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Archaeometric Studies on Bricks from the Ancient City of Stratonikeia in Caria

[STRATONİKEİA (KARİA) ANTİK KENTİ TUĞLALARI ÜZERİNDE ARKEOMETRİK İNCELEMELER]

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Keywords
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Anahtar Kelimeler
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ABSTRACT

The ancient city of Stratonikeia is located within the territory of Eskihisar Neighborhood in Yatağan District of Muğla Province. Systematic excavations have been undertaken at the site since 1977. Settlement at the site of the ancient city is understood to extend back to the second millennium BCE. At the site, it is possible to see buildings from a wide time span ranging from the Classical period through the 20th century. This study aims to shed light on the archaeometric characteristics of the brick samples, to retrieve information on their production technologies, to obtain data regarding their firing temperatures and their production sites whether local or imported. Within the scope of the study, a total of 25 samples were taken from seven buildings in the ancient city of Stratonikeia. The samples were investigated using a stereomicroscope, optical microscope, color analysis, XRF, XRPD, SEM-EDS, and statistical methods. Petrographical investigations led to the categorization of the brick samples into three main groups and one subgroup. It was found that most of the samples were fired at 750-850°C and all of them were produced with clay taken from similar clay deposits.

ÖZET

Stratonikeia antik kenti Muğla İli Yatağan İlçesi Eskihisar Mahallesi sınırları içerisinde kalmaktadır. Alanda 1977 yılından beri düzenli arkeolojik kazılar yapılmaktadır. Antik kentteki yerleşimin MÖ 2. binyıla kadar uzandığı anlaşılmıştır. Alanda Klasik Dönem'den 20. yüzyıla kadar uzanan geniş bir zaman dilimine ait yapıları görmek mümkündür. Bu çalışmada, tuğla numunelerinin arkeometrik karakteristiklerini saptamak, üretim teknolojileri hakkında bilgi edinmek, pişirme sıcaklıklarını ve yerel üretim mi? ve/veya ithal mi? olduklarını belirlemek hedeflenmiştir. Bu kapsamda, antik kent dahilindeki yedi yapıdan toplam 25 tuğla numunesi alınmıştır. Numuneler stereomikroskop, optik mikroskop, renk analizi, XRF, XRPD, SEM-EDS ve istatistiksel yöntemlerle incelenmiştir. Petrografik incelemeler sonucunda tuğla numuneleri üç ana ve bir altgruba ayrılmıştır. Numunelerin çoğunun 750-850°C sıcaklıkta pişirildiği ve benzer kil yataklarından alınmış hammadde ile üretildikleri tespit edilmiştir.

1. Introduction

The ancient city of Stratonikeia is located within the territory of Eskihisar Neighborhood in Yatağan District of Muğla Province (Fig. 1). The village of Eskihisar was moved 2 km west when the Yatağan power plant came to function in 1984, and the village settlement directly above the ancient city was abandoned to a great extent. As the city lies within the coal strip-mining area of the power plant, the topography has changed tremendously starting right by the ancient city since then. Systematic excavations have been undertaken since 1977 and the settlement is understood to extend back to the second millennium BCE. The architectural structures at the site are attributed to a wide time span ranging from the Classical Period through the 20th century CE.

Bricks, one of the traditional building materials in use for a very long time, can be mass-produced at a standard size in a short time; their strength, water absorption, resistance against frost and the elements are quite high when

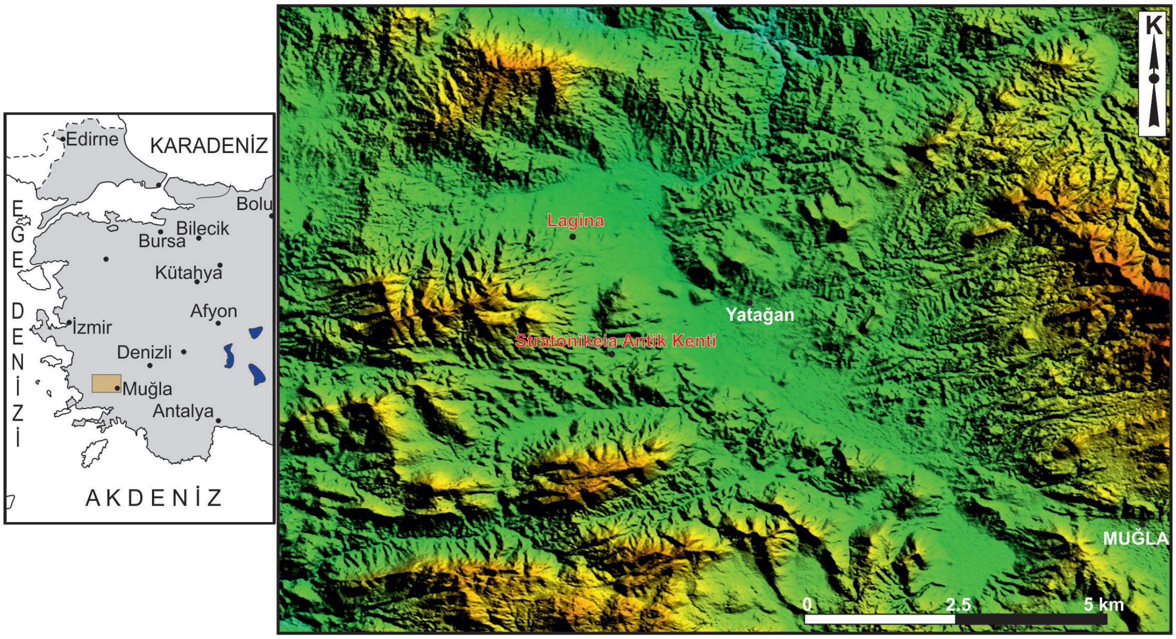

Fig.1. Map showing the location of ancient Stratonikeia

properly manufactured; thus, they have been widely used. First-hand information on ancient bricks, which constitute the scope of the present study, is found in Vitruvius' *De Architectura.* In his book presented to Julius Caesar, Vitruvius wrote why bricks needed to be produced from white clay and red or coarse grained sand. Moreover, it was elaborated that the bricks needed to be dried in spring or fall months with underlying reasons; it also listed the brick types as Lydian bricks (*Lydium*, ca. 30x45 cm), *pentadoron* (five handbreadths, 37x37 cm) and *tetradoron* (four handbreadths, 30x30 cm). It was mentioned that half and full size bricks were placed alternately to reinforce the masonry. However, bricks mentioned by Vitruvius are those called *later*, which were molded and dried. Studies on ceramics as well as bricks have increased recently with the advances in archaeometric methods. The investigations were based on more conventional methods in the beginning but in time they have become more efficient with advanced analysis methods.The present study aims to unveil the archaeometric characters of brick samples taken from various buildings in the ancient city of Stratonikeia in Caria, to obtain information regarding their production technologies, to derive data regarding their firing temperatures and to determine whether they were local productions.

2. Historical and Archaeological Context

The ancient city of Stratonikeia in Caria, located within the territory of Eskihisar Neighborhood of Yatağan District in Muğla Province, was named after the Seleukid Queen Stratonike and houses architectural structures from the second millennium BCE through twentieth century CE. The buildings, from which samples were taken, have been uncovered in the course of systematic excavations and attributed to the Late Antiquity (4^{th}-7^{th} centuries CE) according to archaeological evidence such as pottery and coins. With regards to excavated areas, it can be stated that brick usage increased during Late Antiquity. The buildings from which samples were taken are briefly described below (Fig.2).

