AN ARCHAEOMETRICAL INVESTIGATION ON PROVENANCE AND TECHNOLOGICAL PROPERTIES OF SELJUK PERIOD POTTERY FROM KOMANA (TOKAT)

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

MEHMET BİLGİ ER

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
ARCHAEOMETRY

MARCH 2020

Approval of the thesis:

AN ARCHAEOMETRICAL INVESTIGATION ON PROVENANCE AND TECHNOLOGICAL PROPERTIES OF SELJUK PERIOD POTTERY FROM KOMANA (TOKAT)

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ABSTRACT

AN ARCHAEOMETRICAL INVESTIGATION ON PROVENANCE AND TECHNOLOGICAL PROPERTIES OF SELJUK PERIOD POTTERY FROM KOMANA (TOKAT)

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March 2020, 254 pages

The archaeological excavation at Komana (Tokat) unearthed great number of pottery reflecting wide variety in decorations and archaeological evidences including biscuit-fired pottery and tripod stilts showing local production of glazed pottery dated back to Seljuk period (12 – early 14th centuries). In this study, analytical techniques were used to identify the local compositional groups and import wares in the pottery collection, the production technology of local pottery, and to locate the clay used for the production of pottery samples from Komana.

The samples from the clay pastes of glazed and unglazed pottery, biscuit-fired pottery, tripods and soil samples were analysed with optical microscope, XRD and ICP-MS techniques. Statistical methods including two sample t-test, cluster and principal component analysis were carried out to identify the patterns in data produced from chemical analysis.

Pottery samples were classified into six compositional groups based on the variations in their mineralogical and chemical compositions. The analysis results showed that majority of glazed pottery and local reference samples supported a single production in Komana. Compositional affinity between local group, unglazed moulded wares and coarsewares indicated that moulded wares were produced from same local clay source with different recipes and firing regimes. Observations of variations in the petro-mineralogical composition of local groups presented deviations in the clay paste due to the fractionation and firing parameters in the production process. Few samples of monochrome turquoise glazed pottery having calcareous paste were identified as import wares.

Chemical and mineralogical analysis of soil samples showed that the most optimal clay for glazed pottery production is alluvial deposits from the banks of Yeşilırmak River. The mineralogical composition of the deposit from Yeşilırmak river consist of illite/mica, calcite, quartz, feldspar and hornblende overlaps with the paste of local glazed pottery.

This thesis is the first study using archaeometrical analysis presented provenance and production technology of local glazed pottery of Komana. Compositional groups created with this study will contribute the prospective research focusing on understanding of regional economic, political and cultural interactions in Black Sea region.

Keywords: Komana, Seljuk Period Pottery, Provenance Analysis, XRD, ICP-MS

ÖZ

KOMANA (TOKAT) SELÇUKLU DÖNEMİ SERAMİKLERİNİN HAMMADDE KAYNAKLARI VE TEKNOLOJİK ÖZELLİKLERİNİN ARKEOMETRİK YÖNTEMLERLE İNCELENMESİ

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Komana (Tokat)'da gerçekleştirilen arkeolojik kazılarda, Selçuklu Dönemi'ne (12 – erken 14.yy) tarihlenmiş geniş bir dekorasyon çeşitliğine sahip çok sayıda sırlı seramik ile birlikte bisküvi pişirimli yarı-mamül seramikler ve üç-ayaklar ortaya çıkarılmıştır. Bu çalışmada, Komana'da üretilmiş ve ithal edilmiş seramik gruplarının tanımlanması, üretimde kullanılan kilin belirlenmesi ve üretim teknolojisinin anlaşılması için analitik teknikler kullanılarak örnekler analiz edilmiştir.

Sırlı ve sırsız seramikler, yarı-mamül seramikler ve üç ayak parçalarından alınan örnekler ile toprak örnekleri optik mikroskop, XRD ve ICP-MS teknikleri kullanılarak analiz edilmiştir. Örneklerin kendi içlerinde elementlerin derişimlerine bağlı olarak gruplandırılması amacıyla, bağımsız örneklem t-testi, kümeleme analizi, temel bileşenler analizlerini içeren istatistiksel yöntemler kullanılmıştır.

Seramik örnekleri mineralojik kompozisyon ve elementel derişimlerdeki farklılaşmaya göre altı gruba ayrılmıştır. Analiz sonuçları, sırlı seramiklerin büyük bölümünün Komana'da üretilmiş olduğuna işaret etmektedir. Yerel olarak tanımlanan sırlı seramik grubu ve kalıp yöntemi ile bezenmiş sırsız seramikler ve kaba kaplar arasındaki kompozisyon benzerliği sırsız seramiklerin de yerel kil kullanılarak ancak farklı reçete ve ısıl işlemlere tabi tutularak üretilmiş olduğuna işaret etmektedir. Yerel sırlı seramik hamurunun petro-mineralojik özelliklerindeki farklılıklar, üretim sürecinde kilin ayrıştırma ve fırınlama koşullarındaki farklılıklara işaret etmektedir. Az sayıdaki tek renkli turkuaz/firuze renkli sıra ve kireçli beyaz hamura sahip seramikler ithal olarak tanımlanmıştır.

Toprak örneklerinin kimyasal ve mineralojik analizleri sırlı seramik hamurunun üretiminde kullanılmış en uygun kilin Yeşilırmak nehrinin alüvyonlarından elde edilmiş olabileceğini göstermektedir. Buradan alınan kil örneklerinin illit/mika, kalsit, quartz, feldspat ve hornblenden oluşan mineralojik kompozisyonları sırlı seramiklerinki ile örtüşmektedir.

Bu tez, Komana'da üretilmiş sırlı seramiklerin hammadde kaynakları ve üretim teknolojilerinin belirlenmesinde arkeometrik yöntemlerin kullanıldığı ilk çalışmadır. Bu çalışma ile tanımlanan kompozisyon grupları geçmişte Karadeniz Bölgesi'ndeki ekonomik, politik ve kültürel etkileşimin anlaşılması amacı ile gelecekte yapılabilecek çalışmalara önemli katkı sağlayacaktır.

Anahtar kelimeler: Komana, Selçuklu Dönemi Seramiği, Hammadde Kaynak Analizi, XRD, ICP-MS.

To Melek and Melis Doğa

ACKNOWLEDGEMENTS

I would like to thank my supervisor Prof. Dr. Gülay Ertaş for her great supervising at every step of this thesis and accepting me to her research group in Chemistry Department, METU and providing scientific environment and facility.

I would like to thank my co-supervisor Prof. Dr. Burcu Erciyas for endless support and advices and to conduct this interdisciplinary reseach from the beginning.

I would like to express my gratitudes to Prof. Dr. Asuman Türkmenoğlu and Assoc. Prof. Dr. Zeynep Kalaylıoğlu for their contribution to this thesis with advices and comments especially during thesis monitoring meetings.

I would like to thank Prof. Dr. Ayşen Yılmaz for providing me to access XRD instrument in Chemistry Department, METU. I also would like to thank Assoc. Prof. Dr. Evangelia Ioannidou-Pişkin for providing me to use thin section microscope in Environmental Archaeology Research Unit, METU. I also would like to thank Dr. Tasha Vorderstrasse from Chicago University and Yunus Emre Karasu for dating and classifying sample collection taken from Komana. I would like to thank Orhan Karaman, technican of thin section preparation laboratory in Geological Engineering Department, METU for preparing great thin section samples.

I would like to thank Dr. Mustafa Nuri Tatbul, field director of KARP (Komana Archeological Research Project) for our fruitful discussion and his friendship and support for this thesis and Özgen Sütçü and other members of KARP team to their help during especially fieldwork.

I would like to thank Canan Höçük and Sezin Özdemir, research assistants of Chemistry Department, METU and Melis Çetmeli and Erhan Özdemir,

current researchers and Emrah and Selin previous researchers of C49 and Yeliz from C-50 to their friendship and help to laboratory part of this thesis.

I would like to thank Dr. Emine Sökmen from Archaeology Department in Hitite University for her assistance during clay sampling.

I would like to thank Prof. Dr. Şahinde Demirci and Prof. Dr. Aymelek Özer of Archaeometry Department to their support during my education in Archaeometry Department in METU.

I would like to thank Prof. Dr. Vedat Toprak and personel of IKA Madencilik A.Ş. to allow me to use petrographic microscope.

I would like to thank my mother Şehriban Er and my father Kazım Er and my sister Deniz Tozan and my mother in law Makbule Tendürüs and father in law İbrahim Tendürüs and sister in law Dilek Tendürüs for their support.

I would like to thank my wife Melek Er to her love and endless support at every stage of this thesis, and my daughter Melis Doğa Er for especially her patience.

TABLE OF CONTENTS

CHAPTERS

APPENDICES

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF EQUATIONS

EQUATIONS

CHAPTER 1

INTRODUCTION

Archaeological research has enlighted the history of Komana region from the Hellenistic Period since 2004. Archaeological excavation revealed a layer with an evidence for production activities in Hamamtepe region in 2009. This layer, which was later found to be "workshop phase" and to be dated back to the 12 - early 14th century AD, has structural remains and features such as ovens and pits used for firing, storing and waste disposal; and also small findings indicating various production activities such as agriculture, animal husbandry, butchering, wool growing, tannery or bone working. In this workshop phase, there are wasters of biscuit fired pottery with sgraffiato decoration and tripod stilts which are both strong evidence for glazed pottery production in this period.

Historical sources and archaeological record present that the period of the workshop phase coincided with the rise of political instability in the Black Sea region; political control of the region had been transferring among Byzantines, Seljuks and Danishmends.[1, 2] Nevertheless, not only the presence of intensive production activities in Komana and observation on pottery corpus indicating the affinity between common glazed pottery of Komana and pottery types from Eastern Anatolia and Caucassia; but also the presence of imported pottery such as lusterwares related to Iran, shows that Komana maintained its importance as being a trade and production center as a fortified rural settlement.

The main motivation of this thesis on the 12-early 14th century medieval pottery from Komana is to contribute to the understanding of glazed pottery production with its many aspects such as availability of raw materials and technology employed in the production and the understanding of trade and connection at regional scale through pottery mobilization based on compositional analysis.

The number of archaeological investigations and archaeometric studies is limited in the Black Sea region compared to western Anatolia.[1, 3–6] This study will contribute to the accumulation of knowledge on production and distribution of glazed pottery in the 12-early 14th centuries in Komana and the Black Sea region in Turkey.

1.1. Pottery

1.1.1. Definition

Ceramics had many functions in past daily life; they were used for storing, cooking and serving foods, as building materials, refractories, tools, toys. Within the wide and diverse use of ceramics, tableware, cooking pots, and storage vessels are called as pottery.[7] Discovery and use of pottery has been an important step in the history of human life ever since its first production in the Neolithic Period.

Pottery is one of the most frequently found materials in archaeological surveys and excavations due to its extensive use in daily life and strong resistance to environmental conditions after losing its function. From its production to its disposal, pottery carries valuable information about the activities of past humans. It reflects the cultural identity of people; political influence on the society; economic and industrial activities in the settlement; human-environment relationship; connection and trade between settlements. In conclusion, it has been extensively studied by archaeologists and pottery experts for the interpretation of a site, a region or a period. Archaeometrical studies on the pottery have been carried out to contribute to these interpretations and answer specific questions using analytical techniques for almost 150 years.[8]

1.1.2. Production Process of Pottery

Pottery is a ceramic material synthetically produced from clay. Ceramics refers to the entire range of mixtures of metals and non-metals or sometimes slightly more restrictively, to materials manufactured from silicates usually clays which are hardened by application of heat.[7]

The production process of pottery includes five stages: 1) raw material procurement, 2) raw material processing, 3) shaping, 4) decorating and 5) drying and firing. These stages are explained in detailed in the following sections.

1.1.2.1. Raw Material Procurement

There are five basic raw materials used to produce pottery: clay, water, temper, pigment and fuel.[9] Clay, water and fuel are obligatory raw materials and others are optional in the production of pottery. In order to reach the desired technical and visual attributes, the potter might use mixture of more than one type of clay in the preparation of the clay paste. In this case, the potter needs to extract one or more than one type of clay, temper or other raw materials from their resources and transport them to the pottery workshop.

Long-range transport of clay from one or more deposits to the pottery workshop is problematic due to the tonnage of the amount of clay. According to an ethnographic investigation on the distance between workshops and raw material sources, 84% of clay sources are located within a 7 km range. For temper, 79% of sources are located within 7 to 9 km around the workshop; for slip, 57% of sources are found at 30 km or less.[10]

1.1.2.2. Raw Material Processing

Pottery raw materials have generally been modified in order to obtain the desired properties. Raw clay is usually crushed, grounded, sieved, or levigated to remove non-plastic inclusion from the raw material to improve plasticity. Plasticity of clay is defined as “the property of a material which allows it to be repeatedly deformed without rupture when acted upon by a force sufficient to cause deformation and which allows it to retain its shape after the applied force has been removed”.[11] Besides, organic/inorganic tempers might be added to the clay paste to decrease the plasticity and improve workability. One of the other options to modify workability of clay is mixing highly plastic clay with low degree of plastic clay.[7] Aging clay in aqueous medium improves the plasticity by wetting clay particles. Kneading also helps to eliminate air bubbles and provides uniform particle distribution to increase the workability.

1.1.2.3. Shaping

Plastic clay gains its shape with various techniques with the help of some equipments or just by hand. Pinching and drawing are some techniques used to shape the lump of clay by vertical movement of hands and fingers. Moulding is another technique involving the use of a mould to provide the pottery a general form by pressing or pouring clay into a mould. Coiling is the other technique performed mainly by sticking the coils or rolls of clays one over the other. Coiling technique has several variations such as; ring coiling, segmental coiling and spiral coiling depending on the application of sticking and length of the coil. Each method differs in working principle based on how the coils brought together and added to the vessel as it grows. Throwing technique consists of working a body of clay on a spinning wheel, while taking advantage of centripetal force to shape the clay. Wheel throwing technique is performed by putting a lump of clay at the center of a wheel to provide even thickness, then increasing the length by lifting and drawing the lump inside and outside by both hands aided by centrifugal force.[7]

1.1.2.4. Decorating

Decoration of pottery consists of different techniques called “secondary forming techniques” by modifying the pottery surface and giving it the desired visual characteristics. These techniques such as smoothing, scraping, burnishing, slipping and glazing mainly affect the surface of the pottery, but it may change the vessel dimensions as well. Rice categorized the decoration techniques under two main groups: displacement or penetration and addition to the surface.[7] These treatments are applied with the help of smooth or hard tools, leather or some textiles, or just by the hand of potters. Displacement or penetration techniques include impressing, stamping, punctuation and cutting to decorate the vessel surface causing it to be displaced on the surface and at the same time causing a penetration into the body of pottery.

Impressing and stamping are similar techniques applied by impressing a pattern on the pottery surface. In stamping, repeated patterns of identical motifs are impressed with a stamp.

In cutting techniques, a sharp tool is applied along the pottery surface. There are three main subclasses; incising, carving and perforating which are preferred depending on the amount of material removed from the surface of pottery. Incising is cutting lines on the vessel surface with the help of a sharp tool. The incised decoration can be applied under or over the slip. Sgraffiato and champlevé techniques are common cutting techniques in medieval pottery in Anatolia. Sgraffiato decoration is a technique of incising through the slip and the whole surface is glazed and fired. Champlevé is a decoration technique applied by removing a large slip layer from the pottery surface.

