>99.91</b>	<b>100.02</b>	<b>99.83</b>	<b>100.54</b>	<b>100.06</b>	<b>100.02</b>	<b>99.83</b>	<b>99.65</b>	<b>99.90</b>	<b>99.90</b>
Y	ppm	99.9	98.7	107.9	116.9	75.1	71.5	63.3	19.9	21.0	19.6	20.4	20.4	20.5	21.4	21.5	19.9	20.3	25.5	25.5
Zr	ppm	149.8	122.7	132.3	113.2	131.2	93.4	120.6	170.6	176.5	159.9	179.3	171.5	167.4	176.0	179.0	171.3	174.9	268.2	268.2
Nb	ppm	38.7	34.8	40.7	39.9	27.2	24.5	22.9	16.4	15.9	14.1	16.3	14.9	14.4	17.2	15.2	16.3	15.2	17.9	17.9
Sr	ppm	505.1	725.0	552.7	614.0	719.8	756.7	770.6	240.9	224.6	276.9	207.7	229.8	259.4	268.9	220.0	226.6	283.7	226.9	226.9
Cr	ppm	87.0	94.0	66.9	75.1	88.9	97.7	102.4	361.0	338.6	329.6	311.3	348.8	340.1	352.1	370.7	345.5	332.2	271.0	271.0
Ni	ppm	101.6	108.0	90.2	95.7	113.5	124.7	120.1	364.1	364.1	322.7	336.5	364.6	330.9	355.2	381.6	372.0	343.3	252.8	252.8

clay minerals. The samples indicate that the firing temperatures of the samples examined due to the presence of vitrification and high temperature minerals are around 900 °C. It has been found that the SA8 had a higher firing temperature than both the textural difference and the mineralogical abundance contained therein. Group 3a has a slightly higher firing temperature than those of Groups 1 and 2.

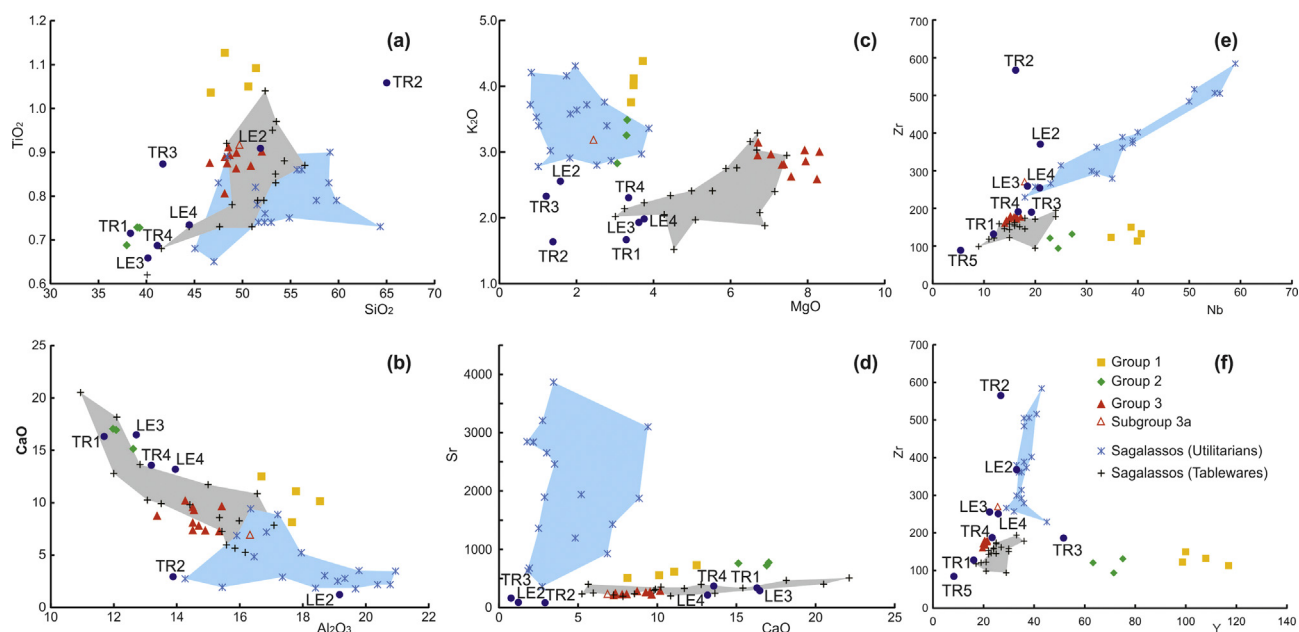
4.3. Chemical (XRF) analysis

Concentration of trace (in ppm) and major (in wt%) elements normalized versus loss on ignition (LOI) are reported in Table 3. All measured elements were compared with each other by means of bivariate plots. Three main compositional groups can be distinguished on the basis of the major and trace elements. The results are accordant with the groups defined by petrographic investigations.