Church Complex at Erikli Locality comprises a three-aisled basilica oriented in the east-west direction with a narthex on the west and surrounded with other rooms to the west and south sides. The church's narthex is accessed via the southernmost room of the western annexes. North and south side aisles of the church are paved with brick flooring whereas the nave has mosaics and the narthex is paved with stone plaques. At the western end of the north side aisle is a basin and a canal runs eastward from this basin along the middle of the north side aisle. A bench paved with bricks runs along the western

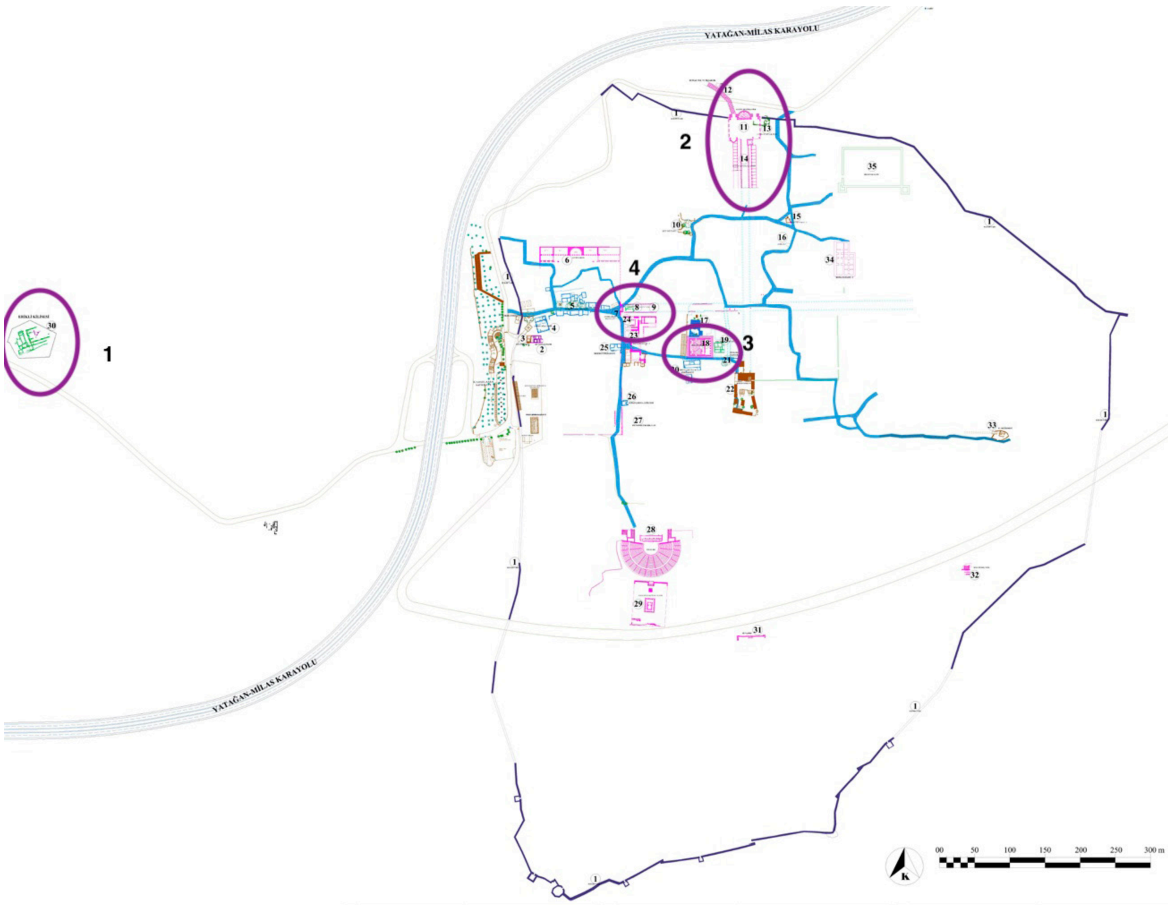

Fig. 2. Locations of the structures from which samples were taken in Stratonikeia (Stratonikeia and Lagina Excavations Archive): 1 – Erikli Basilica; 2 – North City Gate area; 3 – House to the east of the Bouleuterion; 4 – West Street Church

end of the south wall of the south side aisle and the eastern wall of the narthex. Rooms annexed to the west have bricks in their masonry and arches.

Rooms are found along the west side of the North City Gate Square and during the excavations an opus spicatum flooring of 3.30×2.25 m was uncovered in the second room from the north. However, this flooring could not be attested during sampling process. Samples could be taken from the walls.

A building complex comprising a courtyard with four rooms opening into it was uncovered to the northwest of the western entranceway of North City Gate. Entrance to this structure is on the east side and leads directly into the courtyard. According to the excavated part, rooms A, B and D are accessed directly from the courtyard and room C is accessed from room D. Samples were taken from the benches paved with bricks. North City Gate Fountain has a semi-circular pool measuring 14.50 m in the east-west direction and a radius of 7.50 m in the north-south. An oblong fore-pool extends along the front and it has a floor paved with large rectangular bricks. The semi-circular pool floor is paved with mosaics with a floral composition but there is a patch of brick repair, which displays two different types of intervention. The first intervention has irregular large brick fragments placed into mortar within a semi-circular area. The second intervention extends northwestward with opus spicatum pavement. Along the east side of the North City Gate Square runs a building named SKB2 and thought to be a basilica. Excavations were carried out here in 1980; the section adjoining the city wall was exposed and thought to be the north side aisle of a basilica, with a doorway opening onto the square by the Fountain. Recent excavations brought to light a second doorway further south, which was later cancelled. Three rooms were partially uncovered between these two doorways and named as A, B, and C starting from the south. Room A contained a marble threshold and a fragment of brick flooring, not on the original floor level, while rooms B and C contained fragments of brick vaulting. West Street (Propylon) Church is located on the western end of West Colonnaded Street just before the Propylon to the Gymnasium. When the remains of the Late Ottoman and Early Turkish Republican periods were removed a three-aisled basilican church was uncovered and attributed to the 5th – 7th centuries CE. The church was originally accessed via the Propylon of the Gymnasium. The structure was built directly on the flooring of West Colonnaded Street; its nave was paved with marble in *opus sectile* technique. Brick was sampled from a bench and flooring fragment in the south side aisle· The area to the east of the Bouleuterion was used as a residential area during Late Antiquity. The rooms uncovered have walls built with ancient architectural elements such as column drums, broken marble fragments, and rubble with mud mortar; one full house is discernible. The house is accessed via a wide doorway and has floorings of brick, slate and compressed earth and some rooms have benches. Except for the North City Gate Fountain, all the other buildings are attributed to the Late Antiquity (4th – 7th centuries CE). The Fountain was originally built in the 2nd century CE; however, the repairs should have been made in the Late Antiquity, probably after some earthquakes. The two patches with different repair techniques suggest two phases. Sample ST18 was taken from the fore-pool attributed to the 2nd century CE. The bricks used in the two repairs may or may not come from the 2nd century CE.

3. Materials And Methods

3.1. Materials

For the scope of the study a total of 25 samples were taken from seven buildings within the ancient city of Stratonikeia in Caria (Fig.2; Appendix 1). The Church Complex at Erikli Locality, about 600 m to the west of the city, is attributed to the Late Antiquity (4th – 7th centuries CE) and has more than one construction phase. This building has the most extensive use of bricks among the monuments in Stratonikeia so ten samples were taken (ST1-10). Two samples (ST14-15) were taken from the building of the Early Byzantine Period (6th – 7th centuries CE) located just outside the North City Gate. The monumental Fountain located in the middle of the North City Gate produced three samples (ST16-18): one from the original fore-pool and two from the interventions in the main pool. Three samples were taken from the row of rooms on the west side of the North City Gate Square (ST11-13). Four samples were taken from structure SKB2, partially excavated, on the east side of the North City Gate Square (ST19-22). One sample (ST25) was taken from the floor of the Early Byzantine House to the east of the Bouleuterion (City Council House). Also on West Colonnaded Street is a church built in the Early Byzantine Period and two samples were taken from it (ST23-24).