Attachments to the surface, painting, slipping or covering with glaze are the techniques of supplementing material on the pottery surface.

Slip is the suspension of fine clay particles in water. However, it may also contain fluxes, fillers such as silica, hardeners like borax, as well as opacifiers and colourants. The colour of the slip is generally different from that of the body. Clay is generally applied to leather hard bodies of pottery by dipping it into the slip, pouring the slip, wiping the pottery with slip and applying it with a brush.

Glazing applies and fuses a thin, glass-like coating onto the surface of the clay to seal its pores. Glaze can be used to colour, decorate or waterproof the pottery surface. The main constituent of glaze is silica which is the raw material of glass. Other constituents such as potassium oxide (K_2O), sodium oxide (Na_2O), lead oxide (PbO), magnesium oxide (MgO) and boric oxide (B_2O_3) are added to the glaze batch providing flux and reducing melting point of silica. Metallic oxides such as the oxides of iron, copper, manganese, cobalt and chromium are added as colourants to the glaze. Aluminium oxide (Al_2O_3), lead oxide (PbO), calcium oxide (CaO), zinc oxide (ZnO), zirconium oxide (ZrO_2) and cadmium oxide (CdO) are usually used as stabilizing agents to control the viscosity of the glaze and give it strength by reducing the defects during the firing process. Glaze can be applied directly through various techniques such as dipping, pouring, splashing, painting and spraying on the unfired body of the vessel or after the first firing, so-called “biscuit firing” of the body. After the application of glaze, the vessel is subjected to a second firing step to melt the glaze on the pottery surface at the temperature of which may be the same or it could be higher or lower compared to that of used in biscuit firing step.

1.1.2.5. Drying and Firing

Drying is the removal of residual moisture from the green body through evaporation. Evaporation of moisture from pottery is a necessary step before firing because it prevents the formation of production failures due to uncontrollable removal of water during the firing step. Firing causes irreversible physical and/or chemical changes to the clay. The crystal structure of the clays is lost at elevated temperature from 550 °C. There are three main variables in pottery firing affecting the production of the pottery; firing atmosphere, firing temperature and soaking time (firing duration). The firing atmosphere inside oven determines the properties of pottery such as colour, hardness and porosity.[12] Air circulated in the kiln during firing and the oxidizing nature of the atmosphere inside the kiln causes the oxidation of elements in clay structure.

Firing temperature and its duration changes the chemical structure of mineral. These parameters mainly depend on the type and design of the kiln and fuel used. Pottery and other ceramic materials have been fired in kilns in Europe, Asia and Africa for thousands of years. However, its use in firing was rare in America before European influence.[7]

1.1.3. Raw Materials of Ceramic Body

1.1.3.1. Clay

1.1.3.1.1. Definition

The term “clay” is defined in three different ways.[13]

i. Clay is fine grained and ordinarily loose material providing plasticity when mixed with water.
ii. Clay (or clay size) is used for grain size classification for the small size particles (less than 0.002 mm) found in geological sediments.
iii. Clay (or clay minerals) is a mixture of hydrous alumino-silicate minerals.

1.1.3.1.2. Occurrence

Clay is a sedimentary deposit formed by accumulation of the products of older rocks. Formation of clay is based on two surface weathering mechanisms: (i) chemical weathering is decomposition of minerals in rocks due to the chemical reactions taken place in the presence of water and free hydrogen ions; (ii) fragmentation is mechanical disintegration of rocks due to several abrasive forces due to wind, water and glacial ice.[7, 12] Different clay minerals can be obtained from different kinds of rocks and weathering mechanisms.

Clay can be classified according to their occurrence and distance to parent bedrock. *Primary clay* is formed in situ by weathering of bedrocks; it is often coarse and it has low plasticity and usually contains coarse fragments due to the uncompleted formation process of clay. *Secondary clay* is produced by means of fluvial transport and deposition of clay minerals and clay sized particles produced by eroding pre-existing rocks and soils in complete sedimentary cycle. Secondary clay is more homogenous and finer in texture compared to primary clay.

1.1.3.1.3. Definition of Clay Minerals

Clay mineral can be defined as hydrated aluminium silicate, $Al2O3 \cdot 2SiO2 \cdot 2H2O$. The table showing the classification of clay minerals given in Table 1.1.[14] Most of the clay minerals fall into the category of layered silicates. The grain shapes of the minerals are in the layered silicates or “phyllosilicates” look like a sheet. This is because bonding directions of the constituent atoms are stronger in two directions and weaker in one direction which is more likely to be broken.[15]

Table 1.1. Classification of clay minerals

Layer Type	**Group**	**Subgroup**	**Species**
1:1	Serpentine – kaolin	Serpentines (Tr)	Chrysotile, antigorite, lizardite, berthierine, odinite
		Kaolins (Di)	Kaolinite, dickite, nacrite, halloysite
2:1	Talc-pyrophyllite	Talc (Tr)	
		Pyrophyllite (Di)	
	Smectite	Tr smectites	Saponite, hectorite
		Di smectites	Montmorillonite, beidellite, nontronite
	Vermiculite	Tr vermiculite	
		Di vermiculites	
	Illite	Tr illite	
		Di illite	Illite, glauconite
	Chlorite	Tr, Tr chlorites[a]	
		Di, Di chlorites	Donbassite
		Di, Tr chlorites	Sudoite, cookeite
		Tr, Di chlorites	
2:1	Sepiolite-palygorskite		

[a] 2:1 layer first in name of chlorite, Tr: trioctahedral, Di: dioctahedral

Clay mineral structures are composed of interlinked tetrahedra and octahedra composed of oxygen anions and silicon, or frequently aluminium cations as shown in Figure 1.1.

Tetrahedra are composed of a silicon cation (Si^{4+}) surrounded by four oxygen anions (O^{2-}). The electrical neutrality of tetrahedron is maintained by linking to adjacent tetrahedron by sharing three corners, which results in infinite two-dimensional ‘hexagonal’ mesh pattern along with the x, y crystallographic directions.[16]

Octahedra which are composed of aluminium (Al^{3+}), magnesium (Mg^{2+}) or iron ions (Fe^{2+}, Fe^{3+}) are surrounded with 6 oxygen anions (O^{2-}). In the octahedral linkages, the number of cations varies between two and three. When aluminium with a positive valence of three is the cation present in the octahedral sheet, only two-thirds of the possible positions are filled with cations in order to balance the charges. When only two-thirds of the positions are filled, the structure is termed dioctahedral. When magnesium with a positive charge of two is present, all three positions are filled to balance the structure and the mineral is termed trioctahedral.[17] d(060) diffraction peak at ~60.0° (2θ) is used to differentiate di- and tri-octahedral clays with X-ray diffraction analysis. Dioctahedral minerals have a d(060) reflection near 1.50 Å, when trioctahedral minerals have a d(060) reflection near 1.53-1.54 Å. [15]

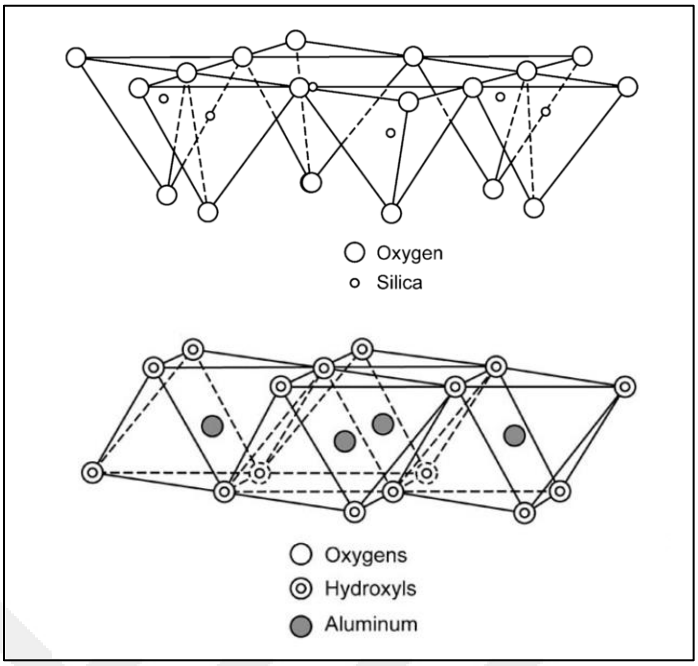

Figure 1.1. Sketches of silica tetrahedron and alumina octahedron[17]

The silica tetrahedral sheet and the octahedral sheet are linked by sharing the apical oxygens or hydroxyls to form clay minerals. The arrangement and composition of the octahedral and tetrahedral sheets account for most of the differences in their physical and chemical properties.

Kaolin Group

Kaolinite, dickite, nacrite, and halloysite are types of mineral species present in kaolin group. Kaolin structure or 1:1 structure comprises of a single tetrahedral sheet and a single octahedral sheet.[15] Silica tetrahedrons and octahedral sheets are linked with apical oxygens. All of the apical oxygens of the silica tetrahedrons point the same direction so that these oxygens and/or hydroxyls are shared by the silicons (Si^{4+}) in the tetrahedral sheet and the aluminium (Al^{3+}) in the octahedral sheet.[17]

The chemical formula of kaolinite is $Al_4Si_4O_{10}(OH)_8$ and the chemical composition is SiO_2, 46.54%; Al_2O_3, 39.50%; and H_2O, 13.96% by weight. The thickness of the unit layer is 7.13 Å.[7]

Illite – Mica Group

Illite is occasionally defined as a mica-like mineral or fine grained mica-like mineral (grain size is smaller than 2 µm). The general chemical formula of illite is $K_{0.8\text{-}0.9}(AI,Fe,Mg)_2(Si,AI)_4O_{10}(OH)_2$. It has two tetrahedral and one octahedral sheets (2:1 structure) in its structure and interlayer cation is potassium. The basal spacing d(001) of illite is 10 Å.[15, 17]

The size, charge, and coordination number of potassium ion allows the potassium ion fits snugly in the hexagonal ring of oxygens of the adjacent silica tetrahedral sheets. Presence of potassium ion between layer units provides an ionic bond which prevents water molecules entering the interlayer position as in the smectite structure.[17]

Smectite Group

Smectite minerals has 2:1 structure which is composed of two silica tetrahedral sheets with a central octahedral sheet. The general chemical formula of smecitite is $(OH)_4Si_8Al_4O_{20}\cdot NH_2O$.[17] Smaller layer charge allows hydrated ions or polar ions can be placed between the layers. This unique property causes to change the average interlayer distance, and thus, this mineral group is called swelling or expanding minerals. The usual basal spacing d(001) of smectites is greater than 10 Å because of the presence of hydrated cations in the interlayer positions and the normal basal spacing are 12.5 Å for a monohydration state (one water layer) and 15.2 Å for two water layers.[15]

Chlorite Group

Chlorite has a structure composed of two silica tetrahedral layers with a central octahedral sheet (2:1 structure) and an interlayer brucite sheet ($Mg(OH)_2$). Chlorite structure is sometimes defined as 2:1:1 structure due to the presence of brucite sheet.[18] The basal spacing d(001) of chlorite is about 14 Å. Chlorite is generally intimately mixed with other clay minerals so it can be identified by the 14 Å basal spacing.[17]

Chemical formula of chlorite is $(OH)_4(SiAl)_8(Mg\text{-}Fe)_6O_{20}$. The brucite-like sheet in the interlayer position has the general composition of $(MgAl)_6(OH)_{12}$. There is a variety of cation substitutions in chlorites, most commonly Mg^{2+}, Fe^{2+}, Al^{3+} and Fe^{3+} ions.[17]

1.1.3.2. Temper Materials

Pottery is a composite material which may contain rock fragments, mineral grains and organic materials besides clay minerals. The constituents other than clay minerals might be present naturally or added intentionally to the clay paste.

Potters usually add different materials to modify the characteristic of the clay. Tempers can be defined as intentionally added materials into the clay paste. Sand (quartz or carbonate minerals), grog (old pre-fired clay or pre-used ceramics) or natural and vegetal materials such as shells, straw and chaff are commonly used tempers.[19] The addition of these non-plastic constituents changes physical and mechanical properties of clay during production and also changes visual appearance of final product.[7, 20]

The major effect of temper is the change plasticity of clay paste. Addition of non-plastic materials into highly plastic and sticky clay makes it less plastic to work with it easily. Tempering (or adding tempers to the clay paste) increases the mechanical strength which is an important parameter for durability of clay paste before and after firing. Tempers also affects drying and firing characteristics of the material.

The properties of final product such as permeability, heating effectiveness, thermal shock resistance and toughness can be controlled by addition of different types of temper. Permeability, which is the ability of a liquid passing through the pottery, is closely related with the interconnected pores between large particles in clay paste. The presence of vegetal tempers in clay paste could be destroyed during firing process and turned into pores. It is reported that the cooking pots also contain considerable amount of tempers such as mineral and rock fragments modifying durability under elevated temperature.[7, 21] The specific tempers provide distinctive physical properties to the final form of pottery. For instance, mica fragments provide shiny appearance to the pottery surfaces and may be added to either paste or slips. Rock fragments, such as limestone, chert, sandstone, calcarenite, sedimentary or volcanic breccia, schist, phyllite, basalt, granite can be intentionally added to clay paste as temper.[22] Under optical microscope, presence of angular grains indicate that these grains were crushed and added to the paste.[20] Thus, angularity of mineral shape and rock fragments has been occasionally checked during thin section analysis of archaeological pottery.

1.2. Site Description

Komana is situated in Gümenek[i] village which is 10 km far from modern Tokat city center, in Black Sea Region of Turkey as shown in Figure 1.2. Visible remains of Komana are dispersed on both sides of a wide valley of Yeşilırmak in 8 km radius around Gümenek as shown in Figure 1.3.

Archaeological research (Komana Archaeological Research Project - KARP[ii]) was initiated with an archaeological field survey conducted by a team led by Prof. Dr. Burcu Erciyas from Settlement Archaeology Department at Middle East Technical University from 2004 to 2009. Since 2009, the archaeological excavation has been more concentrated on a medium sized mound (150 x 250 m^2) called Hamamtepe which is next to modern Tokat – Niksar road as shown in Figure 1.3.[1, 23] Hamamtepe is placed on metamorphic bedrock next to the Yeşilırmak River (ancient Iris), which flows along the valley. The fertile valley of Yeşilırmak contains Turhal and Tokat plains in the northwest and expands through Zile plain in

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[i] The name of the village “Gümenek” was inherited from ancient Comana which has been changed in the history of settlement. The village was also named called as “Kumanat” in 20th century.[42] The name of the village was recently changed from Kılıçlı to Gümenek.

[ii] More information about KARP can be found in the following web page: http://komana.org/.

the west, and it was used for agriculture in the past and also in modern times.[24] On the other hand, Komana is in the region sharing the same topographical characteristics of Black Sea region and defined generally as mountainous and steep. Hills and mountains are lying mostly in east-west direction; bordering the valley naturally. Yeşilırmak valley ends by Yaylacık Mountain in the north, Deveci Mountain in the south and Buzluk Mountain in the north-west.