The lowest SiO<sub>2</sub> content (38.75%) and the highest CaO content (16.4%) belong to the Group 2 samples and the SiO<sub>2</sub> (48.2–51.4%) and CaO (6.9–12.3%) contents of the other groups are approximately similar (Fig. 6a and b). Abundant levels of SiO<sub>2</sub> were observed in Group 3 samples, in which these values are related to the abundant quartz and also to the feldspar contents. The changes in SiO<sub>2</sub> contents appear to be directly related to the silica mineral contents in the Group 3 samples. The highest SiO<sub>2</sub> content belongs to the SA8 sample with an average of 52%. In other samples, this value is 48.5% on average. The high Loss-On-Ignition (LOI) values of Group 2 samples are attributed to the abundant calcite and CaO presence. The highest K<sub>2</sub>O (4.07%) content was observed in Group 1 samples, reflecting their greater K-feldspar and illite/muscovite content (Fig. 6a and c). Potassium are mainly hosted in micas and K-feldspar. The highest TiO<sub>2</sub> (1.08%) was observed in Group 1 samples and lowest TiO<sub>2</sub> content in Group 2 samples (0.71%). The highest Fe<sub>2</sub>O<sub>3</sub> concentrations were observed in Group 3 samples. They likely reflect the abundance of hematite/magnetite and clay minerals. Reflecting their higher clay mineral and feldspar content, Group 1 samples, contain the highest amount of Al<sub>2</sub>O<sub>3</sub>. Samples of Groups 1 and 2 showed similar values to one another for MgO contents. Group 3 samples contain higher MgO values. In Subgroup 3a sample, MgO contents also show significant differences. Other elements are close to each other (Fig. 6c). The major element results generally relate to the mineralogical composition of all groups.

It is observed that the highest zirconium (Zr) content is found in Group 3, which is also rather high (especially in Subgroup 3a [268.2 ppm]), probably linked to the igneous phases [2,58]. In other groups, these values are close to each other (Fig. 6e and f). The highest Y and Nb contents are seen in the Group 1 samples and the lowest in the Group 3 samples (Fig. 6f). These values in Group 2 samples are moderate. The concentration of Y and Nb is largely determined by the abundance of heavy resistance minerals, such as zircon, xenotime and garnet. Garnet is especially common in some metamorphic rocks like schist and amphibolite. It is a common rock-forming mineral in some igneous rocks. These metamorphic rocks are very common in the Menderes Massif located to the west of Tripolis. Sr contents are the highest in Group 1 samples (Fig. 6d). Sr mostly resides in feldspar. The fractionation of Sr can result from the selective weathering of these feldspar. Group 3 samples differ significantly in terms of Cr and Ni contents from other groups (Groups 1 and 2) which have similar values.

The samples were evaluated on the basis of the main element oxides (Si, Al, Fe, Ti, Mg, Ca, Na, K) and compared with the Sagalassos analyzes made by [5]. It is seen that Sagalassos samples, which are generally divided into seven groups, basically split into two different areas (utilitarian and tablewares) (Fig. 6c). This property is valid for Groups 1 and 2 of the Tripolis samples. Group 1 samples contain high Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub>. The higher TiO<sub>2</sub> content (> 1.04%) can be associated with the higher SiO<sub>2</sub> content in the Group 1 sample. Besides, TiO<sub>2</sub> together with Al<sub>2</sub>O<sub>3</sub> content increases the melting point. Groups 1 and 2 samples contain high K<sub>2</sub>O content. It is thought that the content of K<sub>2</sub>O originates especially from illitic clays. In group 1, the extra K<sub>2</sub>O can be came