3.2 Methodology

Sample dimensions were measured to the best possible representation, and they were photographed to scale, hence the first documentation (Appendix 1). For macroscopic properties, the sample colors were measured using PCE-CSM1 Colorimeter. From each sample five measurements were made from the edge and core of the section each; their arithmetic means were calculated and thus L*a*b* values and Munsell color values were obtained both for edges and cores (Appendix 1). The macroscopic descriptions of the samples were examined with the Leica EZ4 W stereomicroscope. For petrographic studies, thin sections were prepared for each sample at the Pamukkale University (PAU), Department of Geological Engineering. Thin sections of the samples were taken to show all layers from the outside to the inside. The prepared thin sections were investigated using the Leica DM750P polarizing microscope in the same department to identify the mineralogical and petrographical properties.

The major and trace elements analyses of all brick samples were made at the Advanced Technology Application and Research Center (ILTAM) of the PAU using Spectro XLAB 2000 PEDXRF X-Ray spectrometer. The samples were first ground to 200 mesh size using a ring mill, then mixed with a special wax and pellets of 32 mm diameter were prepared and analyzed. United States Geological

Survey (USGS) standards, which are referred to as GEOL, GBW-7109, and GBW-7309, were used in XRF analysis.

XRPD (X-ray powder diffraction) analyses were also carried out at PAU-ILTAM. First, the samples were ground into powder using a ring grinder, and shots were taken by preparing non-oriented plaques. XRPD analyses were made using a GNR model diffractometer at Cu Kα, 40 kV, 40 mA conditions using a nickel filter with $2\theta = 5\text{-}90^{\circ}$ interval. XRPD diffractograms were evaluated semi-quantitatively using the Match program of a computer connected to the diffractometer and ICDD (International Center for Diffraction Data) library.

Scanning Electron Microscopy and Energy Dispersion Spectroscopy (SEM-EDS) were used to characterize the crystal morphologies.[1] Fourteen samples among 25 samples whose thin sections were analyzed were picked for SEM analysis. SEM-EDS investigations were carried out at PAU-ILTAM using FESEM SUPRA 40 VP. Sample fragments with fresh broken surface were fitted onto an aluminum stub with double-face tape and coated with Au/Pd using a Quarum Sputter Coater.

4. Results and Discussions

4.1. Macroscopic Studies

According to the results of the color analysis on the brick samples, no color change was discernible between the edge and core color values of 13 samples in total (Appendix 1). However, 12 samples had differences between edge and core color values. These color differences may suggest that the bricks were fired before they fully dried, that the heat was not distributed uniformly inside the kiln, that they were fired with reducing or oxidizing condition, that different raw materials were used, that the ingredients were not blended well, or other similar reasons.

Stereomicroscopic studies showed substantial amount of coarse quartz and less mica minerals in the first group (Fig. 3a). In Group 2 samples, a significant excess of mica minerals and coarse carbonate minerals are observed (Figs. 3b-c). The last group contains large metamorphic rock fragments and brick fragments in high quantities (Fig. 3d).

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4.2. Optical microscopy analysis

Mineralogical and petrographical studies allow identification of porosity, voids, minerals and rock contents of bricks. Furthermore, clay fabrics of bricks were investigated, size, shape and dispersion of particles were observed. All the samples studied display similar properties in general. Differences were attested according to the quantities of certain minerals. These studies allowed for categorizing the samples into three main groups.

Group 1 (ST1, 3, 6, 7, 21, 22, 23, 24, 25): These samples contain high quantities of quartz, muscovite, and biotite minerals and little quantities of plagioclase and pyroxene minerals (Fig. 4a). Quartz particles are usually observed in large sizes (0.42-1.94 mm). Muscovite minerals are usually equal in size (0.39 mm) and they are noted larger in some samples. Micas are noted with a discernible orientation. Some samples (ST1) are noted with K-feldspar mineral measuring 1.32 mm in size at places. Opaque minerals are attested few in this sample group. Round-shaped carbonate bulks reaching 1.5 mm in size are noted in the samples. Differences between the color values of edges and cores of the samples are clearly observed in thin section investigations. Darker color shades on the interiors are clearly discernible. Round and oval voids are noted in the samples. Some samples (ST3 and ST7) are noted to contain mica-schist and quartzite particles. These rock fragments reach 2.1-3 mm in size in places.

Subgroup 1 (ST5, 9, 11, 12, 19): These samples are categorized as a subgroup because they contain less muscovite mineral but more opaque minerals (Fig. 4b). Quartz minerals of small size (0.37-0.84 mm) are observed widely. Plagioclase minerals are also attested in this subgroup. Biotite mineral is also widely attested in this subgroup. The orientation of minerals is discernible and voids reaching a size of 4 mm are noted along the orientation. Quartzite pebbles reaching 3.2 mm at places were observed. Some samples (ST12) contain limestone particles. Brick fragments are noted in low quantity.

Group 2 (ST2, 4, 8, 10, 13, 14, 15, 17, 20): The samples in this group are quite similar to Group 1 and contain high quantities of quartz, muscovite, and biotite minerals and small quantities of

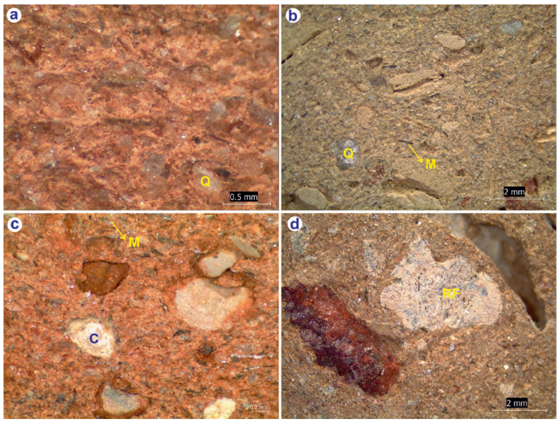

Fig. 3. Stereomicroscopic images (Q: Quartz; C: Calcite; M: Mica; RF: Rock Fragment)

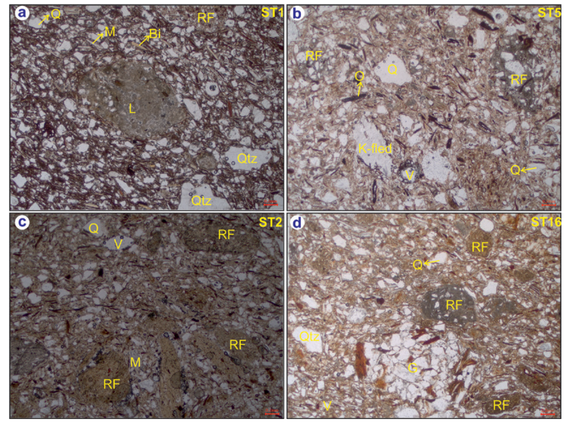

Fig. 4. Microscopic images of sample groups (Q: Quartz; RF: Rock Fragments; M: Muscovite; Qtz: Quartzite; K-feld: K-Feldspar; L: Lime; B: Biotite; V: Void)

plagioclase and pyroxene minerals (Fig. 4c). This group is categorized separately due to the high content of rock fragments (phyllite, mica-schist, and quartzite) and brick fragments. Quartzite fragments are measured at 0.59-1.27 mm and mica-schist fragments at 1.57 mm. Carbonate minerals observed in the samples are measured as 0.43-1.45 mm. Mica minerals are measured between 0.28-1.08 mm. Sample ST17 contains marble fragments. Sample ST20 contains K-feldspar mineral at places.

Group 3 (ST16, 18): This group stands out with high quantity of brick fragments (Fig. 4d). Grog sizes reach up to 2 mm. Quartz minerals are widely attested whereas opaque minerals are little. Discernible carbonate fragments and marble were observed.

An overall evaluation of all sample groups indicates that all groups are quite similar. Categorization is based solely on the differences in the quantity of materials added later on (quartz, rock fragments and grog). That marble is attested in some samples is considered an indicator for firing at relatively low temperatures.