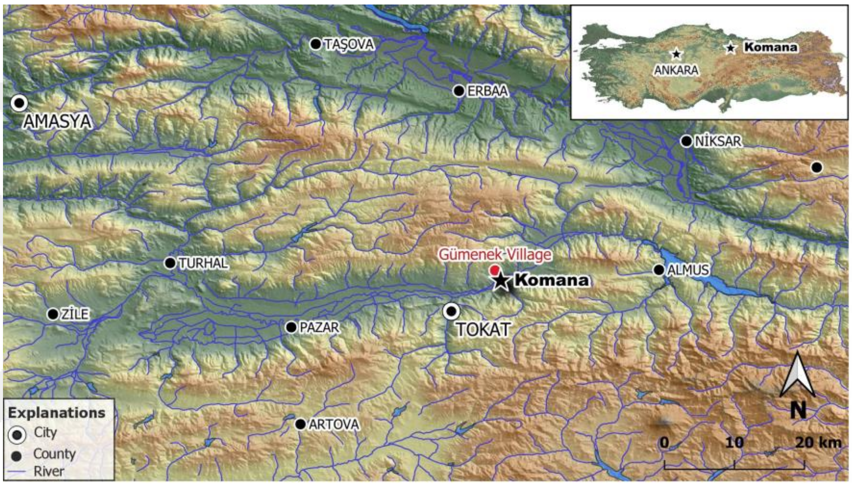


Figure 1.2. Location of Komana

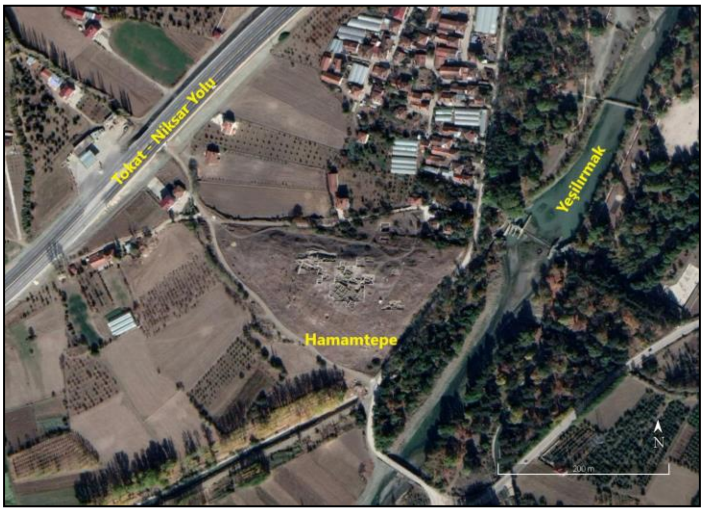


Figure 1.3. An aerial photo of Hamamtepe

1.3. Archaeological Research in Komana

Survey and excavation show that Komana has been settled since Hellenistic Period. From the earliest years of research, KARP has been going on as an interdisciplinary study with the contribution from fields such as anthropology, archaeometry, geoarchaeology, remote sensing, zooarchaeology and bioarchaeology.[25–29]

Komana was cited in some of the historical resources. Strabo describes Komana as a populous city (not less than 6000 in population), a notable trade center for the people of Armenia, probably from the late 1st century B.C. to the early 1st century AD. The city has a temple which was dedicated to goddess Ma, and it attracted a lot of people from Black Sea region to practice religious rituals in the name of Ma.[30]

The city was mentioned in a medieval historical source "Danışmendname", which is an epic of Danişmend Gazi. Komana was mentioned as a settlement called Sissiye which included numerous churches and chapels.[2]

The location of Komana was firstly suggested by Cramer, due to the presence of architectural remains in the vicinity of Gümenek.[31] Hamilton gave details about architectural remains such as a rock-cut tomb and remains of a Roman bridge.[32] Hogart and Munro visited Komana during their survey in the 1890s, and reported the presence of architectural remains of a temple and again the rock-cut tomb.[33] Anderson mentioned the presence of the bridge, a cemetery, an Islamic tomb and the rock-cut tomb when he visited Komana and Gümenek.[34] In the 1920s, von der Osten also located and took photographs of the Islamic tomb and the rock-cut tomb in Komana during his expeditions as show in in Figure 1.4.[35, 36]

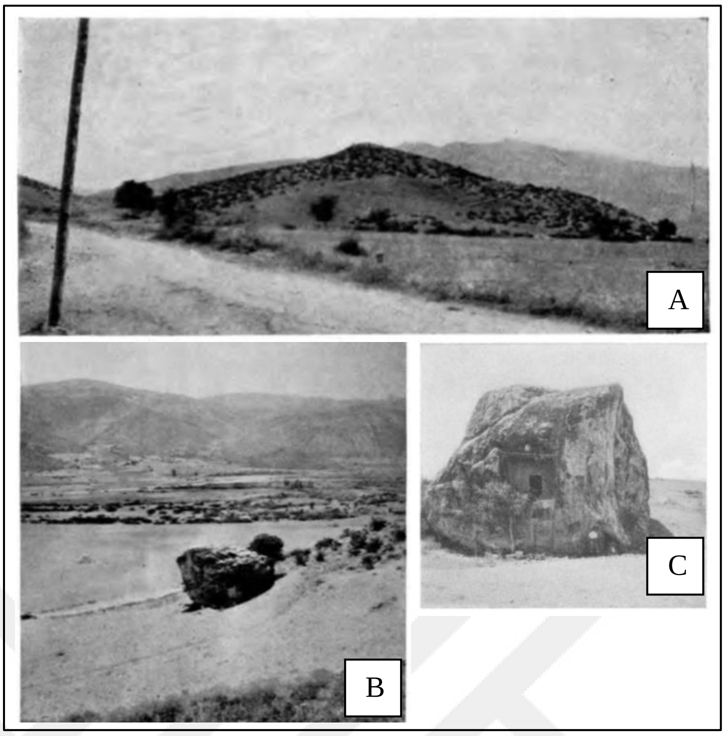


Figure 1.4. Pictures of Komana from 1920s, A: Hamamtepe, B and C: rock-cut tomb

1.3.1. Archaeological Survey

Archaeological field survey of Komana was conducted for 5 years between 2004 and 2008. In the first three years, archaeological survey was focused on Hamamtepe and its close vicinity. Intensive and extensive survey methods were used to locate the extent of the settlement and to identify visible remains of Komana on the surface. During the extensive survey, a Byzantine basilica in the northern slope of Kılıçlı (Gümenek), a stone quarry and a hexagonal pool in the fields of Bula village are important finds which were discovered and documented in the first year of the survey.[23] Two inscribed architectural elements reused for the construction of modern regulator to irrigate agricultural fields in the valley, were located in the area of DSİ (The General Directorate of State Hydraulic Works) which is next to Hamamtepe as shown in in Figure 1.5.[23] Additionally, a rock-cut tomb and an Islamic tomb which were mentioned in the previous surveys were also documented.[34–36] The intensive archaeological survey method[iii] was used in the western part of Hamamtepe; Bakışlı, Ballıdere and Kılıçlı (Gümenek) villages.[37] Geophysical surveys were conducted as a part of the archaeological survey. Magnetic and electrical resistivity methods were used to locate the potential of architectural remains on Hamamtepe and in the field next to the hexagonal pool. Following these surveys, it was also observed that architectural elements were reused for the construction of modern buildings in Ballıdere, Döllük, and Kılıçlı (Gümenek).[23, 37, 38]

In 2007 and 2008, the survey has extended along the Yeşilırmak valley on the west and east directions and Tokat – Sivas road on the south. Many sites including fortresses, churches, public buildings, tumuli, necropolis and rock-cut tombs which were dated from 2nd millennium BC to the Ottoman period were discovered.[39, 40]

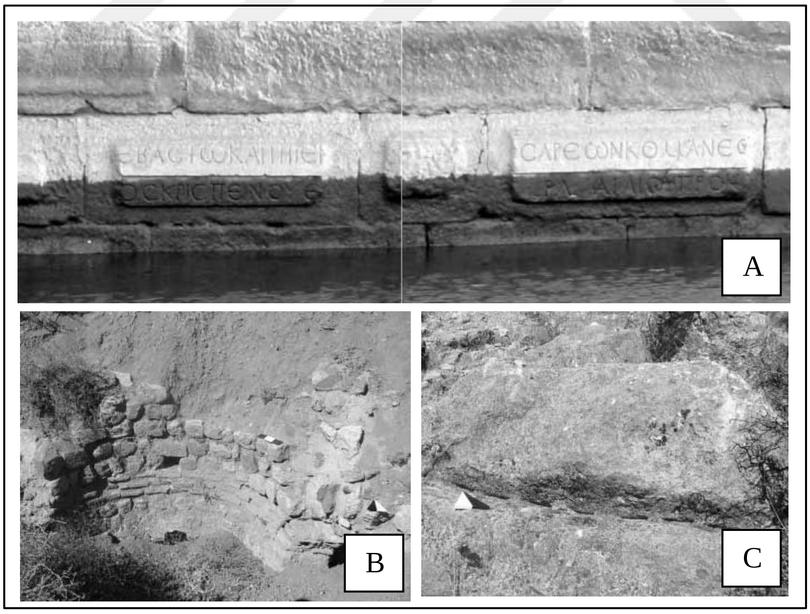


Figure 1.5. A: Inscribed architectural elements; B: Basilica in Kılıçlı; C: Stone quarry in Kılıçlı

[iii] Recording archaeological material encounted during fieldwalk.

1.3.2. Archaeological Excavation in Komana

Archaeological excavations have been ongoing at Komana since 2009 The excavations aiming to unearthing the physical evidence related to the temple-state structure at Komana and to understand the social, economic and administrative structure of Komana, initiated in three sectors on Hamamtepe in the first season in 2009.[41] The number of excavated sectors increased to seven in 2016 as listed in Table 1.2.[42]

There are five archaeological phases in Komana:[1, 4]

1. Ottoman phase (rural village settlement) (17th-18th century)
2. Danishmend/Seljuk phase (fortified rural settlement) (12th-14th century)
3. Middle Byzantine phase (cemetery with two churches) (11th-12th century)
4. Early Byzantine phase (fortified rural settlement) (7th-8th century)
5. Hellenistic-Roman phase (very few structural remains could be identified so far (in 2018))

Table 1.2. Excavated areas in Hamamtepe (HTP: Hamamtepe)

Sector ID	**Location**
HTP01	At the center of Hamamtepe
HTP02	Western side of Hamamtepe, fortification walls and architectural remains related to this wall
HTP03	Eastern side of Hamamtepe, step trench
HTP04	Northeastern side of Hamamtepe
HTP05	Test trench outside of fortification walls at the eastern side of Hamamtepe
HTP06	At the center and top of Hamamtepe
HTP07	Test trenches outside of the fortification walls at the western side of Hamamtepe

In this study, pottery samples were taken from trenches and layers of the HTP01 sector which is the most widely excavated area on Hamamtepe as illustrated in Figure 1.6.[42] HTP01 area provides architectural and material evidence for all phases (Ottoman dwellings of 17-18th centuries, medieval workshops and domestic units of 12-early 14th centuries and Middle Byzantine churches and graves of 11th - 12th centuries, and pre-11th-century phase).

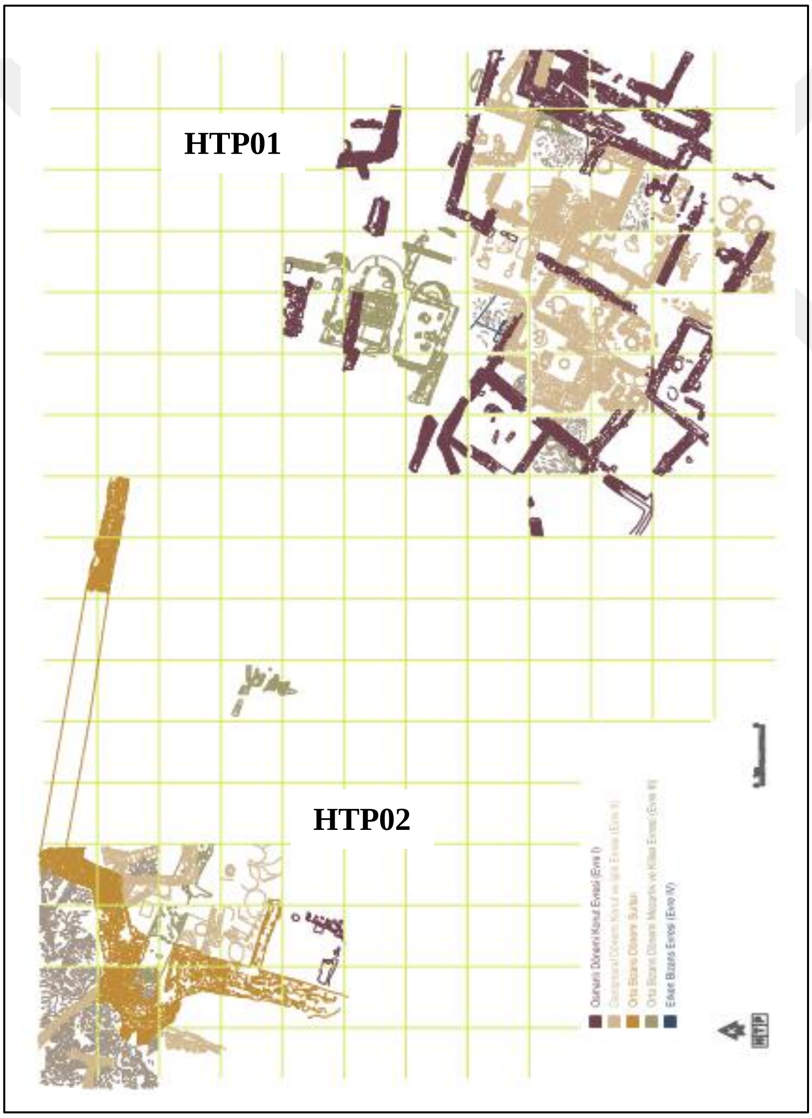


Figure 1.6. Plan of the excavated sectors (HTP01 at the top and HTP02 at the bottom) on Hamamtepe

1.1.1. Byzantine/Danishmend/Seljuk Phase (12- early14th century)

This phase was dated with the presence of characteristic glazed pottery (12th-14th centuries), a glass bottle (13th century), coins (end of 10th-11th century anonymous follies occurring together with 12th-13th century Seljuk coins) and radiocarbon dating of carbonized samples were shown that this phase was dated back to 13th century (personal communication with Prof. Dr. Burcu Erciyas).[4]

The architecture of this phase is very similar to the Ottoman architecture. Building walls were probably arisen on these stone foundations and made of mudbrick supported with wooden frames as shown in Figure 1.7 and Figure 1.8. The structural integrity of 12th – early 14th-century buildings and walls were destroyed by Ottoman phase and mud bricks were possibly decomposed by environmental conditions. Earlier architectural materials such as marble and limestone blocks were re-used as spoila on the walls similar to the later phase.[1, 4]

Various types of features such as ovens with or without air circulation pipes, pits carved in the bedrock, containers, and waste pits, were found in this phase. Bedrock was used intensively in this period. It was occasionally used as floors in the rooms, base for ovens or was carved to make pits.

Archaeological finds are rich in this phase. Pottery includes glazed sgraffito decorated pottery dated to the 12th – early 14th centuries, unglazed wasters of biscuit-fired pottery which are strong evidence of local production, tripods stilts, and import wares. Different sized cooking and storage vessels were found in this phase. Metal objects in different forms such as iron nails and fragments of some instruments and tools were also found. Glass objects and ornaments such as bracelets are present in this phase. Presence of Byzantine, Danishmend, and Seljuk coins belonging to 12th – early 14th centuries are important to date this phase. Animal bones and bone objects (spindle whorls, needles, buttons, and ornamental elements) are also rich in these workshop layers. The presence of numerous bone objects was interpreted as the versatile use of animals, domestic and industrial operations. Plant remains also were recovered from burnt and mineralized contexts.[42]

After detailed analyses of archaeological evidence (architecture, features, small finds etc.) found in these building, the buildings of this phase were identified as parts of workshop.[4]

The pottery samples studied in this thesis were sampled from archaeological layers of Byzantine/Danishmend/Seljuk Phase (12 – early 14th century). The results would contribute to the understanding of pottery production in this period.