**Fig. 6.** Bivariate plots of the major elements a.  $\text{TiO}_2$  versus  $\text{SiO}_2$ , b.  $\text{CaO}$  vs.  $\text{Al}_2\text{O}_3$ , c.  $\text{K}_2\text{O}$  vs.  $\text{MgO}$  (in wt.%), d.  $\text{Sr}$  vs.  $\text{CaO}$ , and trace elements e.  $\text{Zr}$  vs.  $\text{Nb}$  and f.  $\text{Zr}$  vs.  $\text{Y}$  concentrations (in ppm) in the red slip wares from Tripolis (TR2, LE2, LE3, LE4) clays from Pamukkale, TR3 from Başkarıcı and TR1, TR4, TR5 from Yenicekent clays from Semiz [46,47] and Sagalassos references samples from Braekmans [5].

from potassium feldspar. In addition,  $\text{MgO}$  contents show significant differences between the sample groups (Fig. 6c). The Group 3 samples have values close to each other in terms of their  $\text{MgO}$  content with average value of 7.5%. In this case, it is seen that the tableware shows similarities. The differences in  $\text{MgO}$  contents can be attributed to the pyroxene and chlorite minerals observed in the samples [5,59]. Unlike Group 3 samples, the subgroup 3a remains in the field of utilitarian wares.

Some trace elements (Cr, Zr, Ti, Nb, etc.) are often used as geochemical guides because they are associated with specific petrological species [2,60,61]. Elemental profiles of trace elements show similar properties for almost all examined samples (Fig. 6e and f). It is also observed that the Sagalassos red slip wares have differences in terms of their trace element contents and it is clearly understood that the utilitarian wares and tablewares are distinctly separated [5]. In this context, as a result of comparison of Tripolis samples, it is observed that Groups 1 and 2 specimens stay in different areas than Sagalassos samples while Group 3 samples and Sagalassos samples are located in the field of tableware. Subgroup 3a samples were found to be associated with Sagalassos samples and with utilitarians.

NASC (North American Schist Composites), PAAS (Post-Archean Australia Shale) and Upper Crust (UC) are widely applied in normalized major and trace element patterns, especially in geochemical analyzes related to magmatic, sedimentary and metamorphic petrology [62,63]. This normalization is achieved by dividing the measured values to the normative value. In order to observe fractionation process NASC normalization is used it was determined that ceramics were more closely related to sedimentary materials. In Fig. 7, Sagalassos red slip wares were compared by Braekmans [5]. As a result of this comparison, it was determined that Groups 1 and 2 showed similar compositions and Group 3 samples showed similar patterns and showed similarity with the group called tableware (Fig. 7a). In the same way, both Sagalassos and Tripolis red slip wares were compared with PAAS (Post-Archean Australia Shale) [64,65] and upper crust (UC) [66] (Fig. 7b and c), similar results were found.

#### 4.4. A comparison of red slip wares and raw materials

Neogene clay deposits were examined from Yenicekent, Pamukkale

and Başkarıcı (Denizli region) by Semiz [46,47]. These clay locations were obtained from historical sources and interviews with local people and modern employers in the ceramic industry [46]. It is inferred from these studies that TR2, LE2, LE3, LE4 clays from Pamukkale, and TR3 from Başkarıcı can be used in the ceramic industry, on the other hand, TR1, TR4, TR5 from Yenicekent clays cannot be used in the ceramic industry. In the present study, red slip wares were correlated with clay samples from Denizli region (Fig. 6). Chemical composition of all clay samples show differences. The  $\text{MgO}$  concentrations were lower than that in the mafic source rocks.  $\text{K}_2\text{O}$  contents were not found in high quantity and this situation is related to lower muscovite contents. Y contents were very low; however, in TR3 sample this content was found to be higher. This could be interpreted that these clays originated from metamorphic rocks. The clayey raw material from the Tripolis red slip ware is compositionally distinctive among region clays. In our studies on the red slip wares from Laodikeia in the Lykos Valley these were found to be local productions related with local clays [67].

When the three groups of samples identified according to mineralogical and chemical studies were assessed for their source areas, these were understood to be different. In this context, Group 1 (Lykos Valley Red Slip Ware,  $n = 4$ ) is characterized by very high levels of  $\text{K}_2\text{O}$ ,  $\text{TiO}_2$ , Y and Nb. the clay color is pink (7.5YR 7/4) and reddish yellow (7.5YR 7/6) and the interior and exterior surfaces are red. However, some samples have blackened areas caused by firing. Samples with similar form and slip fabric are also found at Hierapolis and dated to the late fourth century AD. [68,69]. Both chemical and petrographic results suggest that Lykos valley red slip ware was also produced from local clay material (Pamukkale area) in Denizli region. Group 2 (Menderes Valley Red Slip Ware,  $n = 3$ ) is characterized by very high levels of  $\text{CaO}$  (up to 15 wt%) and relatively low amounts of trace elements. This group distinguishes itself from the pottery of the Lykos Valley with regards to clay, slip and form. The slips of these wares with dark red slip have flaked off due to its fine texture [70]. This flaking should be related with the muscovite mineral content. The presence of abundant muscovite and metamorphic rock fragments brings forward the source of its raw material beyond the Menderes Massif. Group 3 (Sagalassos Red Slip Ware,  $n = 11$ ) can be considered as very distinct from the other chemical groups. Braekmans [5] mentioned that there are many clay deposits developed especially in different valley systems in the