4.3. XRPD Investigations

The results of XRD analyses were assessed according to the groups identified in petrographical analyses. XRPD analyses have verified the presence of mica, illite, quartz, plagioclase, feldspar, calcite, diopside and hematite minerals (Fig. 5). Samples in Group 1 contain high quantities of illite, mica, quartz, plagioclase, hematite, and calcite whereas some samples contain fewer amounts of feldspar and diopside. Sample ST7 contains less amount of mica and a high amount of quartz, plagioclase, and feldspar. Sample ST24 contains a very high amount of feldspar in addition to similar mineral levels. The minerals identified are seen to conform with petrographical study results. Plagioclase and feldspar minerals attested in the samples are thought to be of primary origins. XRPD results suggest that the samples were fired at about 750-800^{o}C.

XRPD analyses have also verified that samples in Subgroup 1 have similar mineralogical contents. However, the samples did not result in any peaks for illite and mica minerals. Subgroup 1 samples contain quartz, plagioclase, feldspar, diopside, and hematite minerals. This suggests that the samples in this subgroup may have been fired at a slightly higher temperature. Some samples contain few peaks of calcite. As the samples in this group did not show peaks for illite and mica it is thought that they were fired at about 800-850^{o}C. The high number of peaks for hematite is worth noting in these samples (Fig. 5). This suggests that they were fired in oxidizing atmosphere. Moreover, common opaqueness of mica minerals and certain levels of diopside minerals attested pave the way for firing temperatures at about 800-850^{o}C.

Samples in Group 2 are similar to Group 1 with regards to mineralogical contents (Fig. 5). These samples contain mica, illite, quartz, plagioclase, feldspar, diopside, hematite, and calcite. Clay contents were observed less. Evaluation of XRPD analyses suggests that they were fired at about

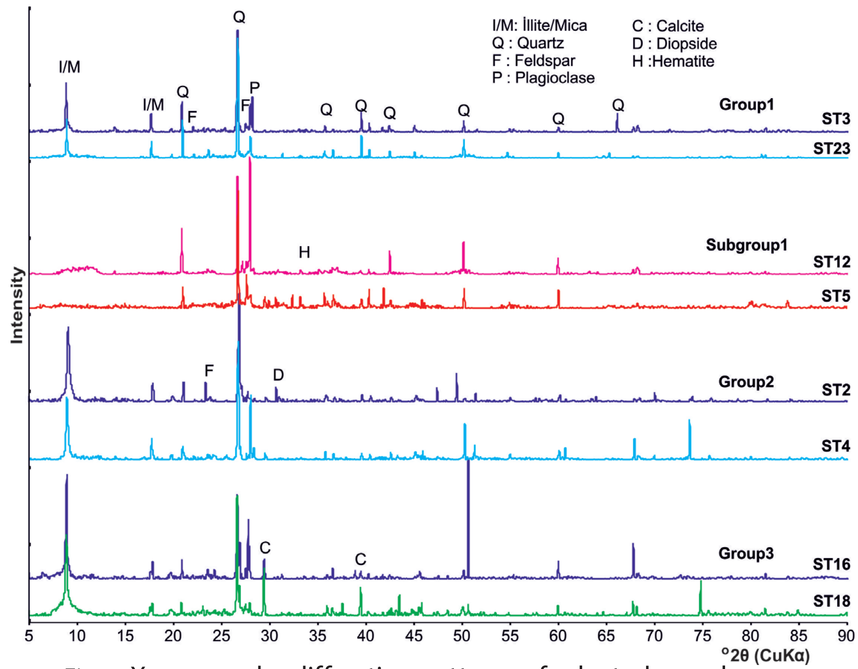

Fig. 5. X-ray powder diffraction patterns of selected sample groups

750-800°C. Sample ST15 did not show peaks for illite and mica and this suggested that it was fired slightly at a higher temperature.

Samples in Group 3 contain mica, illite, quartz, feldspar and hematite (Fig. 5). Sample ST18 contains calcite. That marble fragments are attested in the samples of this group indicates that they were fired at the lowest temperatures among all the samples studied. These samples are thought to have been fired at 700-750°C based on the density of illite/mica peaks and calcite peaks.

4.4. Scanning Electron Microscopy (SEM) analyses

Micro-structures of the bricks were investigated with SEM at much higher magnifications than the petrographic technique and chemical characterization was done at certain areas using EDS (Fig. 6). As a result of analyses, considering the raw material contents, it can be said that equivalent temperatures were attained in most of the bricks. The absence of voids in the samples (such as ST11) supports the thought that firing temperatures were not very high (Fig. 6a). Sample ST15 exhibits newly forming melting voids. In this regard, this sample is thought to have been fired at a slightly higher temperature (Fig. 6b). This conforms with the evaluations obtained from XRPD analyses.

4.5. Chemical analyses

XRF analyses have shown the major oxides and trace element contents of the samples (Appendix 2). In parallel to the mineralogical analyses, chemical analyses also resulted in three groups. As different from petrographical groups, samples ST2, ST13, and ST14 are now categorized in Group 1 instead of Group 2 (Appendix 2).

Thus, samples in Group 1 have the highest SiO_2 (avg. 55.86%) content. This drops down to 51.02% in Group 2 samples and to 46.20% in Group 3 samples (Fig. 7a). The SiO_2 content in Group 1 is high and this is thought to be directly linked to the quartz mineral content. Group 2 samples have the highest TiO_2 content with a 1.03% average. Group 1 samples have 0.92% and Group 3 has 0.81% (Fig. 7a). The TiO_2 content is the highest in Group 2 samples and this can be explained by the high content of metamorphic rock fragments. Al_2O_3 content is the highest with 23.77% in Group 2 samples. This rate (22.17%) is approximately similar to Group 1 samples (Fig. 7b). Group 3 samples have the lowest Al_2O_3 content as 18.10%. This is evaluated as the Groups 1 and 2 have higher clay content. Fe_2O_3 contents are parallel to Al_2O_3 contents with Group 2 having the highest and Group 3 the lowest. Fe_2O_3 contents indicate that the iron in raw materials

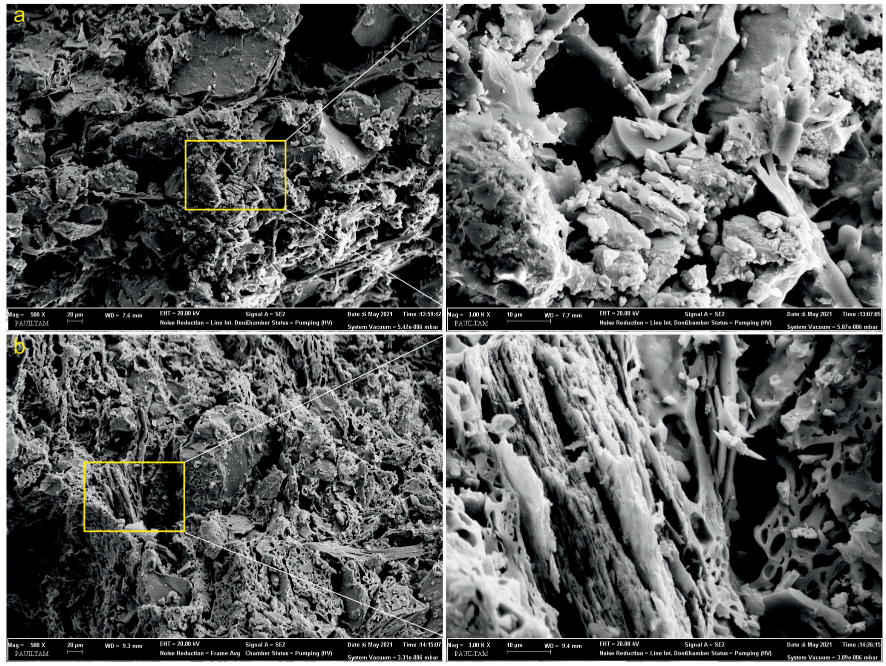

Fig. 6. SEM images of selected samples a. ST11 and b. ST15

is oxidized to Fe^{+3} producing hematite minerals.[2] The binary diagram of Al_2O_3 and Fe_2O_3 contents shows that Fe_2O_3 content rises in direct proportion to Al_2O_3 content (Fig. 7b). In overall, K_2O and Na_2O contents are high in all the samples, but the highest content is attested in Group 1 and the lowest in Group 3. The binary diagram of K_2O and Na_2O contents also shows that K_2O contents rise directly proportional to Na_2O contents (Fig. 7c). Rises in K_2O and Na_2O contents are linked to feldspar and plagioclase minerals determined in the samples. CaO content is determined the