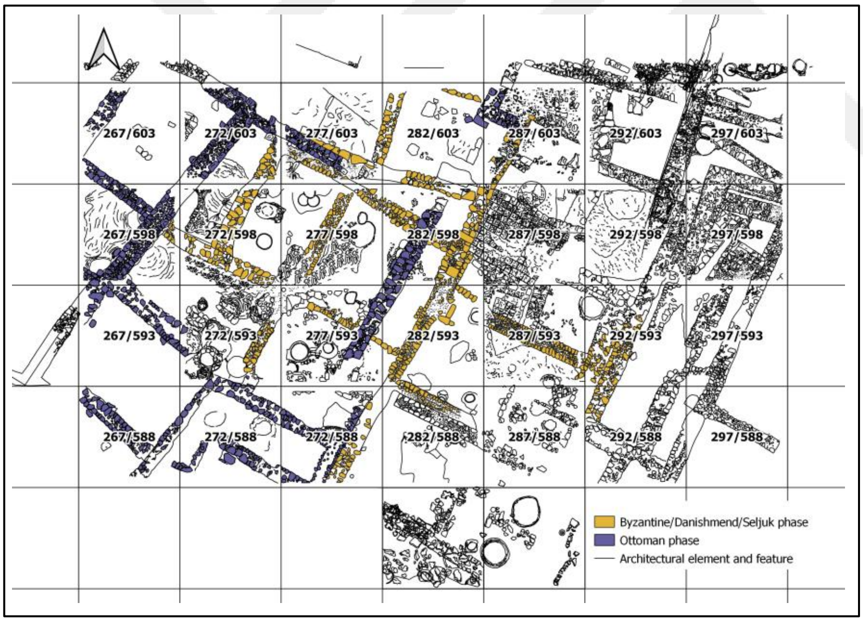


Figure 1.7. Plan of Byzantine/Danishmend/Seljuk phase. [42]

Figure 1.8. A photograph showing Byzantine/Danishmend/Seljuk phase.[42]

1.4. Medieval Pottery of Komana

1.4.1. Summary of Seljuk Period Pottery

Although the Turkic tribes started to settle in Anatolia from the 8th to the 10th centuries, Anatolia was handed over to the Seljuks after the Battle of Manzikert in 1071. The Anatolian Seljuk State or “Sultanate of Rum” was founded as part of the Great Seljuk State by Suleiman ibn Qutulmish (Kutalmışoğlu Süleyman Şah) who was a general and noble. The period between the conquest of İznik in 1075 and the decline of the state in 1308 after Mongol invasion is called the Anatolian Seljuk period.[43]

The multicultural society of Anatolia and mobilized population on trade routes had contributed to variations of ceramic art containing the elements of Central Asia, Iran, Islam and local culture. Especially the ceramic artists and potters who escaped from the Mongolian raids from Iran and Iraq contributed to the development of the ceramic art in Anatolia.[44]

Underglaze painting, lustering, minai, incising (sgraffiato and champlevé), slip painting, moulding and stamping are major decoration techniques applied to produce pottery with red and white paste during the Seljuk period.[45]

A special type of white paste known as fritware, stonepaste or artificial paste first appeared in the 11th century during the Fatimid dynasty in Egypt.[46] In the 12th – 13th centuries, stonepaste was probably developed to imitate Chinese porcelain.[47] Later on, fine tablewares with stonepaste body decorated with luster and minai techniques were produced and distributed in Anatolia, Syria and Iran. According to historical sources, stonepaste consisted of ground quartz, frit and clay.[48] Mason published several papers on provenance and production technology of high quality glazed pottery having stonepaste from Syria, Iraq and Iran.[49–51] Redford and Blackman performed chemical analysis on stone paste bodies of lusterwares and suggested the regional productions instead of centralized production and distribution of lusterwares in 12th and 13th centuries.[52] Stonepaste bodies continued to be used for well-known İznik pottery manufactured for the Ottoman palace. Several publications were made to understand production technology of stonepastes of İznik pottery.[53–55]

Lustering, which is an over-glaze decoration technique, is the formation of luster or iridescence effect given on the surface of glaze by fixing metal oxides on glaze surface with firing in a reduction atmosphere kiln.[56] Production of lusterware was expanded to Raqqa and Hama in Syria; Kashan and Ray in Iran; and after its birth in Egypt. Lusterwares were unearthed in Samsat, Ahlat, Harran, Hasankeyf, Gritille and Kubadabad in Turkey. Beside the application of lustering technique on pottery, luster decorated tiles in the Seljuk Kubadabad Palace are outstanding and well-known examples of this technique.[57]

Minai technique emerged in Iran in the second half of the 12th century and ended in the first quarter of 13th centuries.[58] The minai is a technique in which under-glaze and over-glaze decorations of different colours are used together. In the underglaze technique, painting/decoration process is made on surface after the first firing; a second firing is made by covering surface with transparent glaze.[59] Pottery decorated with minai technique were found in excavations in Ahlat and Ani during the Anatolian Seljuk period.[60]

In the incising techniques (sgrafiato and champlevé), the decoration is created by removing materials on the clay paste with a sharp tool. The decoration could be also incised either on the white/cream slip layer or directly on the clay paste. When the pottery decorated with combination of painting and incising techniques, then this type of pottery called *incise-splashed ware.*[61] The similarity between sgrafiato and slip painted pottery produced by Seljuk and Byzantine potters in terms of decoration and techniques which was the result of interaction between two cultures.[45] Raw material and technological properties of incised pottery from caravanserai in Eğirdir (Isparta) investigated with optical microscope, SEM (scanning electron microscope) and XRD. Firing temperature was estimated between 800 and 1100 °C with regarding to formation of new phases like mullite, wollastonite.[62] In another publication, firing temperature of Seljuk and Byzantine pottery samples from Ephesus, Iznik and Korucutepe was estimated around 750 – 800 °C based on mineralogical composition of body.[63]

Surfaces of glazed pottery were occasionally covered with slip layer. Slip is coloured or colourless suspension of clay particles in water. Slip painting technique was used for covering and decoration purposes, especially on the outer surface of the vessels during the Seljuk period.[64]

Moulding is one of the main techniques to shape pottery with hand shaping and wheel throwing. Moulding technique reduces production costs and provides a certain degree of standardization in pottery shapes. Moulds were also used to decorate especially outer surface of vessels.[65] During the excavations carried out in Hasankeyf, Sahil Sarayı workshop mainly produced unglazed pottery with moulding technique during Artuqid period.[66]

1.4.2. Known Production Centers of Seljuk Pottery in Turkey

Workshops dated to Seljuk period were discovered in Ahlat, Kalehisar, Antakya and Hasankeyf.

Archaeological excavations in Ahlat (Bitlis) that was a populous and an important Seljuk settlement, have revealed a context that completely showed the complete production chain consisting of four kilns dated to the second half of the 13th century, kiln furnitures, semi-finished products, frit residues and two dumpsites where wasted lusterwares and painted pottery were accumulated.[60] Karamağaralı emphasized the connection between pottery from Ahlat pottery and production centers in Iran and Syria, in terms of sharing similar stylistic features (decoration patterns and figures).

Archaeological research in Kalehisar (Çorum) revealed two kilns, kiln furnitures, sgrafiato and slip painted pottery dated to Seljuk period.[67] Yetkin highlighted the connection between Seljuk pottery of Kalehisar and following production in İznik during Ottoman period.[68]

Two different workshops discovered in Hasankeyf (Batman) show the glazed and unglazed pottery production in Artuqids (12 – early 13th centuries) and Ayyubids periods (14 – 15th centuries). Unglazed pottery shaped with moulding technique were produced in the first workshop called Sahil Sarayı workshop.[66] Pottery decorated with underglazed painting, incising, splashing techniques were produced in Selahiye workshop dated to Ayyubids period.[69, 70]

Even though pottery kilns are the primary evidence for pottery production in archaeological record, in most case structural remains could not be recovered. However, kiln furniture, biscuit-fired pottery and wasters are strong evidences of production.[71] Accordingly, local pottery production were identified in Anaia, Ani, Akşehir, Avşankale, Al Mina (St. Simeon), Gritille, Kinet (Hisn al-Tinat), Komana, Konya, Korucutepe, Kubadabad, and Samsat through the presence of kiln furniture, biscuit-fired pottery and wasters.[4, 57, 72–79]

1.4.3. Medieval Pottery of Komana

Danishmend/Seljuk phase of Komana represents the most various and abundant archaeological materials including Medieval pottery at Komana. Potteries found in Komana have been studied systematically since 2015. Pottery research began with an examination of pottery in a closed context in a cesspit (green pit) dated back to 12 – early 14th centuries, and then continued with an investigation of figured glazed pottery from same period.[80, 81]

It was reported by Dr. Vorderstrasse that glazed pottery mostly consists of decorated and undecorated bowls having green and yellow glaze colours with a white slip. Different colours can be seen on both the interior and exterior surfaces of the pottery. Glazed potteries were mostly decorated with sgraffiato and champlevé techniques, but slip trailed decoration was also used to decorate the exterior surfaces of the glazed pottery. Common glazed wares generally have geometric and floral designs. These designs include pseudo-Arabic inscriptions, floral designs, and incised bands. It is common to see glazed pottery decorated with sgraffiato techniques on both sides.

A yellow glazed bowl that has a human figure is holding flowers (or poppy plant) in both hands, was found in the green pit. This design is similar to wall tiles of Seljuk palaces dating back to the late 12th to early 13th centuries. Potteries with similar designs were found in the settlements of Central and Eastern Anatolia, Caucasus, Crimea and Cyprus.[80, 81] Vorderstrasse points out that this is the expansion of Seljuk art and culture in pottery production starting from Konya to the rest of Anatolia and beyond.[80] Karasu and Özkul emphasized the history of representation of poppy plant on different archaeological materials since Hittite period in Anatolia.[81] Another interesting example is a bowl with a bird figure on the interior surface. Some other similar bird designs which were associated with Seljuk art, were found in the inventory of İstanbul Archaeology Museum (probably origin of Aksaray) and in Cherson in Crimea.[81] Karasu and coworkers were worked with 23 glazed and 3 unglazed biscuit fired pottery samples containing human, fantastic and animal figures such as siren, bird, lion, and fish in order to characterize pottery samples from 12th – 14th centuries.[81] It was reported that figured pottery samples are very similar in terms of paste colour, additives and hardness. Few amounts of mica, lime and sand added to dense and homogenous paste fired at elevated temperatures. Detailed investigation on the decorations showed that the clear connection between Komana pottery and potteries from Anatolian Seljuk settlements. The stylistic details of human figured pottery and the presence of prey birds as figures were considered as the reflection of Turkic roots of this fashion.[81] Even though, most of the finished samples and one of biscuit fired samples were considered as local, two biscuit fired samples decided be imported. There are two main types of coarsewares in Komana; red slipped redware and whiteware. Red slipped red ware is the most abundant one consisting of storage jars and cooking pots. They have mica, obsidian, and unidentified white inclusions.[80] Mica inclusion gives a shiny look to the coarseware. Whiteware of Komana was also used as tableware in addition to its function as storage and cooking. This pottery type has a Sasanian origin that was spread in the Middle East in the early Islamic Period. Vorderstrasse emphasized that the presence of whitewares is an indication that Komana has close ties with the Islamic world. There are also two types of lids that can be classified under the coarseware group; the lid has strap handles peculiar to Anatolia, and the lids have a knob handle associated with south Caucasus origin.

1.5. Geological Context of the Region

Clay is the main raw material that contains the petrographical and geochemical signatures of bedrock. Therefore, lithology of the region is assessed by desktop study. The border of the geological study is limited by a drainage model created with geographical information systems. Hydrology is one of the basic processes that contribute to the clay formation. Drainage model was developed by MapInfo© software as shown in Figure 1.9. Geological map were prepared from the digital data provided by MTA (The Directorate General of Mineral Research and Exploration) by QGIS© software.[82]

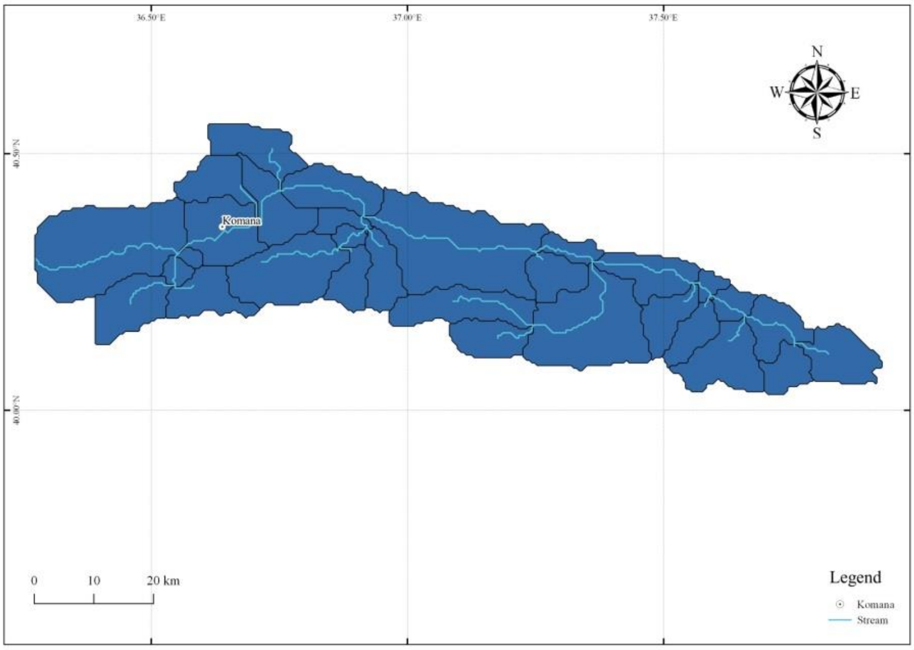


Figure 1.9. Drainage model around Komana

Komana was placed on metamorphic bedrock surrounded by a Quarternary alluvial deposit. Metamorphic rocks, ophiolithic mélange, sedimentary rocks and volcano sedimentary rocks are the main rock types found in the area as shown in Figure 1.10 [83]. The studied area is largely covered with Paleozoic age metamorphic rocks containing schist/phyllite, marble, crystallized limestone and metabasic rocks which are called Tokat metamorphics [84]. Pre-Campanian Artova ophiolitic mélange contains basic, ultrabasic, volcanic and sedimentary rocks. Artova ophiolitic mélange exists generally with Tokat metamorphics in the region.[85] Middle – late Eocene age sedimentary rocks which are conglomerate, sandstone, mudstone, limestone are present in the eastern part of the region (Haydaroğlu formation).[86] Aquitanian – Burdigalian age Volcano sedimentary rocks which are present around Almus region is called Almus formation which contains volcanites, conglomerate, sandstone, mudstone and marine limestone.[87]

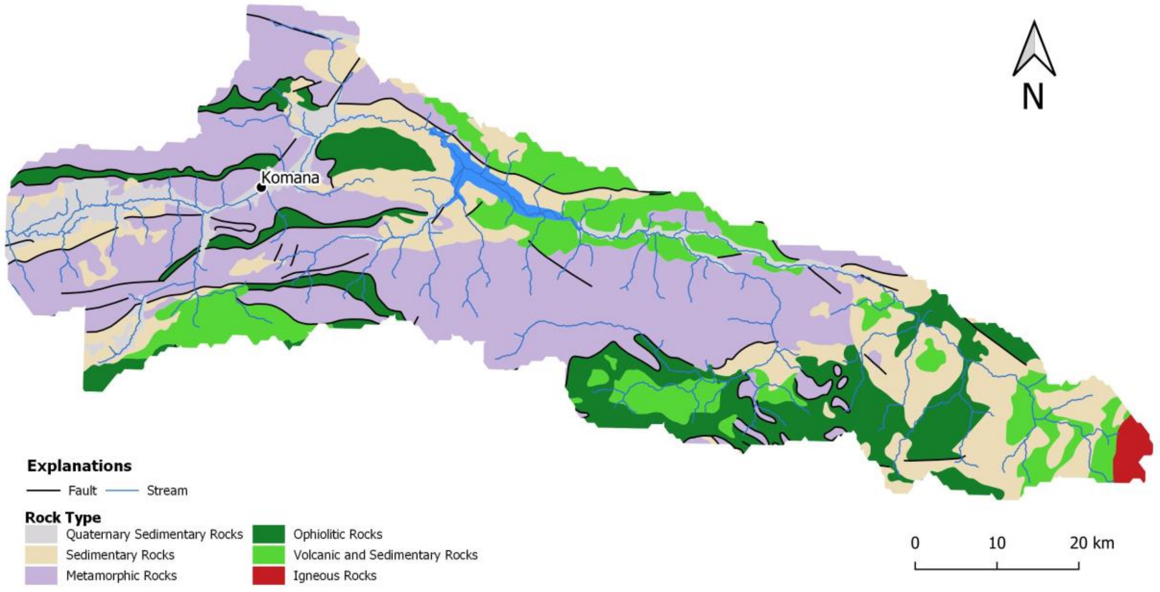


Figure 1.10. Geological map of the Komana and surroundings.