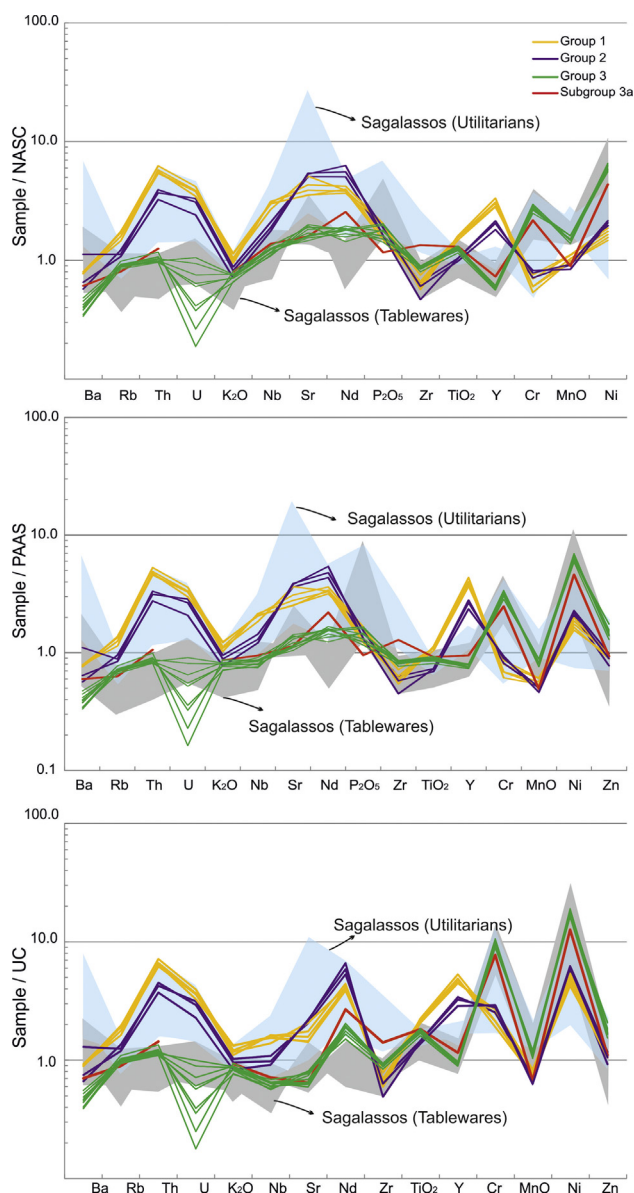


Fig. 7. Spider diagrams for Tripolis red slip ware samples and Sagalassos references samples [5] normalized to NASC [59,63], PAAS [64,65] and UC [66].

region. In this context, detrital clays of the Çanaklı valley, that is associated with the alternation of shale, is used for the production of the Sagalassos red slip wares [5,16,71]. This clay consists mainly of chlorite and smectite type clays. As a result, the Çanaklı clays mainly consists of illite and chlorite, besides kaolinite and less smectite, plagioclase and feldspar, quartz, pyroxene and biotite. It is believed that these clays are probably moved during the deposition processes due to their granular content. It can also be said that clays contain very high MgO. As a result of the evaluation of all data, a group of red slip wares in Tripolis were found to be product of Sagalassos and the results also indicated that clay materials was obtained from the Çanaklı plain. Subgroup3a is more compatible with the detrital clays from the western part of the Ağlasun valley [71]. Although closer dates are foreseen for various find sites the Tripolitan materials can be attributed to the fourth century AD based on supporting materials and comparisons.