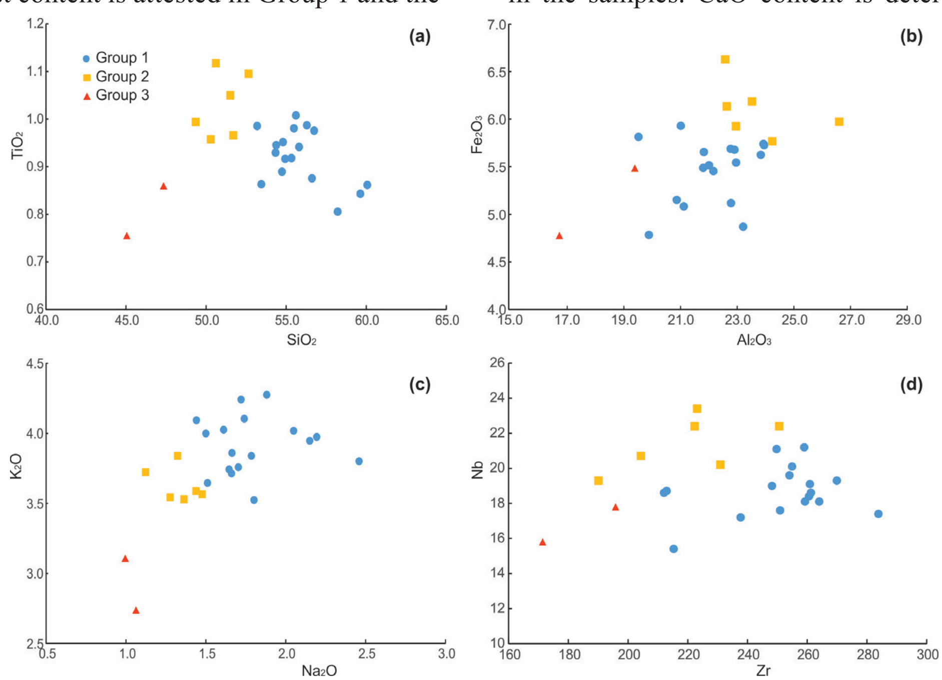

Fig. 7. Major and trace elements binary diagrams of sample groups

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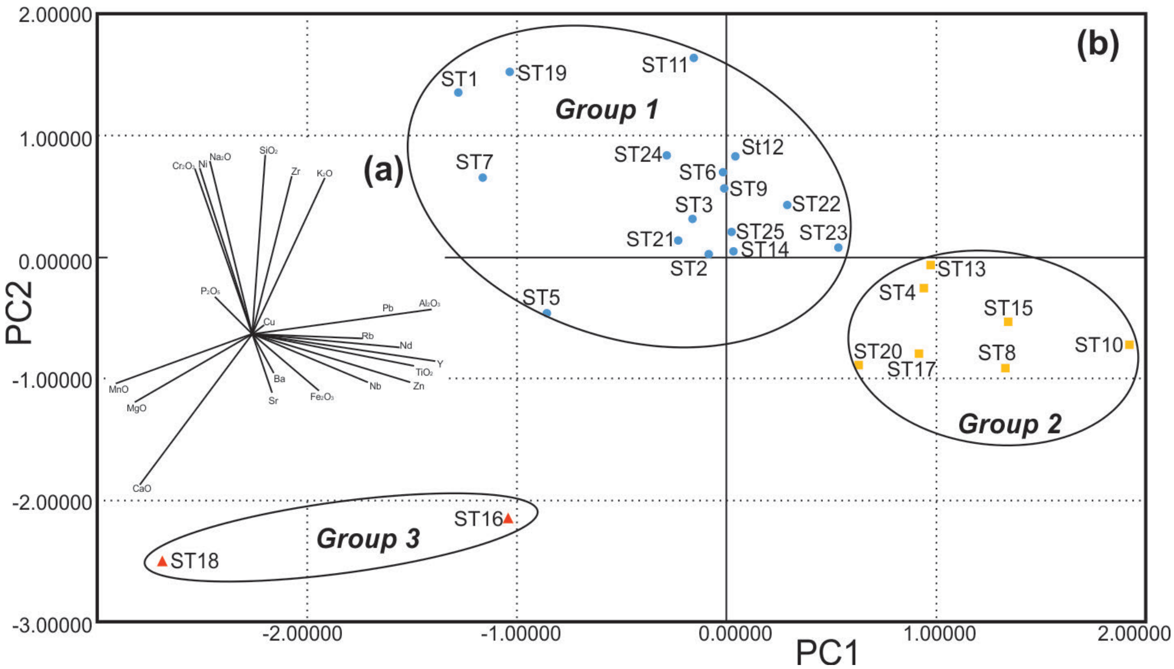

Fig. 8. Showing the scatter plot of two principal components (PC1 and PC2) of the selected element concentrations. The inset diagram shows the variable loadings.

highest in Group 3 samples with 9.78% on average. This is related to the secondary calcite and marble minerals determined in the samples. In other groups, CaO contents are quite similar with Group 1 having an average of 2.29% and Group 2 having 3.63%. This arises from the secondary carbonate (calcite) minerals and lime lumps observed in petrographical analyses.[3] MgO, P_2O_5 and MnO values are about the same levels in all groups.

Trace element contents of the samples are all close to each other. Zr content in Groups 1 to 3 is 250.25 ppm, 220.22 ppm, and 183.60 ppm respectively. Nb content is measured at 18.68 ppm, 21.40 ppm, and 16.80 ppm respectively. The binary diagram of Zr and Nb shows that Zr increases with Nb increasing (Fig. 7d). The levels of trace elements are quite close to each other and this is evaluated as the clays used for producing these bricks were procured from clay deposits coming from similar origins.

4.6. Statistical Investigations

Principal component analysis (PCA) is one of the most common multivariate statistical methods used in compositional data evaluation of archaeological artefacts. In this study, the application of principal composition analysis was used. The PCA of all the samples is based on the levels of all major elements and some trace elements (Ba, Rb, Sr, Y, Zr, Nb, Ni, Pb, Cu, Zn and Nd), which are considered in this study as most suitable for achieving the aims of the analysis. Thereafter, the statistical calculations were performed using the Statistical Package for the Social Sciences (SPSS version 27).

PCA performed on brick samples showed that the samples may be classified into three groups. Results obtained conform to the petrographical and chemical groupings. The correlation diagram of PC1 and PC2 show that Groups 1 and 2 samples cluster close to each other whereas Group 3 clusters into a very different part (Fig. 8). Samples in Group 1 spread into positive part of PC2 and both positive and negative sides of PC1. Samples of this group have correlated SiO_2, K_2O, Na_2O, Zr, Ni, Cu contents. Samples of Group 2 spreads into the negative part of PC2 and positive part of PC1. This group's samples are correlated with high contents of Al_2O_3, TiO_2, Fe_2O_3, Rb, Nd, Y, Zn, Nb, Ba, Sr. Samples of Group 3 spread into the negative sides of both PC1 and PC2. This is explained with the high contents of CaO, MgO and MnO. It is thought that this is in conformity

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with the high content of brick fragments and rock fragments in Group 3 samples.