1.6. Overview of Provenance Studies of Archaeological Pottery

Provenance analysis is the identification of geographical location of production place and/or location of the raw materials used for the production by using chemical and petrographic analyses techniques.[88–90] The potential results of such an analysis contribute to the understanding source of production, trade, and exchange in ancient societies.

Harbottle reported that Damour's pioneer research on stone axes is the first study on the area of archaeological provenance performed through the analysis of mineralogical and chemical composition of archaeological samples.[91, 92] In this study, it was reported that the mobility of people in the past could be followed using the data obtained from analytical techniques by analyzing rock samples found far from main the source of the samples. The first pottery provenance analysis goes back to 1879 with petrographic analysis of potteries found in Santorini island.[8] In the first half of the 20th century, together with the development of instrumental analytical techniques; emission spectrometry and neutron activation analysis were used for chemical analysis of archaeological metal objects.[93] Since the second half of the 20th century, the identification of the source of archaeological materials such as potteries has been one of the most attractive research questions in the field of archaeometry.[94–96]

Even though the early modern history of using analytical techniques to localize pottery goes back to the 1950s, the approach was conceptualized as *provenience postulate* by Weigand and his colleagues.[97] The term was described as;

"there exist differences in chemical composition between different natural sources that exceed, in some recognizable way, the differences observed within a given source".

These differences are differences in concentration of chemical elements and/or relationship between concentrations of multiple elements.

Provenance analysis can be described as “the observation of a systematic relationship between the chemical composition of an artifact and the chemical characteristics of one or more of the raw materials involved in its manufacture”.[98]

The approach of analysis depends on comparison of chemical and mineralogical compositions of pottery of interest with geographically known references.[99] Harbottle suggested some basic definitions in the frame of provenance analysis to avoid confusion about terms related to the pottery provenance. The source is the main starting point that is a clay bed and a natural deposit of raw materials; a production center is a pottery workshop (it is likely to be close to the source, but it also may not be); local pottery is near or associated with the production center; and import wares.[100] A production is manufacturing a certain type of pottery in a production center (workshop). In order to obtain desired final features, it can be assumed that the production process needs a certain degree of standardization of gathering raw materials and preparing clay paste.[71] Thus, it can be expected that potteries which were output of a certain production present similar geological and chemical features, since they were produced from similar clay materials gathered from near to or same deposits. This expression has been known as *chemical fingerprint* specific to every production.[101] A production can be represented through a compositional group which is provided by petrographic and chemical analysis of pottery. Consequently, potteries with unknown origin can be compared with these compositional groups and may be attested to a workshop.

Presence of pottery kiln and in a workshop context is some valuable evidence of local pottery production proof in a settlement. Beside kilns, there are other infrastructures such as spaces and rooms for wheel and drying green ware, pools, storage rooms for raw materials and fuel in a workshop context. Pottery kilns dated from Byzantine to Early Ottoman/Beylik periods were discovered in the settlements in Turkey such as Ahlat, İznik, Hasankeyf, Sagalassos, Sirkeci.[45, 69, 102–106] Some of the photographs from kiln contexts are given in Figure 1.11. However, in most cases, the local pottery production has been also attested by the presence of material evidence which were related to production processes such as kiln furniture and wasters, when structural remains of a kiln was not recovered by archaeological excavations.[107, 108] The chemical fingerprint of production has to be represented through analyzing samples of undoubtedly locally produced potteries known as *stricto sensu.*[71] Local reference pottery groups generally contain pottery wasters (such as overfired and unfinished pottery) fragments of moulds and kiln furniture (tripod stilts, an example given in Figure 1.12) beside the samples of *stricto sensu.*[65, 106, 109, 110] Suspected samples or local imitations of import pottery groups can be checked by comparing their results with that of local reference group.

Locating clay deposits which were available for pottery production is another aspect of pottery provenance analysis.[71, 99, 111–113] It was generally accepted that the distance between the location of the raw material source and workshop are not far away from each other.[7] According to Arnold's ethological investigation on pottery production, most of the clay sources are at the range of 1 km pheric distance[iv], and 84% of clay sources are located within 7 km range. For sources of temper, 79% of sources were located within 7 to 9 km around the workshop, for the slip, 57% of workshops transport slip from the sources at 30 km or less.[10]

[iv] Pheric distance is calculated based on energy cost.

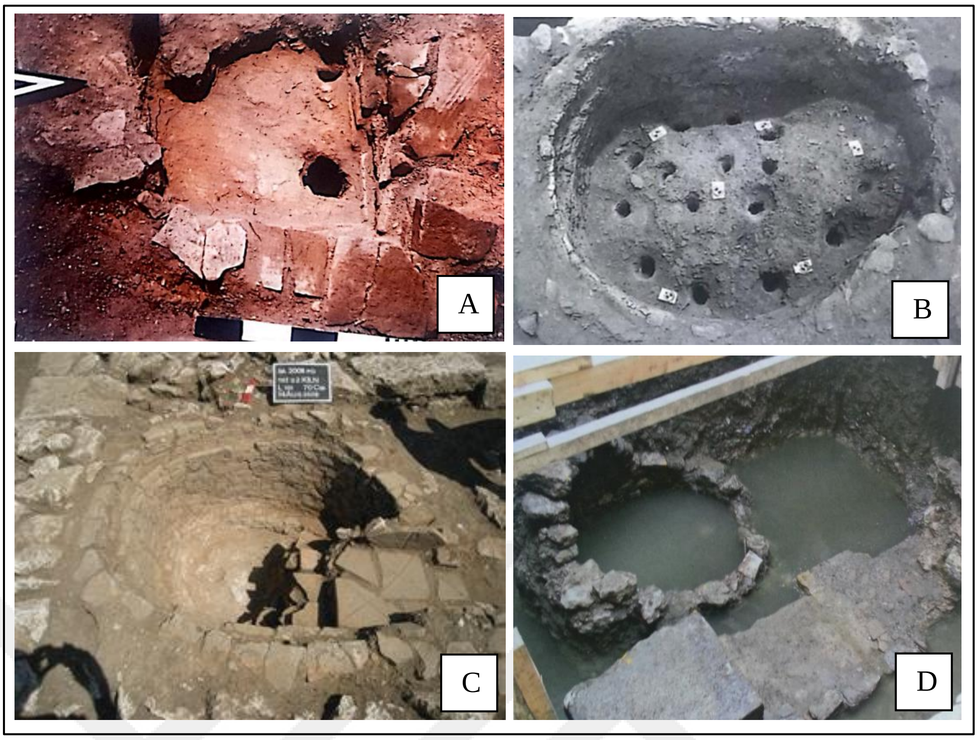


Figure 1.11. Pottery kilns were unearthed in: İznik[106] (A), Hasankeyf[69] (B), Sagalassos[114] (C) and Sirkeci – İstanbul[102] (D)

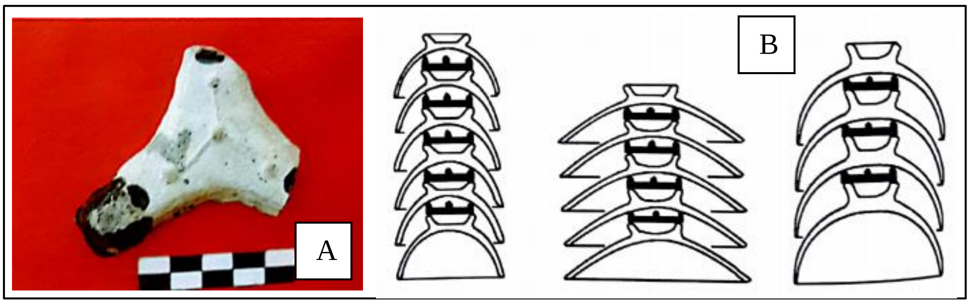


Figure 1.12. A tripod stilt from İznik[106] (A) and the use of tripod stilt[109] (B)

1.7. Chemical and Mineralogical Analyses

The aim of elemental compositional analysis of pottery is to identify compositional groups and distinguish them from different groups to obtain meaningful archaeological interpretations. Chemical analyses used to determine concentrations of elements in clay paste whereas petrographic analyses reveal mineralogical compositions, technological features of investigated pottery. Common approach to compositional analysis is using both chemical and petrographic analyses as complementary techniques.[7, 71, 115]

Chemical Analysis

There are various kinds of chemical analysis techniques used for the analysis of clay samples such as Atomic absorption spectrometry (AAS), inductively coupled plasma-optical emission spectrometry (ICP-OES), X-ray fluorescence spectrometry (XRF), instrumental neutron activation analysis (INAA) and inductively coupled plasma mass spectrometry (ICP-MS) Selection and use of these techniques depend on analytical figures of merit such as precision, accuracy, sensitivity, cost of the instrument, multielement capability, effect of interferences and ease of sample preparation.[90]

The variations in chemical compositions of elements in archaeological pottery are mostly related to clay source and differences in the fabrication process. Elements are usually grouped depending on their concentration in the clay paste. Concentration of Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti and P is in percentage scale (generally 2% or more) called major elements. On the other hand, there are elements in the concentration range of ppm (parts per million) to ppb (parts per billion) called as trace elements.[7] Trace elements are present in rocks less than 0.1% (or 100 ppm) and they may form mineral species but generally they are substituted with major elements in the rock forming minerals. From the geochemical perspective, in the periodic table, trace elements are classified as rare earth elements having atomic number from 57 to 71, noble metals (platinum group elements) having atomic number from 44 to 46 and 76 to 79, and transition metals having atomic numbers from 21 to 30 (except for Fe and Mn).[116]

Concentrations of major elements such as Si, Ca, Al and Fe provide limited information for source due to their high and varying concentrations in clay. Concentration of SiO_2 in 50-65% range is associated to the presence of high amount of detritic quartz, silicate minerals such as feldspar and mica and rock fragments in clay.[13] Calcareous clays contain CaO concentration higher than 5%.[117] Concentrations of Al_2O_3, K_2O and Na_2O are commonly associated with the presence of clay minerals and feldspars. Amount of Fe_2O_3 is controlled by poorly crystalline iron oxides and hydroxides in clay. MgO is usually associated with dolomite. The concentration of TiO_2 is related with the presence of rutile and leucoxene among the accessory heavy minerals.[13]

From the geochemical perspective, trace elements are grouped with respect to their distribution in solid phase or melt phase when earth's mantle is melted. Trace elements in solid phase are called *compatible elements* whereas the ones which tend to leave the solid matrix at the first available opportunity are called *incompatible elements*.[116]

An important factor that should be considered is the mobility of the elements during the process of rock weathering forming clay minerals. Geochemical mobility of elements controls the transport and the availability to take part in geochemical reactions. Generally, geochemical mobility of elements decreases from left to right in the periodic table. The elements of alkali metals (IA) and alkaline earth metals (IIA), especially Na, K, Ca and Ba are the most mobile elements and easily washed out from primary minerals and sorbed onto the secondary clay minerals. Elements of IIIA, IIIB, IVA and IVB groups are immobile during the formation of clay. The mobility of the transition elements depends on the oxidation state and on the conditions of weathering. Oxidation state of transition elements such as Fe, Ni, Co, and Zn changes their mobility when they are in combination with sulphide minerals.[118]

Ionic potential or field strength which is the ratio of electric charge to the radius of an ion (charge/size ratio) is a parameter used to determine the incompatible elements.[116] Rare earth element (Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Pm, Sm, Tb, Tm and Yb) and Sc, Y, Th, U, Pb, Zr, Hf, Ti, Nb and Ta classified as *high field strength elements* (HFSE) with an ionic potential higher than 2.0. Cs, Rb, K, Ba. Sr, divalent Eu and divalent Pb are the elements called as *large ion lithophile elements* (LILE) with an ionic potential smaller than 2.0.[116] The elements belonging to LILE group are classified as mobile, whereas the elements of HFSE group are classified as immobile.

Trace elements, the ones that are less mobile, are easily and quantitatively transferred to sediments during weathering and transportation processes of rocks.[116] Therefore, qualitative and quantitative analyses of clay and its products are important in provenance analysis.[7]

Kuleff and Djingova made extensive literature survey on provenance analysis of pottery to choose the types of elements to classify pottery groups.[118] They reported that 23 elements (Al, Ca, Ce, Co, Cr, Cs, Cu, Fe, Hf, La, Mg, Mn, Na, Ni, Rb, Sc, Si, Sm, Sr, Ti, Th, V, and Zr) can be used for provenance analyses of pottery. They emphasized the importance of mobility of elements during formation process and classified 23 elements according to geochemical mobility: Na, Rb, Cs, Mg, Ca and Sr are generally mobile; Ce, Th, Ti, Zr, Hf, Se, and La are generally immobile; V, Cr, Mn, Fe, Co, Ni, and Zn are immobile\mobile. It is pointed out that clays with basaltic origin have higher concentrations of Co, Cr, Mn, Ni, Se, Ti, than those with granitic origin of Al, Cs, Hf, La, rare earths, Rb and Th

Major and trace element concentrations are also used to define original parent rock composition of the clastic sediments when studying archaeological pottery.[119] In this study by Kibaroğlu and coworkers, K_2O

versus Rb plot was drawn in order to distinguish between felsic/intermediate and basic source rocks. Additionally, the ratios of Cr/Th, Co/Th, Ni/Co, Cr/V and concentrations of Cr and Ni point to a dominance of mafic-ultramafic rock associations.