#### 4.5. Archaeological implications

The Sagalassos Sigillatas where production started from the Late Hellenistic Period to the 7th century A.D were found in archaeological

excavations in many ancient cities outside Sagalassos during the Ancient Ages. These ceramics were produced in the interior of Anatolia unlike other red slipped ceramic groups and exported to the different regions and geographies. In this study, it is seen that Sagalassos Sigillatas were also used intensively in Tripolis that is located in the western Anatolia borders. These ceramics found in Tripolis have a thick walled structure except a few samples. This findings are already supported by several publications that Sagalassos potters produce their products that are made for export at far distances and suitable for the land transportation.

Among Sagalassos Red Slip Ware in Tripolis, there are limited number of samples with ornamentation, especially the examples of samples dated to the 4th century CE indicate a commercial relation with Sagalassos in this period. These commercial relations are supported by the discovery of a lot of coins found on such dates in Tripolis Arched Building.

## 5. Conclusions

This study is about the characterization of red slip ware from ancient Tripolis in Denizli province. The red slip ware samples show differences in their mineralogical and chemical composition, reflecting variation in the manufacture technology and the type of clays used. Differences in matrix, and the distribution and size of grains were also analyzed. The red slip wares were classified into three distinct groups: (i) Group 1 (Lykos Valley) – dominated by biotite, feldspar and pyroxene grains (ii) Group 2 (Menderes Valley) – dominated muscovite and with carbonate matrix (iii) Group 3 (Sagalassos) – dominated by fine silicate crystals. The major element compositions of the three groups generally related to mineral composition of the samples. It is observed that the samples of Groups 1 and 2 were fired < 800 °C and samples of Group 3 were fired at temperatures up to 900 °C.

All the data were evaluated and it was determined that the red slip ware ceramics recovered in Tripolis had different origins in terms of archaeometric properties. Group 1 was probably produced from local clays in Denizli region. Group 2 shows clear similarity with the local clay but it has a different origin (probably Menderes Massif clays). Whereas Group 3 is not a local production of Tripolis. Furthermore, it was understood that the samples were imported from another geography, namely Sagalassos in Burdur province. In order to clarify the Denizli region clays, investigation of clay raw materials in the surrounding area of the archaeological site needs to be carried out in the future.

## References

- [1] A.A. Akyol, B. Tekkök, Y.K. Kadioğlu, Ş. Demirci, Tarsus-Gözlükule Erken Roma Dönemi Seramikleri Arkeometrik Çalışmaları, 22. Arkeometri sonuçları toplantısı, Çanakkale, 2006, sy, pp. 99–114.
- [2] A. Iordanidis, J. Garcia-Guineab, G. Karamitrou-Mentessidic, Analytical study of ancient pottery from the archaeological site of Aiani, northern Greece, *Mater. Charact.* 60 (2009) 292–302.
- [3] G. Montana, L. Iliopoulos, V. Tardo, C. Greco, Petrographic and geochemical characterization of archaic-hellenistic tableware production at Solunto, Sicily, *Geoarchaeology* 24 (1) (2009) 86–110.
- [4] L.A. Ortega, M.C. Zuluaga, A. Alonso-Olazabal, X. Murelaga, A. Alday, Petrographic and geochemical evidence for long-standing supply of raw materials in Neolithic pottery (Mendandia site, Spain), *Archaeometry* 52 (6) (2010) 987–1001.
- [5] D. Braekmans, P. Degryse, J. Poblome, B. Neyt, K. Vyncke, M. Waelkens, Understanding ceramic variability: an archaeometrical interpretation of the Classical and Hellenistic ceramics at Düzen Tepe and Sagalassos (Southwest Turkey), *J. Archaeol. Sci.* 38 (2011) 2101–2115.
- [6] M. Kibaroglu, A. Sagona, M. Satir, Petrographic and geochemical investigations of the late prehistoric ceramics from Sos Höyük, Erzurum (Eastern Anatolia), *J. Archaeol. Sci.* 38 (2011) 3072–3084.
- [7] S. Kramar, J. Lux, A. Mladenović, H. Pristacz, B. Mirtiç, M. Sagadin, N. Rogan-Šmuc, Mineralogical and geochemical characteristics of Roman pottery from an archaeological site near Mošnje (Slovenia), *Appl. Clay Sci.* 57 (2012) 39–48.
- [8] A.A. Akyol, Y.K. Kadioğlu, A.K. Şenol, Bybassos Hellenistik ticari amphoralari arkeometrik çalışmaları, *Cedrus I* (2013) 163–177.
- [9] O.P. Gosselain, Technology and style: potters and pottery among bafia of cameroon,