5. Conclusions

A total of 25 brick samples (4th–7th centuries CE) taken from seven buildings in the ancient city of Stratonikeia in Caria were analyzed. For the scope of the present study, spectroscopic and microscopic studies were implemented to identify the mineralogical and chemical contents of the brick samples. The differences between the edge and core color values of half of the samples using color analysis are due to firing temperatures and durations and/or remaining in oxidizing atmosphere. Brick samples are categorized into three groups by optical microscopic studies and XRPD analyses. The samples are mostly similar and contain quartz, illite/mica, plagioclase, feldspar, and calcite. Only the samples in Group 3 differ for they contain brick fragments and carbonate particles. In the XRPD and SEM analyses, it was understood that the great majority of the samples were fired at about 750-850°C whereas only Group 3 samples were fired at slightly lower temperatures (700-750°C). It is also thought that the differences in mineralogy and petrography are reflected in chemical properties. According to the principal component analysis, the samples were also categorized into three groups. As a result of the archaeometric investigations, it should be noted that the brick samples have similar characteristics, and/or the same clay deposits may have been used in their production. That the bricks display similar properties and that they have similar production technologies suggested that these bricks were produced using local raw materials, probably at different times, perhaps by the same workshops. They were produced in a manner not requiring much expertise or specialization.

As a result of archaeological investigations, bricks from more than one group in one monument may suggest that such buildings were repaired several times during their lifespan. Therefore, ST16-18 were taken from the monumental Fountain at the North City Gate. Samples ST16 and ST17 belonged to two repairs in the same monument but ST18 belonged to the original flooring of the monument. Samples nos. ST16 and ST18 constituting Group 3 seem to come from the same source with similar firing temperature slightly lower than the rest. This may suggest that ST16 belonged to the same period as ST18 whereas ST17 from the same monument but classified into Group 2 came from a different source belonging, most likely, to a later period, e.g. Late Antiquity. It may also be considered a possibility that the repair with the ST16 brick sample was earlier than the repair with the ST17.

Systematic excavations are conducted at nearby sites such as Labraunda, Beçin, Mylasa, Euromos, and Iasos and future archaeometric studies on brick finds from these sites and rescue excavations in the vicinity may allow comparisons and even help identify possible clay deposits or production sites. Therefore, these analyses conducted are thought to help design restoration and conservation projects conveniently and properly conforming to historical facts.

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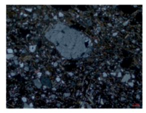
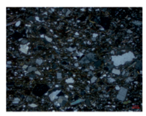
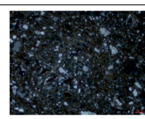
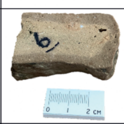
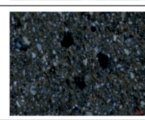
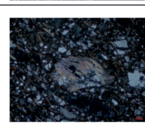
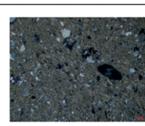
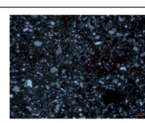
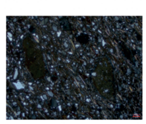
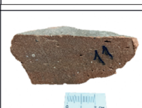
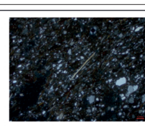
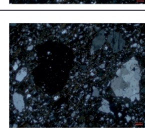
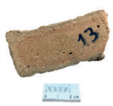
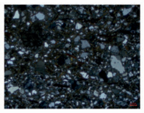
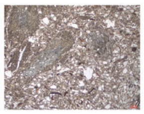
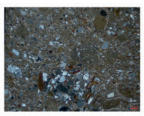
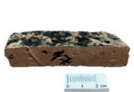
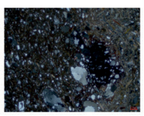
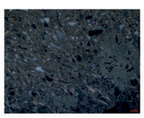
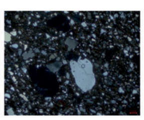
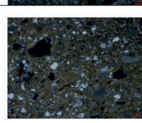
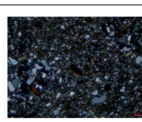
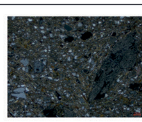
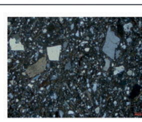
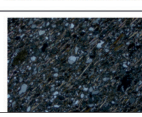
Appendix. 1

No	Makro view	Optic Microscopy	L	a	b	Munsell Color Value	Color	Measuring area	Sample taken from	Measured brick dimensions WxLxH (cm)	Analysis methods implemented
ST1			56.38	19.31	25.62	5YR 6/6	Orange	core	Erikli North Side Aisle Canal Cover	31x31	SM, OM, XRF, XRD, SEM-EDX
			55.22	19.66	25.85	5YR 5/6	Yellowish Red	edge			
ST 2			61.35	3.91	15.12	10YR 6/2	Light Brownish Grey	core	Erikli North Side Aisle Flooring	45x45x4	SM, OM, XRF, XRD
			55.66	9.95	20.37	7.5YR 6/4	Light Brown	edge			
ST 3			60.53	13.26	24.93	7.5 YR 6/6	Orange	core	Erikli South Side Aisle Flooring	33x33x4-4.5	SM, OM, XRF, XRD, SEM-EDX
			58.26	14.15	24.71	7.5YR 6/6	Orange	edge			
ST 4			56.44	14.46	24.33	7.5YR 6/6	Orange	core	Erikli Exedra Bench	45x40x5	SM, OM, XRF, XRD
			54.32	17.30	24.94	5YR 5/6	Yellowish Red	edge			
ST 5			55.33	16.51	23.83	5YR 5/6	Yellowish Red	core	Erikli Narthex West Bench	32x33x4.5	SM, OM, XRF, XRD, SEM-EDX
			51.03	16.09	23.06	5YR 5/6	Yellowish Red	edge			
ST 6			59.66	8.71	22.29	10YR 6/4	Light Yellowish Brown	core	Erikli Courtyard Bench	43x40x5	SM, OM, XRF, XRD
			55.05	9.92	20.79	7.5YR 5/4	Brown	edge			
ST 7			56.81	17.87	26.07	5YR 6/6	Orange	core	Erikli Entrance Room South of Courtyard	35x35x4.5	SM, OM, XRF, XRD, SEM-EDX
			58.25	14.52	22.10	5YR 6/6	Orange	edge			
ST 8			58.18	5.22	18.05	10YR 6/4	Light Yellowish Brown	core	Erikli Entrance Room South of Courtyard SW Corner	45x45x5	SM, OM, XRF, XRD
			54.30	8.40	20.22	10YR 5/4	Yellowish Brown	edge			
ST 9			51.31	19.66	25.51	5YR 5/6	Yellowish Red	core	Erikli Entrance Room Canal in the North	28x38x4.5	SM, OM, XRF, XRD, SEM-EDX
			47.39	15.20	21.17	5YR 5/6	Yellowish Red	edge			
ST 10			57.62	15.90	27.37	5YR 6/6	Orange	core	Erikli Narthex SE Bench	45x40x5	SM, OM, XRF, XRD
			61.53	15.20	25.64	5YR 6/6	Orange	edge			
ST 11			52.12	16.80	22.91	5YR 5/6	Yellowish Red	core	North Gate W Shops – 1 (33x6 cm)		SM, OM, XRF, XRD, SEM-EDX
			52.00	17.37	23.25	5YR 5/6	Yellowish Red	edge			
ST 12			53.04	17.81	26.71	5YR 5/6	Yellowish Red	core	North Gate W Shops – 2		SM, OM, XRF, XRD
			52.74	19.47	25.56	5YR 5/6	Yellowish Red	edge			