Mineralogical and Petrographic Analysis

Archaeological pottery is a synthetic material bearing the evidence of technology involved in their manufacture. Petrographic and mineralogical analyses contribute to the understanding of production process of pottery. The aims of petrographic analysis are compositional analysis, pottery classification, interpretation of pottery provenance and reconstruction of production technology. It is usually employed as a complementary technique with chemical analysis for provenance studies.[120]

Petrographic analysis is based on examination of thin section samples under optical microscope. Thin section sample is a thin layer of the sample sticked on microscope slide. The thickness of sample should be around 30 µm so that light can pass through the minerals. The optical properties of minerals can be distinctive for the identification of minerals in pottery samples.

Petrographic analysis applies the techniques of optical mineralogy and thin section petrography to archaeological materials in order to identify the types of minerals and rock fragments, the shape and texture of grains and the characteristics of the matrix that surrounds the grains and pores in the pottery.[20]

Many different types of grain and particle inclusion such as mineral grains, rock fragments, shells, bones, microfossils, grog, slag, plant remains may present in pottery paste. Minerals and rock fragments are fragments of bedrock in residual clay formed in situ, or came with natural processes such as erosion, transportation and deposition into clay. Rock fragments are polymineralic inclusions composed of more than two minerals. The type of original fragment (sedimentary, metamorphic or igneous) can be informative about geological environment where clay had been formed.

The shape and texture of grains can be informative about the degree of erosion and production technology. Rounded particles may have eroded because they have come from longer distances during clay formation processes, whereas angular particles might be crushed and deliberately added to the clay paste.

Clay matrix is surrounded by fine-grained materials generally composed of clay minerals. The colour of clay matrix is controlled by concentration of organic compounds such as vegetal remains, inclusion; and calcium carbonates in clay and oxidation state of iron.

Voids provide important information about the production process, utilization and underground conditions during burial. Voids can come from clay, developed during decomposition process of calcium carbonate and after burning of organic temper or formed by dissolution of calcareous inclusions in burial.

1.8. An Overview of Pottery Provenance Analysis in Asia Minor (Turkey) and the Surrounding Region of Komana

In Turkey, the first attempt to determine the provenance of ancient pottery was carried out by Birgül and her colleagues.[121] Concentrations of Ba, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Rb, Sc, Ta, Th and U were determined with NAA of eighty pottery samples taken from Phrygian, Roman and Byzantine layers of different sites near to Ankara, and fifty eight clay samples were collected from St. Jean Vianney (Quebec) and Templeton (Ontario) in Canada (thirty samples) and clay beds are close to archaeological sites (twenty eight samples). Cluster and discriminant analysis were applied to group the pottery and clay samples. They reported that concentrations of Cs, Th, Sc, Hf, Ta, and Co are discriminative for clay and pottery samples. As a conclusion, Roman and Byzantine pottery from Yalincak and Phrygian pottery from Great Tumulus and Tumulus 2 were most probably produces using local clay beds. It was emphasized that a possible connection between pottery and clay can be established through the composition of trace elements such as Cs, Th, Sc, Hf, Ta, and Co rather than oxides of Si, Al or Fe found commonly in soil.

In another study by Birgül and her colleagues, four hundred clay samples collected from Çanakkale, Bilecik, Nevşehir, Hatay, Ankara in Turkey and Quebec in Canada and pottery samples collected from Antalya, Yalincak, Büyük Tümülüs, Alişar, Koçumbeli, Höyük, Beytepe, Karayavşan were analysed to determine the concentration of elements most useful in defining a clay bed.[122] The concentrations of As, Ca, Cr, Cu, Fe, K, Mn, Ni, Pb, Rb, Sr, Ti, V and Zn were determined with X-ray fluorescence spectrometry (XRF). However, concentration of the As, Ca, K, Pb, Rb, V and Zn were below detection limit and thus the results of only seven elements (Ti, Cr, Mn, Fe, Ni, Cu and Sr) were used for statistical analysis. Statistical analysis results showed that Phrygian pottery from Yalıncak and Büyük Tümülüs show a tendency to form a group with clays from the major clay bed of this region in Ankara.

North Mesopotamian Metallic Ware is a type of stoneware dated from the first half of the Early Bronze Age II until the beginning of Early Bronze Age IVA (ca. 2800-2300 BC).[119] It is characterized by a hard and dense fabric produced from fine clay fired at elevated temperatures around 1000 – 1100 °C. North Mesopotamian metallic ware was found in the settlements of the northern part of Syria and southeastern part of Turkey. It is assumed that a large group of North Mesopotamian metallic ware was produced from a special type of fine clay which contains low amount of calcium and free from large inclusions. The hypothesis is that a distribution of non-calcareous North Mesopotamian Metallic Ware from a single production location. Pottery and clay samples in this region were analysed in order to trace the origin of the clay source used for the production of the non-calcareous chemical group of North Mesopotamian Metallic Ware.[119] Totally 120 potteries were sampled from fifty two different sites and fifteen clay samples from Pötürge region. The approach was using major and trace element data in a similar way as it was applied in sediment geochemistry for provenance studies of sedimentary rocks. K_2O versus Rb binary plot was used to differentiate between source rocks according to felsic/intermediate and basic origins. The ratios of Cr/Th, Co/Th, Ni/Co, Cr/V and concentrations of Cr and Ni point to a dominance of mafic-ultramafic rock associations. The statistical analysis results showed that low level of calcerous metallic ware was associated with their being produced from clay sources of Pötürge in the northern border of North Mesopotamia.

The production and distribution of medieval Byzantine pottery in Asia Minor and Mediterrenian region has been studied especially in the last 20 years.[103] The presence of archaeological evidence comes from the wrecks of cargo ships carrying Byzantine pottery such as Pelagonnesos – Alonnesos, Kastellorizo and Novy Svet shipwrecks providing important information for the patterns of Byzantine pottery distribution.[123] The first chemical analysis on Byzantine pottery was aimed to characterize production centers through the chemical composition of pottery samples, and to correlate pottery classes with workshops to reconstruct the possible pottery movement.[124] Al, Ca, Mg, Fe, Ti, Na, Mn, Cr and Ni concentrations were determined in the samples of different types of glazed, unglazed pottery and coarsewares, wasters and tripod stilts dating from 7th to 15th century AD from Agora (Athens), Chinitsa, Constantinople, Corinth, Dhiorios (Cyprus), Didymoteichon, Halieis, Lapithos (Cyprus), Paphos (Cyprus), Pelagonnisos shipwreck, Thessaloniki. The new research questions for production and distribution of Byzantine pottery arose after this pioneering research on Byzantine pottery.

Zeuxippus ware is a fine glazed pottery named after being revealed in the excavation of the Zeuxippus Baths in İstanbul. It has been characterized with red, fine and dense fabric; high quality glaze; and also with decoration of interior concentric circles. It was widely distributed in the Byzantine

Empire until after 12th century AD.[125, 126] Zeuxippus ware, its imitations and derivatives were found in the settlements of Aegean coasts such as Adramyttion (Balıkesir), Anaia (Aydın), Gülpınar (Çanakkale), Pergamon (İzmir), Selçuk-Ayasuluk (İzmir), Miletos (Aydın); northern and southern coast of Mediterrenean Sea such as Alanya (Antalya), Yumuktepe (Mersin), Acre (Levant), Alexandria and Cairo (Egypt); Southern France in the western Mediterrenean; Chersonesos and Novy Svet shipwreck in the northern coast of Black Sea.[126–137] The theories of distribution from a single production center or different workshops were studied using chemical and mineralogical methods on the samples from different sites.[138] The pottery samples from Anaia were analysed to understand the production and distrubution of Zeuxippus type Byzantine pottery.[75] Similarly, the presence of large amount of Zeuxippus ware discovered in Chersonesos in Crimea triggered the question of local production of this pottery type. Local pottery group consists of amphora, brick, Zeuxippus and Aegean ware pottery. Samples were analysed with WD-XRF and the concentrations of MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, MnO, Fe_2O_3 oxides and V, Cr, Ni, Zn, Rb, Sr, Zr, Ba ve Ce elements were determined. According to the results, the local production of stricto sensu Zeuxippus ware was not related to Chersonsesos whereas the local imitations of Zeuxippusware might be produced.

Local pottery production of Byzantine pottery was related to Pergamon with archaeological evidence of wasters and tripod stilts.[139] PIXE and INAA analysis were performed for provenance analysis on glazed pottery probably produced in Pergamon.[136] Many elements (Al, Si, K, Ti, Fe, Ni, Ga, Rb, Sr, Y, Zr, Ba and Pb with PIXE and Na, Mg, Al, V, Mn, Sc, Cr, Fe, Co, Rb, Sb, Cs, Ba, La, Ce, Nd, Eu, Tb, Yb, Hf, Ta, Th and U with INAA) were determined in 158 samples of pottery, wasters and tripod stilts. According to the results, two or maybe three groups indicating local clay deposits were identified by cluster analysis. Also new questions arose from the possible imports from Ephesus and Sardis.

Archaeological evidence including tripod stilts and wasters indicates the existence of local pottery production in Artemision in Ephesus during the medieval period.[108] Petrographic analysis, heavy mineral and chemical analysis were performed on twenty four pottery samples.[140] In this study, they reported that pottery samples were classified under six groups five of which are representing the local clays. Concentrations of MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, MnO, Fe_2O_3 and V, Cr, Ni, Zn, Rb, Sr, Zr, Ba and Ce were determined in the samples using WD-XRF. The results of mineralogical and chemical analyses showed that there were three different clay sources used to produce local pottery in Ephesus.

The archaeological survey in Sagalassos revealed the presence of workshop complex containing remains of at least ten kilns, kiln furniture, an enormous amount of pottery wasters. This showed that Sagalassos was a major production center in this region.[104, 105] The long-term archaeometrical analysis of pottery of Sagalassos beginning with the initial provenance analyses were carried out to locate clay sources which were used to produce local pottery in Sagalassos.[111] Twenty seven clay samples were taken from three different locations including borehole samples (3-4 meter depth) and soil samples in the top layer (0.5 – 1.0 m depth) around Sagalassos and modern clay pits which are close to Çanaklı village eigth km far from Sagalassos. Concentrations of major oxides (SiO, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, P_2O_5 and TiO_2) in fine and coarse pottery samples and clay samples were determined by atomic emission spectrometry and minerals were detected with X-ray diffraction analysis. They reported that detrital clay from Çanaklı village and fine pottery samples are similar in oxide composition and might be used for fine pottery production in Sagalassos.

1.9. The Aim of the Study

The aim of this thesis is to contribute to the reconstruction of human activities in Komana during 12 – early 14th centuries by investigating the production process and localization of glazed pottery found in Komana.

Archaeological evidence such as biscuit fired pottery and tripod stilts and archeological studies on glazed pottery of Komana not only suggests local production of common glazed pottery but also of production of high quality glazed potteries. These high quality products were fired at high temperatures and have dense fabrics with remarkable surface decorations reflecting cultural interactions with the settlements in Anatolia, Iran, Eastern Mediterranean regions and even northern shores of Black Sea during 12 – early 14th centuries. Therefore, one of the aim of this thesis is identification of local compositional group/s of glazed pottery and their production technology.

Although locating clay deposits used in production process is a challenging part of the archaeometric studies on pottery, it is one of the most secure ways of defining local production. Accordingly, the second aim of this thesis is locating local clay sources used to produce glazed pottery in Komana.

The presence of import pottery from Eastern Mediterranean coast to Sassanian Iran and coins minted at different settlements showed that there has been trade connections between Komana and these settlements since Hellenistic period.[4, 80, 81] Therefore, the third aim of this thesis is to investigate the connection between local pottery and import ware in order to reconstruct the economic connections through pottery mobility.

CHAPTER 2

EXPERIMENTAL

2.1. Sampling

In this study, sample collection includes samples of glazed and unglazed pottery samples, local references consist of biscuit-fired pottery and tripod stilt, coarsewares and local clay deposits. The sampling strategy was based on representative pottery samples with local reference samples and clay samples.[124, 131, 136] Regarding to this sampling strategy, there are eighty glazed and unglazed pottery representing suspected samples, eighteen biscuit fired pottery representing stricto sensu (biscuit fired pottery), sixteen coarseware samples representing local clay, eleven tripod stilt samples representing local clay paste and thirty soil samples representing possible raw materials in this study as listed in Table 2.1.

The detailed visual analysis for all samples and sample photographs with drawings are given in Appendix A, B1 and B2. Dating and visual examination of pottery samples were carried out by Dr. Vorderstrasse.

Table 2.1. Classification and number of sample from each sample group

Sample Groups	Sub-groups	Number of Sample
Pottery samples	Glazed pottery	73
	Unglazed pottery	7
Biscuit fired pottery	-	18
Coarsewares	Cooking pots	14
	Storage jars	2
Tripod stilts	-	11
Soil samples	-	30

2.1.1. Glazed and Unglazed Pottery Samples

The pottery samples are the sherds of thin vessels, plates and jugs which were used mainly for serving functions (tableware/fineware). These samples were dated back to 12 – early 14th century centuries AD.

The paste colour of pottery samples are mostly reddish (orange, red or brown), but there are four samples (K165, K166, K223 and K225) having white – cream paste.

The pastes of pottery samples are commonly covered with white slip layer on both the exterior and the interior surfaces and four samples (K121, K133, K216 and K227) have micaceous slip on exterior surfaces.

Seventy three samples are covered with glaze at least on one surface. Glazed surfaces generally were decorated with sgraffiato and champlevé. The colours of glaze are generally yellow and green, but two samples (K223 and K225) have turquoise – blue glazed on interior surface.

Seven samples have no glaze on both surfaces. However, exterior surfaces of five samples (K120, K121, K126, K216 and K227) were decorated with moulding technique.

Two samples (K133 and K165) have no decoration on both surfaces. The samples were collected from twelve different sectors of HTP01 area are given in Table 2.2 and illustrated in Figure 1.7.

Table 2.2. The sampling location of glazed and unglazed potteries

Trench ID*	**Layer ID**	**Sample ID**
267/588	T2	K228
267/603	T6	K215, K216
267/608	T5, T8, T11, T13	K166, K210, K211, K212, K213, K225, K226, K227
272/593	T7	K164
277/603	T6, T7	K101, K102, K103, K104, K105, K106, K107, K108
277/623	T2, T4	K199, K200, K201, K203, K204
282/583	T5	K220, K221, K222, K223
282/603	T4	K167, K168, K169, K170, K171, K172, K173
282/623	T2	K184, K185
287/588	Surface	K165
287/598	T2	K109, K110, K111, K112, K113, K114, K115, , K117, K118, K119, K120, K121, K122
292/598	T2, T4, T7, T8	K123, K124, K125, K126, , K128, K133, K129, K130, K131, K132, K143, K144, K145, K146, K147, K148, K149, K150, K151, K152, K153, K154, K155, K156, K158, K159, K160, K161
*Trenchs are 5x5 square meter grids in an excavation sectors		

2.1.2. Biscuit-Fired Samples

Biscuit-fired samples are sherds of pottery which were discarded before glazing. There are 18 biscuit-fired potteries dated back to 12 – early 14th century.

The pastes of samples are reddish brown. The pastes were generally covered with white slip layer on both sides of pottery samples.

These samples were decorated mostly with sgraffiato technique with couple of undecorated exceptional samples. There is no trace of paint and glaze on all samples. These samples are probably broken during decoration.

Biscuit-fired samples were sample from four different sectors of HTP01 area as listed in Table 2.3.