- Man, New Series 27–3 (1992) 559–586.
- [10] P.S. Quinn, Ceramic, Petrography: The Interpretation of Archaeological Pottery and Related Artefacts in thin Section, Archaeo press, Oxford, 2013, p. 260.
- [11] B. Duman, Son Arkeolojik Araştırmalar ve Yeni Bulgular Işığında Tripolis Ad Maendrum, *Cedrus*, I (2003) 179–200.
- [12] J. Poblome, W. Viaene, H. Kucha, M. Waelkens, D. Laduron, F. Depuydt, The clay raw materials of sagalassos red slip ware: a chronological evaluation, in: M. Waelkens, J. Poblome (Eds.), *Acta Arch. Lovaniensia Monogr.* 1997, pp. 507–518.
- [13] J. Poblome, Sagalassos red slip ware: typology and chronology, studies in Eastern Mediterranean, *Archaeology* (1999).
- [14] C. Şimşek, M. Bilgin, “Laodikeia Geç Antik Çağ Seramikleri”, C. Şimşek, T. Kaçar (Eds.), *Geç Antik Çağda Lykos Vadisi ve Çevresi*, 2018, pp. 175–200.
- [15] A. Waldner, Ephesus – local vs import: The Early Byzantine fine ware, in: H. Meyza (Ed.), *Late Hellenistic to Mediaeval Fine Wares of the Aegean Coast of Anatolia: Their Production, Imitation and Use*, 2014, pp. 49–58.
- [16] P. Degryse, J. Poblome, K. Donners, J. Deckers, M. Waelkens, Geoarchaeological investigations of the “Potters’ Quarter” at Sagalassos, Southwest Turkey, *Geoarchaeology* 18 (2003) 255–281.
- [17] B. Semiz, Tripolis’ten Bir Grup Kırmızı Astarlı Seramiğin Arkeometrik İncelemesi, *Arkeoloji Dergisi*, XXII, 2017a, pp. 315–325.
- [18] T. Smith, Remarks upon the manners, religion and government of the Turks: together with a survey of the seven churches of Asia, as they now lye in their ruines, and a brief description of Constantinople, 1678, London.
- [19] R. Chandler, *Travels in Asia Minor*, London, 1764–1765, 1969.
- [20] W.I. Hamilton, Extracts from notes made on a journey in Asia Minor in 1836, *J. Royal Geograph. Soc. Lond.* 7 (1837) 34–61.
- [21] W.M. Ramsay, Antiquities of Southern Phrygia and the Border Lands (I), *Am J Archaeol History Fine Arts* 3 (3/4) (1887) 344–368.
- [22] W.M. Ramsay, *The Historical Geography of Asia Minor*, London, 1890.
- [23] A. Ceylan, Tripolis Sütünlü Caddesinde Yapılan Kazı ve Temizlik Çalışmaları, *MKKS* 5 (1995) 159–170.
- [24] N. Atik, Z.K. Erdem, Buldan (Denizli) Arkeolojik Belgeleme Çalışması, *Türkiye Kültür Envanteri Pilot Bölge Çalışmaları 1 (2)* (2002) 1–7.
- [25] N. Atik, Z.K. Erdem, Buldan (Denizli) Arkeolojik Kültür Varlıkları Envanteri 2001–2003 Yılı Saptamalarının Değerlendirilmesi, *TÜBA Kültür Envanteri Dergisi 2* (2004) 9–39.
- [26] A. Erdoğan, U. Çörtük, Tripolis Kazısı 2007 Yılı Çalışmaları, *KST* 30 (2009) 107–138.
- [27] B. Duman, Tripolis Ad Maendrum 2014 Yılı Kazı, Onarım ve Koruma Çalışmaları, 37. Kazı sonuçları toplantısı, 1 (2016) 563–584.
- [28] B. Duman, Tripolis 2015 Yılı Kazı, Koruma ve Onarım Çalışmaları“, 38. Kazı Sonuçları Toplantısı, 2 (2017) 539–562.
- [29] L. Moretti, *Epigraphica*: 18. A propositodi Apollonia al Meandro, *Rivista di Filologia e di Istruzione Classica* Numero 107/3 (1979) 295–300.
- [30] R. Robert, Documents d’Asie Mineure, *Bulletin de Correspondance Hellenique* 107 (1) (1954) 497–599.
- [31] L.J. Robert, *La Carie II: Histoire et Geographie Historique. Le Plateau de Tabai et ses Environs*, (1983) Paris.
- [32] W.M. Ramsay, *The Cities and Bishoprics of Phrygia: Being an Essay of the Local History of Phrygia from the Earliest Times to the Turkish Conquest*, Vol. 1.1, *The Lycos Valley and South-western Phrygia*, Oxford, 1895.