ST 13			58.19	15.54	28.48	7.5YR 6/6	Orange	core	North Gate W Shops Threshold – 3	15x30x4	SM, OM, XRF, XRD
			60.67	13.26	26.06	7.5YR 6/6	Orange	edge			
ST 14			57.62	15.70	28.19	7.5YR 6/6	Orange	core	Early Byzantine Structure Outside North Gate – 1	34x34x6	SM, OM, XRF, XRD, SEM-EDX
			56.77	17.67	25.74	5YR 6/6	Orange	edge			
ST 15			58.21	14.90	24.73	7.5YR 6/6	Orange	core	Early Byzantine Structure Outside North Gate – 2	30x30x4	SM, OM, XRF, XRD, SEM-EDX
			56.02	17.08	24.17	5YR 6/6	Orange	edge			
ST 16			51.81	10.31	19.21	7.5YR 5/4	Brown	core	Fountain, Main Pool Flooring	Repair 1	SM, OM, XRF, XRD, SEM-EDX
			51.63	11.45	22.30	7.5YR 5/6	Dark Brown	edge			
ST 17			58.61	15.82	29.60	7.5YR 6/6	Orange	core	Fountain, Main Pool Flooring	Repair 2	SM, OM, XRF, XRD, SEM-EDX
			60.76	17.03	28.26	7.5YR 6/6	Orange	edge			
ST 18			40.38	1.22	6.70	2.5Y 4/1	Dark Reddish Grey	core	Fountain, Fore-Pool Flooring	61x61x5	SM, OM, XRF, XRD
			51.64	5.01	14.36	10YR 5/2	Greyish Brown	edge			
ST 19			49.09	14.26	24.18	7.5YR 5/6	Dark Brown	core	SKB 2 – Room C	33x32x5	SM, OM, XRF, XRD
			50.00	17.07	25.56	5YR 5/6	Yellowish Red	edge			
ST 20			55.00	5.75	18.59	10YR 5/4	Yellowish Brown	core	SKB 2 – Room C	24x8	SM, OM, XRF, XRD, SEM-EDX
			54.70	21.99	29.39	5YR 5/8	Yellowish Red	edge			
ST 21			56.83	18.38	27.71	5YR 6/6	Orange	core	SKB 2 – Room C	15x24x4	SM, OM, XRF, XRD, SEM-EDX
			57.98	12.68	23.35	7.5YR 6/6	Light Brown	edge			
ST 22			56.61	16.94	26.11	5YR 6/6	Orange	core	SKB 2 – Room C	32x6	SM, OM, XRF, XRD
			57.64	11.30	20.79	7.5YR 6/4	Light Brown	edge			
ST 23			55.49	18.50	27.19	5YR 6/6	Orange	core	West Street Church – Nave Bench	25.5x32x6	SM, OM, XRF, XRD
			57.75	11.83	21.45	7.5YR 6/4	Light Brown	edge			
ST 24			58.34	13.89	25.48	7.5YR 6/6	Light Brown	core	West Street Church – South Apse Flooring	33x33.5x4.5	SM, OM, XRF, XRD, SEM-EDX
			56.60	14.59	25.54	7.5YR 6/6	Light Brown	edge			
ST 25			56.06	12.13	23.47	7.5YR 6/6	Light Brown	core	House East of Bouleuterion	33x33x3.5	SM, OM, XRF, XRD, SEM-EDX
			57.30	12.26	23.47	7.5YR 6/6	Light Brown	edge			