Table 2.3. The sampling locations of biscuit-fired samples

Trench ID	Layer ID	Sample ID
267/603	T6	K217
277/623	T2, T4	K197, K198, K205, K207, K208
282/603	T4	K174
282/623	T1, T2, T3	K186, K187, K188, K189, K190, K191, K192, K193, K194, K195, K196

2.1.3. Coarsewares

Coarsewares are sherds of cooking pots and storage jars. These types of pottery were used for cooking foods, transportation and storing food and liquids. Coarsewares were produced from gritty clay providing sufficient thermal shock resistance to the pottery during its cooking function and aslo mechanical strength. Coarsewares were dated back to 10 – 13th centuries AD.

Paste of coarsewares are generally grey and brown. The exterior surfaces of the samples were mostly covered with reddish slip layer. Coarseware samples K134, K136, K137, K141, K209, K214 and K218 were decorated with incised and corrugation techniques on the exterior surfaces. There is no decoration on the rest of ten samples.

Coarsewares were sampled from four different sectors in HTP01 area as listed in Table 2.4.

Table 2.4. The sampling location of coarsewares

Trench ID	Layer ID	Sample ID
267/608	T5, T13	K209, K214, K224
277/623	T2, T4	K202, K206
282/583	T11	K218, K219
292/598	T7	K134, K135, K136, K137, K138, K139, K140, K141, K142

2.1.4. Tripod stilts

Tripod stilt is a kind of kiln furniture and they used to separate potteries in the kiln during firing.[110] There are totally eleven tripod stilts from four sectors of HTP01 area as listed in Table 2.5. They are unglazed ceramics with reddish-brown colour.

Table 2.5. The sampling location of tripod stilts

Trench ID	Layer ID	Sample ID
247/633	T3	K162
257/633	Surface	K163
277/623	T2	K181, K182, K183
282/623	T2, T3	K175, K176, K177, K178, K179, K180

2.1.5. Soil Samples

Thirty soil samples were collected from 7 km buffer zone from the center of Komana as shown in Figure 2.1. Geographical coordinates of the sampling locations are given in Table 2.6. Buffer zone was determined based on the Arnold’s study indicating the distance between clay source and workshop is mostly less than seven kilometer.[10] Soil samples were collected from the surface of Yeşilırmak alluvium, cross-sections at road cuts and specific locations pointed by local villagers in the buffer zone. Approximately 2 – 3 kg samples were collected into plastic sampling bags after removal of 10 cm top soil.

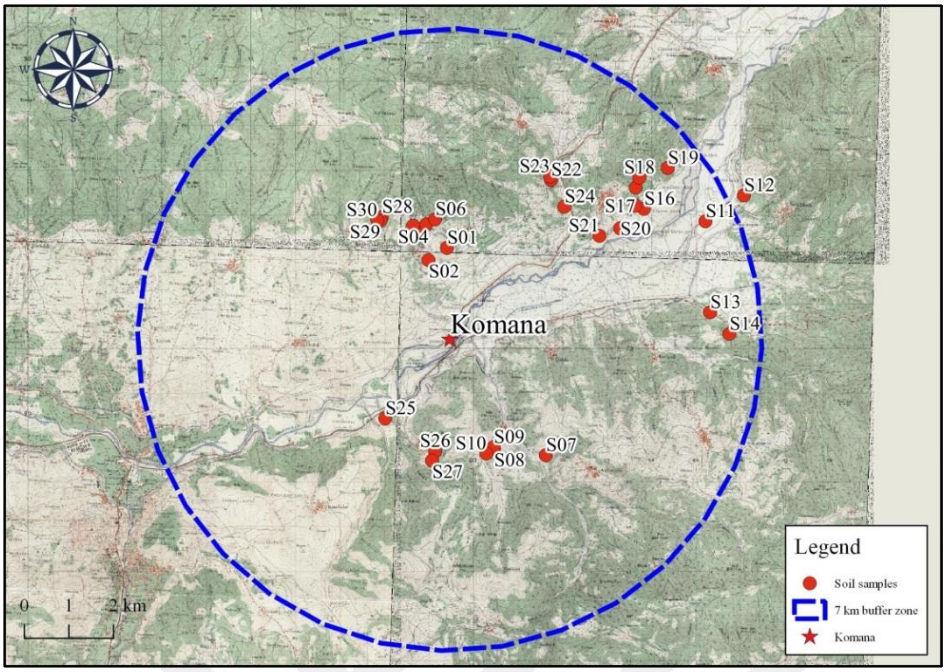


Figure 2.1. Sampling locations for soil samples

Table 2.6. The geographical coordinates of soil samples

Sample ID	**Geographical Coordinates, X, lattitude**	**Geographical Coordinates, Y, longitude**
S01	36.63719116	40.37610788
S02	36.63238155	40.37353226
S03	36.62979394	40.37947853
S04	36.62812436	40.38039913
S05	36.63154048	40.38073041
S06	36.63385776	40.38183181
S07	36.66475561	40.33474473
S08	36.65100744	40.33574535
S09	36.65092468	40.33609498
S10	36.64904054	40.33475952
S11	36.70531258	40.38284916
S12	36.71528305	40.38828035
S13	36.70717236	40.36448263
S14	36.71239258	40.36020813
S15	36.68668092	40.3892788
S16	36.68898155	40.38504602
S17	36.6867227	40.38564941
S18	36.6875655	40.3913143
S19	36.69497447	40.39342604
S20	36.68280697	40.38097689
S21	36.67740919	40.37934619
S22	36.66421184	40.39039427
S23	36.66397566	40.39109212
S24	36.66794182	40.3850648
S25	36.62206616	40.34131516
S26	36.63549665	40.33496073
S27	36.63473961	40.33304456
S28	36.61977573	40.38199305
S29	36.61941393	40.38122894
S30	36.61857408	40.38132874

2.1.6. Test Tiles

Thirty test tiles were prepared from soil samples in order to them to be used for thin section analysis. Firstly, the particle size of soil samples was reduced below 2 mm to remove the large plant remains and other types of impurities. Twenty grams sieved soil samples were mixed with 15 mL de-ionized water then poured into a plastic container in order to make them a permanent shape. Samples were left to dry for 7 – 10 days in laboratory until samples were completely dried. Dried samples were fired in muffle furnace with the program given in Figure 2.2.

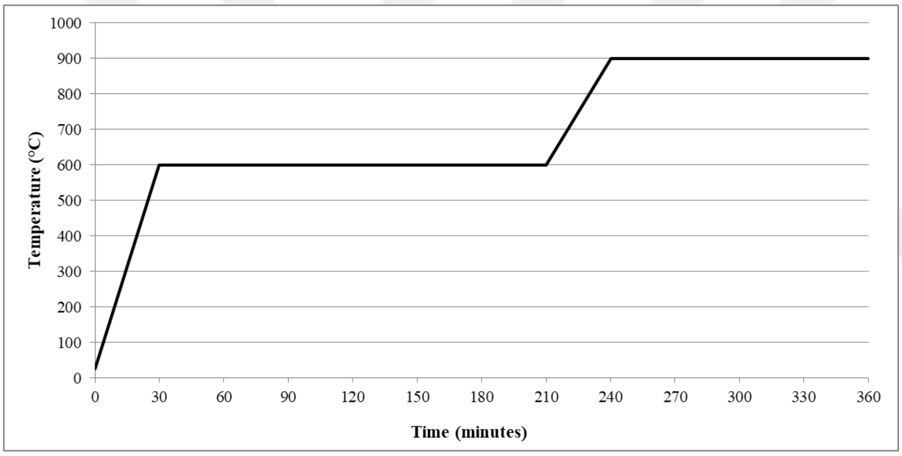


Figure 2.2. Firing program for test tiles

2.2. Chemicals and Reagents

Deionized water was 18.2 M Ω.cm taken from ELGA Purelab Option Q7 Water Purification System (High Wycombe, England). Standard solutions were prepared in 1.0 % (v/v) HNO_3.

All inorganic acids used for experiments were analytical grade. PTFE sub-boiled acid distillation system by Berghof (Eningen, Germany) was used to obtain high purity nitric acid. The list of chemicals are given in Table 2.7.

Table 2.7. Chemicals used throughout this study.

Chemical Name and Formula	**Producer**
Acetic acid (CH_3COOH)	Sigma Aldrich
Acetone (CH_3COCH_3)	Merck
Hydrochloric acid (HCl)	Merck
Hydrofluoric acid (HF)	Sigma Aldrich
Hydrogen peroxide (H_2O_2)	Merck
In standard, 1000 µg/mL	High-Purity Standards
Lithium metaborate ($LiBO_2$)	Merck
Lithium tetraborate ($Li_2B_4O_7$)	J.T. Baker
Methanol ($CH_{43}OH$)	Merck
Nitric acid (HNO_3)	Merck
Rh standard, 1000 µg/mL	High-Purity Standards
Sodium acetate ($CH_3COONa\cdot 3H_2O$)	Fisher
Sodium bicarbonate ($NaHCO_3$)	Carlo Erba
Sodium chloride ($NaCl$)	SCP
Sodium citrate ($C_6H_5Na_3O_7\cdot 2H_2O$)	Riedel-de Haen
Sodium dithionite ($Na_2S_2O_4$)	Merck
Sodium pyrophosphate ($Na_4P_2O_7\cdot 10H_2O$)	Merck

Quality Control Standard 27 (QCS-27, High-Purity Standards) and ICP Working Calibration Standard 4 (WS-4, High-Purity Standards) were used for the preparation of multielement standard solutions. Constituent elements and their concentrations in these standard solutions are listed in Table 2.8 and Table 2.9, respectively. Only zirconium standard solution was prepared from 1000 ppm Zr (Sigma Aldrich) solution.

Table 2.8. Certified values of Quality Control Standard 27 (QCS-27).

No	Element	µg/mL	No	Element	µg/mL
1	Al	100.0	15	Mn	100.0
2	Sb	100.0	16	Mo	100.0
3	As	100.0	17	Ni	100.0
4	Ba	100.0	18	K	100.0
5	Be	100.0	19	Se	100.0
6	B	100.0	20	Si	100.0
7	Cd	100.0	21	Ag	100.0
8	Ca	100.0	22	Na	100.0
9	Cr	100.0	23	Sr	100.0
10	Co	100.0	24	Tl	100.0
11	Cu	100.0	25	Ti	100.0
12	Fe	100.0	26	V	100.0
13	Pb	100.0	27	Zn	100.0
14	Mg	100.0			

Table 2.9. Certified values of ICP Working Calibration Standard 4 (WS-4).

No	Element	µg/mL	No	Element	µg/mL
1	Ce	10.0	10	Pr	10.0
2	Dy	10.0	11	Sm	10.0
3	Er	10.0	12	Sc	10.0
4	Eu	10.0	13	Tb	10.0
5	Gd	10.0	14	Th	10.0
6	Ho	10.0	15	Tm	10.0
7	La	10.0	16	U	10.0
8	Lu	10.0	17	Yb	10.0
9	Nd	10.0	18	Y	10.0

Standard solutions from QCS-27 were used to prepare 1.0, 2.0, 4.0, 5.0, 8.0, 10.0, 25.0, 50.0, 75.0 and 100.0 pbb multielement standard solutions. WS-4 and Zr stock solutions were used prepare 0.1, 0.5, 1.0, 2.0, 5.0, 10.0, 25.0, 50.0, 75.0, and 100.0 ppb multielement standard solutions.

NIST Standard Reference Material 2710a Montana I Soil was used to validate analytical methods and digestion methods used for the analysis of the samples.

2.3. Instrumentation

2.3.1. Inductively Coupled Plasma – Mass Spectrometry (ICP-MS)

Thermo Scientific X series ICP-MS instrument with a concentric nebulizer and Peltier effect cooled spray chamber was used for multiple element determination of Na, Mg, Ti, V, Cr, Mn, Co, N, Cu, Zn, Sr, Y, Zr, Ag, Cd, Sb, Ba, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, Bi, Th and U elements in the samples.

Tune A solution containing 10 µg/L of Li, Co, In, Pb, Bi and U elements in 0.5 mol/L nitric acid solution was used for the optimization of ICP-MS instrumental parameters as given in Table 2.10.

Continuous flow mode with 100 ms dwell time was used. Total acquisition time was 35 seconds. All the samples and the standards were measured three times.

Table 2.10. Operating parametres of ICP-MS

Parameter	Optimum value
Extraction lens voltage, V	-158
Lens 1, V	-7.6
Focus, V	10.9
D1, V	-47.6
Pole bias, V	-7.2
Hexapole bias, V	0.3
Nebuliser pressure, psi	1.1
Sampling depth, mm	140
Lens 2, V	-80
Lens 3, V	-168.9
Forward power, W	1400
D2, V	-160
Diffraction aperture, V	-29.8
Coolant gas flow, L/min	13
Auxiliary gas flow, L/min	0.8

2.3.2. X-ray Diffractometer

All samples were analysed with Rigaku Miniflex X-ray diffractometer at Department of Chemistry, Middle East Technical University.

Totally 128 powder samples were sampled with Proxxon© electrical drill using diamond tips from the inner part of pottery samples. Totatly 3 g powdered were obtained from each sample. These powder samples were used in XRD, thin section and ICP-MS analyses. Soil samples were grinded with agate mortar. Random and un-oriented powdered samples were analysed under CuKα radiation (λ=0.1542 nm) with scan speed of 2 degree/min in the range of 3-70° [2Θ].

For identification of clay minerals, totally 120 oriented samples were measured with a scan speed of 4 degree/min in the range of 3-35° [2Θ]. Oriented clay samples were prepared by following method explained in Section 2.4.2.

The Joint Committee for Powder Diffraction Standard (JCPDS) dataset and the data from literature were used for the identification of the crystalline phases in the samples.

2.3.3. Thin Section Analysis

Thin section samples were prepared in Thin Section Preparation Laboratory in Geological Engineering Department, Middle East Technical University. 128 pottery samples and 30 test tiles were used for thin section analysis.

Thin sections were examined using Leica optical microscope at Environmental Archaeology Unit, Settlement Archaeology Department, Middle East Technical University.

2.4. Procedures

2.4.1. Borate Fusion

Powder samples ca. 0.1 g were mixed with 0.4 g lithium metaborate and 0.1 g lithium tetraborate. This mixture was homogenized by grinding with agate mortar. The flux mixture was placed in platinum crucible and heated to 1050 °C for 1 hour in muffle furnace. The fused glass was cooled and transferred into a PTFE beaker. 3.0 mL of concentrated HNO_3 and 22.0 mL deionized water were added to dissolve the fused glass and then, the mixture was stirred until complete dissolution was achieved. The resultant solution was filtered using syringe type filter with 45 µm pore size PTFE membrane filter. The filtered solution was diluted to 50.0 mL with HNO_3 of 1% (w/v) final concentration.

Two parallel samples of SRM (NIST Standard Reference Material 2710a Montana I Soil) and one replicate from pottery and soil samples were digested with borate fusion. Calculated %RSD values lower than 5% indicated low variability in concentration between parallel samples. Therefore one replicate samples were used to increase the sample size. All the samples without dilution and 1000, 100 and 10 times dilutions of final solutions were measured with ICP-MS.