- [33] W.M. Ramsay, *Anadolu’nun Tarihi Coğrafyası*, (transl. Mihri Pektaş.) İstanbul, 1960.
- [34] A.H.M. Jones, *The Cities of the Eastern Roman Provinces*, Oxford, 1971.
- [35] P.J. Thonemann, Hellenistic Inscriptions from Lydia, *Epigraphica Anatolica* 36 (2003) 95–108.
- [36] C. Habicht, New Evidence on the Province of Asia, *J Roman Stud* LXV (1975) 64–91.
- [37] B. Duman, African Red Slip Ware in Lydian Tripolis, *Rei CretariÆ RomanÆ FaVtorVm Acta* 44 (2016) 699–706.
- [38] B. Duman, Typo-chronological table of Late Roman amphorae from Lydian Tripolis, in: D. Dixneuf (Ed.), *LRCW 5, Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean. Archaeology and Archaeometry*, 2017, pp. 743–758.
- [39] C. Ratte The urban development of Aphrodisias in late antiquity, Ed. D. Parrish, *Urbanism in Western Asia Minor*, *J. Roman Archaeol. Suppl. Series* 45 (2001) 117–148.
- [40] B. Duman, A Group of local production Middle Byzantine Period Pottery from Tripolis: Micaceous White Painted Ware, *Anatolia Antiqua*, XXII (2014) 225–234.
- [41] C. Cahen, Osmanlılar’dan Önce Anadolu, transl. E. Üyepazarcı, 2012, İstanbul.
- [42] A.İ. Okay, Denizli’nin güneyinde Menderes masifi ve Likya naplarının jeolojisi, *Bull Min Res Explor* 109 (1989) 45–58.
- [43] Ş. Şimşek, Denizli-Kızılderle-Tekkehamam-Tosunlar-Buldan- Yenice alanının jeolojisi ve jeotermal enerji olanakları. *Mineral Res. Expl. Direct. Turkey (MTA)*, Scientific Report No: 7846, p. 85. Ankara, Turkey, 1984.
- [44] S. Sun, Denizli-Uşak Arasının Jeolojisi ve Linyit Olanakları. General Directorate of Mineral Research and Exploration Institute of Turkey (MTA), Ankara, Scientific Report No: 9985, 92 p., 1990.
- [45] H. Alçiçek, B. Varol, M. Özkul, Sedimentary facies, depositional environments and palaeogeographic evolution of the Neogene Denizli Basin, SW Anatolia, Turkey, *Sediment. Geol.* 202 (2007) 596–637.
- [46] B. Semiz, Characteristics of clay-rich raw materials for ceramic applications in Denizli region (Western Anatolia), *Appl. Clay Sci.* 137 (2017) 83–93.
- [47] B. Semiz, Pamukkale (Denizli) bölgesi killerin karakteristik özellikleri ve seramik sektöründe kullanılabilirlikleri, *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi* (2018), <https://doi.org/10.5505/pajes.2017.77853>.
- [48] J. Poblome, R. Degeest, M. Waelkens, E. Scheltens, M. Waelkens (Ed.), Part III. Ceramic Studies Sagalassos Ware, Sagalassos I, First General Report on the Survey (1986-1989) and Excavations (1990-1991), Leuven University Press, 1993, pp. 113–130.
- [49] N. Fırat, Perge Konut Alanı Seramiği, İstanbul Üniversitesi Sosyal Bilimler Enstitüsü Arkeoloji ve Sanat Tarihi Anabilim Dalı Klasik Arkeoloji Bilim Dalı, Doktora Tezi, İstanbul (1999).
- [50] Ç. Uygun, Tepecik Kırmızı Astarlı Seramikleri (Ö 2. YY-İS 4. YY), Patara IV.2, İstanbul, 2011.
- [51] B. Duman, Red slip pottery from laodicea/phrygia, *RCRF Acta* 43 (2014) 9–17.
- [52] G.W. Brindley, Quantitative X-ray mineral analysis of clays, in: G.W. Brindley, G. Brown (Eds.), *Crystal Structures of Clay Minerals and Their X-ray Identification*, Monograph 5, Mineralogical Society, London, 1980, pp. 411–438.
- [53] O. Heiri, A.F. Lotter, G. Lemcke, Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results, *J. Paleolimnol.* 25 (2001) 101–110.