Appendix. 2

		Group 1																	Group 2						Group 3	
Elements	**Units**	**ST1**	**ST2**	**ST3**	**ST5**	**ST6**	**ST7**	**ST9**	**ST11**	**ST12**	**ST13**	**ST14**	**ST19**	**ST21**	**ST22**	**ST23**	**ST24**	**ST25**	**ST4**	**ST8**	**ST10**	**ST15**	**ST17**	**ST20**	**ST16**	**ST18**
SiO_2	%	58,22	54,37	56,62	53,45	53,19	60,07	56,75	54,74	55,80	55,61	56,29	59,63	55,33	54,33	55,48	54,80	54,94	50,29	52,65	50,61	51,51	49,35	51,70	47,34	45,05
TiO_2	%	0,81	0,95	0,88	0,86	0,99	0,86	0,98	0,89	0,94	1,01	0,99	0,84	0,92	0,93	0,98	0,95	0,92	0,96	1,10	1,12	1,05	0,99	0,97	0,86	0,75
Al_2O_3	%	20,90	22,81	23,23	19,56	23,97	21,15	22,79	21,04	21,85	23,85	22,98	19,92	22,03	22,93	23,94	22,19	21,83	23,54	24,25	26,60	22,60	22,98	22,66	19,43	16,78
Fe_2O_3	%	5,15	5,12	4,87	5,81	5,73	5,08	5,69	5,93	5,65	5,63	5,54	4,78	5,52	5,68	5,74	5,45	5,49	6,19	5,77	5,97	6,63	5,93	6,13	5,48	4,78
MgO	%	2,13	1,96	1,93	3,38	2,01	1,81	1,99	3,06	1,85	1,95	1,95	1,62	2,06	2,36	2,03	1,99	2,71	1,95	1,74	2,19	3,43	2,39	1,88	2,44	2,54
CaO	%	1,91	2,56	1,50	5,46	1,69	1,54	1,68	2,84	1,94	1,52	1,37	2,30	3,11	2,64	1,47	2,97	2,40	3,09	1,85	2,10	4,42	5,11	5,22	7,77	11,80
Na2O	%	1,79	1,51	1,70	1,80	1,44	1,88	2,15	2,19	2,05	1,50	1,74	2,46	1,65	1,66	1,61	1,72	1,66	1,36	1,12	1,32	1,44	1,28	1,48	1,00	1,06
K2O	%	3,84	3,65	3,76	3,52	4,09	4,28	3,95	3,97	4,02	4,00	4,10	3,80	3,74	3,86	4,03	4,24	3,71	3,53	3,72	3,84	3,59	3,54	3,56	3,10	2,74
MnO	%	0,04	0,04	0,03	0,05	0,04	0,03	0,04	0,05	0,04	0,03	0,04	0,03	0,04	0,03	0,03	0,04	0,05	0,03	0,03	0,04	0,05	0,04	0,04	0,05	0,04
P_2O_5	%	0,13	0,14	0,13	0,18	0,25	0,13	0,14	0,19	0,19	0,13	0,12	0,29	0,15	0,14	0,16	0,27	0,24	0,25	0,12	0,14	0,19	0,19	0,21	0,14	0,19
Cr_2O_3	%	0,10	0,06	0,06	0,05	0,07	0,07	0,06	0,09	0,06	0,05	0,05	0,07	0,07	0,07	0,05	0,07	0,04	0,06	0,03	0,04	0,04	0,05	0,04	0,03	0,05
SO_3	%	0,02	0,05	0,04	0,04	0,04	0,03	0,01	0,01	0,00	0,04	0,02	0,07	0,03	0,03	0,02	0,05	0,03	0,03	0,00	0,09	0,05	0,06	0,06	0,05	0,09
LOI	%	4,50	5,97	4,67	5,19	5,75	3,00	3,48	4,19	4,78	4,31	3,89	4,08	4,39	5,06	4,09	4,97	5,17	8,39	7,30	5,07	4,10	7,68	6,00	12,18	13,47
Total		**99,53**	**99,17**	**99,42**	**99,35**	**99,24**	**99,93**	**99,70**	**99,19**	**99,19**	**99,62**	**99,08**	**99,90**	**99,03**	**99,73**	**99,64**	**99,72**	**99,19**	**99,68**	**99,68**	**99,13**	**99,10**	**99,60**	**99,96**	**99,87**	**99,34**
V	ppm	91,2	103,8	112,6	86,7	90,7	99,5	97,5	97,4	99,5	124,1	111,6	92,6	109,7	107,7	99,3	83,4	105,9	179,4	115,4	114,2	130,8	109,7	120,5	103,4	78,0
Co	ppm	14,5	<7,1	23,9	17,2	20,5	15,2	15,6	18,2	18,8	14,4	19,3	14,1	17,5	12,2	15,8	16,0	20,6	16,6	18,1	22,6	18,4	19,7	21,3	19,5	<7,4
Ni	ppm	223,1	157,1	157,0	118,8	169,6	178,1	144,8	218,5	151,3	118,2	137,9	171,5	169,8	165,3	127,3	169,6	129,3	144,7	101,8	120,4	105,3	146,3	126,4	103,4	117,5
Cu	ppm	46,6	287,5	36,0	38,5	31,8	33,2	32,5	39,0	36,1	35,6	30,4	43,9	39,5	51,4	37,7	31,5	34,6	62,8	29,7	49,4	42,9	42,1	44,8	32,0	28,4
Zn	ppm	79,7	98,5	97,1	84,2	93,6	84,8	98,2	96,1	89,0	107,8	94,2	88,2	94,3	97,7	99,0	85,4	101,2	111,9	107,3	123,6	104,4	111,3	122,2	89,3	71,6
Ga	ppm	28,9	30,1	33,5	30,9	32,6	28,7	33,5	32,5	34,3	35,1	32,5	29,1	31,8	34,3	35,7	31,5	31,3	33,6	37,8	41,7	36,1	38,0	34,9	29,9	25,4
Ge	ppm	<0,5	1,0	0,8	0,7	0,6	<0,5	0,8	0,8	<0,5	1,1	1,6	0,8	0,2	0,8	1,4	1,1	1,2	1,3	1,0	0,2	1,4	0,4	0,9	0,9	<0,5
As	ppm	2,4	6,6	5,7	1,4	5,9	5,7	1,7	0,6	2,1	7,6	7,2	4,1	3,4	2,2	9,0	1,4	0,9	30,2	3,7	22,0	5,1	11,8	18,2	5,1	6,4
Br	ppm	<0,5	1,2	1,2	1,1	1,1	<0,5	0,1	0,5	<0,5	1,0	0,6	1,6	<0,5	0,5	0,2	1,6	0,8	3,1	0,8	0,6	0,5	<0,5	1,0	0,8	0,1
Rb	ppm	141,6	138,3	154,6	163,0	150,7	143,1	165,2	164,7	167,4	171,9	151,2	139,8	160,7	150,1	172,8	151,8	149,3	143,9	176,3	180,1	180,0	168,6	164,2	142,1	113,7
Sr	ppm	103,2	105,0	107,3	95,1	101,5	99,3	106,9	108,4	123,8	98,2	96,3	109,8	107,2	116,8	111,7	111,6	108,9	120,8	95,6	106,4	96,7	269,7	127,2	123,4	147,2
Y	ppm	42,4	55,4	55,6	42,1	50,7	47,5	53,8	48,3	55,0	61,9	59,3	52,9	55,4	57,1	60,6	49,4	48,6	68,2	60,1	61,9	55,7	65,0	60,9	49,4	41,3
Zr	ppm	261,2	254,0	259,2	212,9	260,9	215,3	248,2	269,9	260,6	259,0	250,9	283,8	212,0	249,7	254,9	237,7	264,0	230,9	250,6	222,3	223,1	204,3	190,1	195,8	171,4
Nb	ppm	18,6	19,6	18,1	18,7	19,1	15,4	19,0	19,3	18,4	21,2	17,6	17,4	18,6	21,1	20,1	17,2	18,1	20,2	22,4	22,4	23,4	20,7	19,3	17,8	15,8
Mo	ppm	44,2	27,9	25,4	20,7	26,7	30,7	24,4	41,0	28,3	18,0	19,6	35,5	29,3	33,6	18,6	28,6	16,1	28,4	14,4	16,7	12,7	23,2	20,9	13,8	21,1
Ag	ppm	80,2	77,8	43,6	80,1	65,8	31,2	53,7	69,2	83,4	80,5	46,4	90,0	59,9	83,3	59,9	63,6	69,6	97,4	80,2	55,8	84,9	85,6	76,2	87,7	94,7
Cd	ppm	63,2	63,7	34,6	65,4	49,6	23,5	45,0	57,7	67,9	68,5	35,6	75,6	48,5	68,0	42,9	49,5	61,3	82,1	63,3	42,5	68,6	72,1	62,7	74,5	79,7
Sn	ppm	88,9	88,1	43,1	90,9	58,4	26,8	60,3	72,2	93,0	80,0	50,4	105,8	60,2	96,7	57,6	72,5	77,1	109,1	89,6	60,7	99,1	98,4	91,7	104,4	105,4
Sb	ppm	97,6	93,6	29,0	97,6	61,7	23,8	59,3	67,4	101,6	87,6	45,9	112,2	56,6	100,9	58,2	80,3	75,2	134,7	97,0	60,8	107,8	104,4	90,4	113,7	115,0
Te	ppm	139,9	137,3	32,5	127,7	75,9	22,2	85,6	101,1	148,3	119,4	49,2	162,7	81,1	140,5	73,2	111,4	95,2	187,6	136,6	71,3	152,5	147,8	115,4	164,4	173,9
I	ppm	71,6	70,8	13,2	57,6	21,0	5,4	44,2	53,2	86,4	44,5	15,2	96,0	39,8	78,0	25,0	53,3	37,4	104,7	69,3	30,6	85,5	80,3	77,7	91,2	103,0
Ba	ppm	944,0	870,0	750,0	704,0	786,0	626,0	789,0	712,0	1056,0	772,0	660,0	1087,0	760,0	978,0	787,0	788,0	673,0	1078,0	1011,0	801,0	1039,0	1001,0	820,0	906,0	1006,0
La	ppm	448,0	603,0	134,0	294,0	199,0	<2,0	304,0	230,0	442,0	<2,0	<2,0	583,0	330,0	491,0	183,0	<2,0	<2,0	753,0	509,0	212,0	616,0	438,0	463,0	439,0	607,0
Nd	ppm	109,0	129,2	126,3	102,3	105,3	119,5	92,0	118,3	120,6	144,4	141,0	118,8	128,5	129,3	103,9	131,6	138,9	148,2	151,9	152,3	123,1	140,9	133,1	112,0	89,8
Er	ppm	3,5	8,5	6,5	2,9	5,2	4,8	5,6	5,6	5,6	6,2	4,3	4,2	4,9	8,2	7,7	5,1	3,3	6,6	9,1	8,2	4,8	6,5	5,3	3,5	10,5
Ta	ppm	30,3	31,2	28,9	26,7	25,6	30,8	29,5	29,3	27,7	27,9	26,1	26,7	30,4	28,3	27,3	28,9	29,8	29,5	27,4	28,5	28,8	26,7	30,8	28,2	24,7
Hg	ppm	2,1	1,5	2,1	0,9	1,9	1,8	1,5	1,8	2,4	1,2	<1,0	1,5	1,9	1,9	1,1	0,8	1,3	2,5	2,0	3,3	1,4	2,6	1,9	1,8	1,2
Tl	ppm	1,1	1,1	1,0	0,9	0,9	1,0	0,9	0,8	0,7	1,2	1,1	1,0	0,8	0,8	0,9	0,7	0,7	1,0	1,1	0,8	1,0	0,8	1,1	1,1	0,8
Pb	ppm	26,9	35,4	38,9	22,9	27,9	29,1	29,6	28,5	31,0	31,8	26,1	26,6	29,7	33,7	29,6	32,4	33,4	35,9	31,2	37,1	32,7	31,9	29,9	25,9	23,4
Th	ppm	17,8	21,8	21,3	20,2	20,9	17,0	22,3	20,4	22,2	24,3	21,4	18,2	22,9	21,7	24,7	18,8	19,6	27,0	25,9	29,8	25,8	25,3	24,7	21,0	17,0
U	ppm	6,8	5,1	6,2	4,5	2,3	2,6	7,4	9,6	6,5	10,9	11,6	7,0	5,8	9,3	7,6	4,5	3,6	8,5	7,1	8,6	7,6	9,1	14,9	4,9	6,1