- [54] K. Greene, *The Archaeology of the Roman Economy*, Berkley Press, Berkley, CA, 1986.
- [55] W.G. Lawrence, *Ceramic Science for the Potter*, Chilton Books, Philadelphia, 1972.
- [56] C. Papachristodoulou, A. Oikonomou, K. Ioannides, K. Gravani, A study of ancient pottery by means of X-ray fluorescence spectroscopy, multivariate statistics and mineralogical analysis, *Anal. Chim. Acta.* 573–574 (2006) 347–353.
- [57] S.R. Bertolino, V. Galván Josa, A.C. Carreras, A. Laguens, G. de la Fuente, J.A. Riveros, X-ray techniques applied to surface paintings of ceramic pottery pieces from Aguada Culture (Catamarca, Argentina), *X-Ray Spectrom.* 38 (2009) 95–102.
- [58] A.E. Rassios, *A geologist’s guide to West Macedonia, Greece*. Grevena: The Grevena Development agency. (2004) 119.
- [59] P. Degryse, J. Poblome, Clays for mass production of table and common wares, amphora and architectural ceramics at Sagalassos, in: P. Degryse, M. Waelkens (Eds.), *Sagalassos VI. Geo- and Bio-Archaeology at Sagalassos and in Its Territory*, Universitaire Pers Leuven, Leuven, 2008, pp. 231–254.
- [60] H. Mommsen, Provenance determination of pottery by trace elements analysis: problems, solutions and applications, *J. Radioanal. Nucl. Chem.* 247 (2001) 657–662.
- [61] C.M. Belfiore, P.M. Day, A. Hein, V. Kihikoglou, V. La Rosa, P. Mazzoleni, A. Pezzino, Petrographic and chemical characterization of pottery production of the Late Minoan I Kiln at Haghia Triada, Crete, *Archaeometry* 49 (4) (2007) 621–653.
- [62] H.R. Rollinson, *Using geochemical Data: Evaluation, Presentation, Interpretation*, Longman Publishing Group, Harlow, 1993.
- [63] L.P. Gromet, R.F. Dymek, L.A. Haskin, R.L. Korotev, The “North American Shale Composite”: its compilation, major and trace element characteristics, *Geochim. Cosmochim. Acta* 48 (1984) 2469–2482.
- [64] S.M. McLennan, Relationships between the trace element composition of sedimentary rocks and upper continental crust, *Geochem. Geophys.* (2001).
- [65] S.R. Taylor, S.H. McLennan, *The Continental Crust: Its Composition and Evolution*, Blackwell, Oxford, 1985, p. 312.
- [66] R.L. Rudnick, S. Gao, The composition of the continental crust, in: R.L. Rudnick, H.D. Holland, K.K. Turekian (Eds.), *Treatise on Geochemistry – The Crust*, Elsevier, Oxford., 2003, pp. 1–64.
- [67] B. Semiz, Şimşek, C. Duman, B. Archeometrical study on the late antique unguentariums of Laodikeia. *Quaternary Symposium of Turkey* (2016), 104.
- [68] C. Polito, Saggi stratigrafici nell’area del Teatro, Hierapolis Di Frigia VIII, 1, *Le Attivita Delle Campagne di Scavo e Restauro 2007–2011*, 2016, pp. 121–140.
- [69] G. Mastronuzzi, V. Melissano, Le case bizantine sul lato ovest dell’Agora (Regio II), Hierapolis Di Frigia I, *Le Attivita Delle Campagne Di Scavo E Restauro 2000-2003*, 2007, pp. 541–582.
- [70] A. Waldner, S. Ladstatter, Ephesus-local vs import: The Early Byzantine fine ware, Late Hellenistic to Mediaeval Fine Wares of the Aegean Coast of Anatolia, *Their Production, Imitation and Use*, H. Meyza (Ed.), Varsovie, 2014, pp. 49–58.
- [71] D. Braekmans, P. Degryse, B. Neyt, M. Waelkens, J. Poblome, Reconstructing regional trajectories: the rovenance and distribution of archaic to Hellenistic ceramics in central Pisidia, (south-west Turkey), *Archaeometry* 59 (3) (2017) 472–492.