2.4.2. Separation of Clay Minerals in Soil Samples

Soil is a complex matrix and including various types of natural inclusions other than clay minerals. XRD diffraction patterns of these inclusions mostly overlap and suppress the characteristic peaks of clay minerals. Therefore, carbonates, organic constituents and Fe_2O_3 content were removed by following procedure.[141]

About 10.0 g of soil sample with particle size smaller than 2 mm was analysed throughout this part of experiments. In order to remove carbonates, the sample was put in a beaker and then, 100 mL sodium acetate buffer solution with pH 5.0 was added to the sample. This suspension was boiled for 30 minutes with stirring. The solid part was separated by centrifugation at 4000 rpm.

The organic content was removed by following procedure. The sample was put into 600 mL beaker and then, 5.0 mL of 30% (v/v) H_2O_2 solution was added to the sample. The suspension was stirred with a glass rod for 10 minutes. The mixture was watched for effervesce and existence of black colour. Extra 5.0 mL H_2O_2 solution was added until the disappearance of black colour. Afterwards, 10.0 mL excess H_2O_2 solution was added and then, allowed to sit for 3 h. When dark colour due to the organic matter was mostly disappeared, soil was washed three times with pH 5 buffer solution and twice with methanol, 99% to wash the residues on the surface of the solid by centrifugation at 4000 rpm.

The iron oxide was extracted from the sample by using CBD (Citrate Bicarbonate-Dithionite) method.[142] The soil sample was mixed with 40.0 mL of 0.3 M sodium citrate ($C_6H_5Na_3O_7{\cdot}2H_2O$) and 5.0 mL of 1.0 M sodium bicarbonate ($NaHCO_3$) solutions in 250 mL beaker. The mixture was placed on hot plate and stirred for 15 minutes at 75-80 °C. 1.0 g sodium dithionite ($Na_2S_2O_4$) was added to the mixture and stirred for 5 minutes and then, 1.0 g sodium dithionite was added twice. The temperature of the mixture was kept below 80 °C to prevent the formation of FeS. At the end of 15 min digestion period, 10.0 mL of saturated NaCl solution and 10.0 mL of acetone were added to the mixture to promote flocculation. The mixture was than stirred at about 60 °C and then, it was centrifuged for 5 min at 2000 rpm to separate the solid part from the liquid part.

The soil having 2 µm size was separated from the rest using the following sedimentation procedure.[141] The sample was put in 600 mL beaker filled with deionized water. About 0.5 g sodium pyrophosphate ($Na_4P_2O_7{\cdot}10H_2O$) was added to improve particle dispersion. After 4 hours, the particles which were suspended 5 cm from the surface are clay size particles having 2 µm diameters at most. Suspension contains clay sized particles were collected with volumetric pipette. 25 mL portion of the collected sample was centrifuged at 2000 rpm. The precipitate was used for the preparation of oriented clay samples.

2.4.3. Preparation of Oriented Clay Samples

Clay minerals have similar dimensions in x and y directions but they differ in z direction giving information about multilayer structure. Oriented aggregates enhanced the the basal d(00l) reflections which providing the atomic pattern along z direction changes mineral to mineral.[14] Thus, identification of clay minerals are mostly carried out with the oriented samples. The preparation of four oriented clay samples using the following procedure is given in Table 2.11.[14] This procedure mainly aims to separate clay minerals from the bulk and to prepare oriented samples on a glass slide.

Table 2.11. Treatment of oriented clay samples

Oriented Sample	**Treatment**
1. Air dried sample	Clay size material* was placed on microscope slide and allowed to dry at room temperature
2. Treatment at 375 °C	Clay size material was placed on microscope slide and allowed to dry at room temperature and then heated at 375 °C for 30 minutes.
3. Treatment at 550 °C	Clay size material was placed on microscope slide and allowed to dry at room temperature and then, heated at 550 °C for 60 minutes.
4. Ethylene glycol	Clay size material was placed on microscope slide and allowed to dry at room temperature and placed in a desiccator jar including a petri dish with ethylene glycol and waited for overnight.
* Clay size material consist of particles having size smaller than 2 µm diameter	

2.4.4. Internal and External Calibration

Same concentration of rhodium and indium were put into blank, standard and sample solutions as internal standards (10 µg/mL, each) to follow instrumental drift during each ICP–MS run. The accuracy of the experimental procedure used to dissolve the samples with borate fusion was validated using NIST Standard Reference Material 2710a Montana I Soil (Table 2.12). This SRM was chosen due to the similarity of the matrix components in the samples analysed in this study and the SRM.

External calibration method was used to determine concentration of the elements.

LOD (limit of detection) and LOQ (limit of quantification) of the technique calculated with 3s/m and 10 s/m equations were given in Appendix C.

Table 2.12. Elemental composition of NIST Standard Reference Material 2710a Montana I Soil

Element	Mass Fraction	Certified Value
Na	%w/w	0.894 ± 0.019
Mg	%w/w	0.734 ± 0.038
Al	%w/w	5.95 ± 0.05
Si	%w/w	31.1 ± 0.4
P	%w/w	0.105 ± 0.004
K	%w/w	2.17 ± 0.13
Ca	%w/w	0.964 ± 0.045
Sc[a]	mg/kg	9.9 ± 0.1
Ti	%w/w	0.311± 0.007
V	mg/kg	82 ± 9
Cr[a]	mg/kg	23 ± 6
Fe	%w/w	4.32 ± 0.08
Mn	%w/w	0.214 ± 0.006
Co	mg/kg	5.99 ± 0.14
Ni[a]	mg/kg	8 ± 1
Cu	%w/w	0.342 ± 0.005
Zn	%w/w	0.418 ± 0.015
As	%w/w	0.154 ± 0.010
Se[b]	mg/kg	1
Sr	mg/kg	255 ± 7
Zr[b]	mg/kg	200
Ag[b]	mg/kg	40
Cd	mg/kg	12.3 ± 0.3
Sb	mg/kg	52.5 ± 1.5
Ba	mg/kg	792 ± 36
La	mg/kg	30.6 ± 1.2
Ce[b]	mg/kg	60.00
Nd[a]	mg/kg	22 ± 1
Sm[a]	mg/kg	4.0 ± 0.2
Eu[a]	mg/kg	0.82 ± 0.01
Gd[a]	mg/kg	3.0 ± 0.1
Tb[b]	mg/kg	0.5
Dy	mg/kg	3
Yb[b]	mg/kg	2
Lu[a]	mg/kg	0.31 ± 0.01
Pb	%w/w	0.552 ± 0.003
Th[a]	mg/kg	18.1 ± 0.3
U	mg/kg	9.11 ± 0.30

[a] Reference values
[b] Information values

2.5. Statistical Treatments

2.5.1. Data Exploration

The central tendency, variation and dispersion of element concentrations were evaluated through mean, median, standard deviation, minimum and maximum values and coefficient of variation. The definitions and formulations used to calculate of these measures are given in Table 2.13.[143] Microsoft Excel© 2010 was used to calculate statistical measures.

Table 2.13. Statistical measures used to explore concentration distributions.

Measure	**Definition**	**Formula**
Mean, $\overline{X}$	Mean is the sum of the values divided by total number of values.	$\overline{X} = \frac{\sum Xi}{N}$
Median, MD	Median is the midpoint of the data array.	-
Standard Deviation, *s*	Sample standard deviation is square root of variance.	$s = \sqrt{\frac{\sum(X - \overline{X})^2}{N}}$
Coefficient of Variation, C_{Var}	Coefficent of variation is the standard deviation divided by mean. The result is expressed as a percentage.	$Cvar = \frac{s}{\overline{X}}\ 100\%$
Minimum	Minimum value is the smallest value in the data set	-
Maximum	Maximum value is the largest value in the data set	-

2.5.2. Independent two sample t-test and Mann-Whitney u-test

Independent two sample t-Test and *Mann-Whitney u-test* were applied in order to test compositional similarity between two local reference sample groups, biscuit-fired pottery and tripod stilt samples.

Independent two sample t-test is an inferential parametric test used to determine whether there is a statistically significant difference between the means of the two unrelated groups. The following hypotheses were tested.

> H_0 (Null): element concentration in biscuit-fired and tripod stilt are equal
>
> H_1 (Alternative): element concentration in biscuit-fired and tripod stilt are not equal

Independent two sample t-test is a parametric test which requires the dependent variable should be normally distributed within biscuit-fired and tripod stilt sample groups. *Shapiro-Wilk test* was used to determine the concentration of elements having normal distribution.

Mann-Whitney u-test was used to test the equality of distributions of element concentrations which are not normally distributed. It is generally accepted as non-parametric version of independent two sample t-test. Null and alternative hypotheses of Mann-Whitney u-test were set as follows:

> H_0: distributions of element concentration in biscuit-fired and tripod stilt are equal
>
> H_1: distributions of element concentration in biscuit-fired and tripod stilt are not equal

IBM SPSS$^{©}$ version 20 was used to perform independent two sample t-test, Mann-Whitney u-test and Shapiro-Wilk test.

2.5.3. Pearson Correlation Analysis

Correlation between the concentration of elements were examined with Pearson correlation index. The calculations were performed with IBM SPSS$^{©}$ version 20.

2.5.4. Multivariate Analyses

Cluster and principal component analysis (PCA) methods were applied to group the samples and recognize the patterns in concentration data. IBM SPSS© version 20 was used to conduct cluster and principal component analyses.

Cluster analysis is a generic term for a range of methods aimed at identifying groups within a set of data.[144] In archaeometric studies, it has been frequently used to group samples on the basis of their chemical compositions. Hierarchical cluster analysis defines the groups consisting of similar cases and connects them hieracharchically to make single group.

In this study, “squared Euclidean distance” was used to measure similarity distance and “Ward's method” were used as clustering method. Squared Euclidean distance is calculated using Equation 2.1. where i and j terms are two observations, p is a number of variables obtained for each observation and d is squared Euclidean distance coefficient.[145]

$$d_{ij} = \sum_{k=1}^{p} (x_{ij} - x_{jk})^2 \qquad \text{Equation 2.1}$$

Ward’s method or Ward’s minimum variance method is hierarchical clustering method and was proposed by Joe H. Ward, Jr. [146] The method aims to form clusters successively in such a way that at each step in the fusion process the error sum of squares is the minimum possible. The formula of error sum of squares (ESS) given in Equation 2.2 was used to measure in-group variation. The clusters produced by Ward’s method were defined as homogenous containing very similar cases by some researchers.[145]

$$ESS = \sum_{i=1}^{n} x_i^2 - 1/n(\sum_{i=1}^{n} x_i)^2$$ Equation 2.2

In order to avoid the effect of missing values on clustering, variables with many missing values were removed from the input data. Removing criterion is having missing value more than 5% of samples.[147] Therefore, concentrations of Cr, Fe, Co, Ni, Cu, Zn, Y and Tb in eight samples which were below LOD, were excluded from the dataset used in the cluster analysis.

The similarity measure, squared Euclidean distance, is a scale dependent measure. In the literature, different transformation and standardization methods have been used to remove scale dependency.[148–154] The concentration values were transformed by log, log-ratio and ranking methods and z-score standardization in order to reveal the effects of transformation methods on clusters. Logarithmic and log-ratio transformations and z-score were carried out by formulas given in Equation 2.3, Equation 2.4 and Equation 2.5, respectively. Ranks of each concentration value have been calculated by using *RANK.EQ function* in Microsoft Excel©.

$$y_{ij} = \log(x_{ij})$$ where x_{ij} is the concentration value Equation 2.3

$$y_i = \log(\frac{x_i}{X_D})$$ where x_i is the concentration value and X_D is selected denominator Equation 2.4

$$Z = \frac{x - \overline{X}}{s}$$ where x is the concentration value, $\overline{X}$ is mean and *s* is standard deviation Equation 2.5

Principal Component Analysis (PCA) is a multivariate analysis technique commonly used to develop models to describe experimental data. PCA creates new and fewer variables from the old variables. These new variables have a linear correlation with the old variables and helps to interpret the compositional data to provide the archaeologically meaningful results.[144, 145]

As hierarchical cluster analysis, PCA is also a scale dependent analysis. In order to remove scale dependency and comparable results, the same data (log transformed) used in cluster analysis was also used in PCA analysis.

CHAPTER 3

RESULT AND DISCUSSION

In this chapter, analytical results will be discussed in two parts. In first part petrographic and mineralogical analysis of archaeological and soil samples will be discussed. In the second part, elemental analysis results will be given with statistical interpretation.

Mineralogical compositions and textural properties of the archaeological samples (glazed and unglazed pottery, coarsewares, biscuit-fired samples and tripod stilts), soil samples and test tiles were revealed by thin section and XRD (X-ray diffraction) analyses as listed in Table 3.1. Clay minerals were identified in soil samples by following a specific sample preparation procedure named as oriented samples before XRD analysis. The samples were grouped depending on their petrographic and mineralogical characteristics.

Table 3.1. Summary of mineralogical analysis

Sample type		**Thin section analysis**	**XRD analysis (powder samples)**	**XRD analysis (oriented samples)**
Archaeological samples				
	Glazed and Unglazed pottery	+	+	
	Coarsewares	+	+	
	Biscuit-fired samples	+	+	
	Tripod stilts	+	+	
Soil samples				
	Bulk powder samples (2 mm)		+	
	Test tiles	+		
	Clay fractions			+

Concentrations of 33 elements including major elements (Na, Mg, Al, K, Ti, Mn and Fe), minor elements (V, Cr, Co, Ni, Cu, Zn, Sr, Ba and Pb) and trace elements (Y, Zr, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th and U) in archaeological and soil samples were determined by ICP-MS. The results were investigated with descriptive statistics and evaluated with geochemical approach and cluster analysis. At the final part, petrographic-mineralogical and elemental analysis results were evaluated to reveal local and imported pottery.

3.1. Petrographic and Mineralogical Analysis

Thin section analysis was performed on 125 pottery samples and 30 test bricks prepared from soil samples, in order to reveal mineralogical composition; shape, size and sorting of grains; matrix texture and porosity characteristics.

Crystalline phases in archaeological samples, soil samples and oriented clay sized fractions of soil samples were followed with XRD analysis. The characteristic d-spacing values used for phase identification are given in Table 3.2.[155]

Table 3.2. Characteristic diffraction lines (d-lines) used for phase identification

Mineral Name	**Characteristic d-line(s) (Å)**
Quartz	4.25; 3.34; 1.81
Calcite	3.03
Plagioclases	6.39; 3.68; 3.19
Mica/illite	9.90; 3.32; 1.99
Hematite	2.70; 2.51
Dolomite	2.88
Pyroxene group minerals	2.98-2.99
Hornblende/Amphibole Group	8.42; 3.12

3.1.1. Rock Fragments and Mineral Grains

Fragments of sedimentary (limestone and dolomite) and metamorphic rocks (polyrcrystalline quartz and feldspars and schist/phyllite) and mineral grains (feldspar minerals/plagioclase, mica, quartz and hornblende) were identified in the pottery samples, coarsewares, biscuit-fired, tripod stilt and test tiles with optical examination. Rock fragments and minerals, properties of matrix and pores identified with petrographic analysis is given in Appendix D.

Limestone is a sedimentary rock composed of mainly calcite mineral (calcium carbonate, $CaCO_3$). Limestone fragments were identified in eight coarsewares, thirty three glazed and unglazed pottery samples, seven biscuit-fired and seven tripod stilt samples. Coarseware samples contain large limestone fragments composed of sub-angular and sub-rounded polycrystalline sparry calcite as their examples shown in Figure 3.1A and 3.1B. However, limestone fragments in other samples are small sized sub-rounded spherical primary calcites distributed in the clay matrix (e.g. Figure 3.1C, 3.1D, 3.1E and 3.1F).

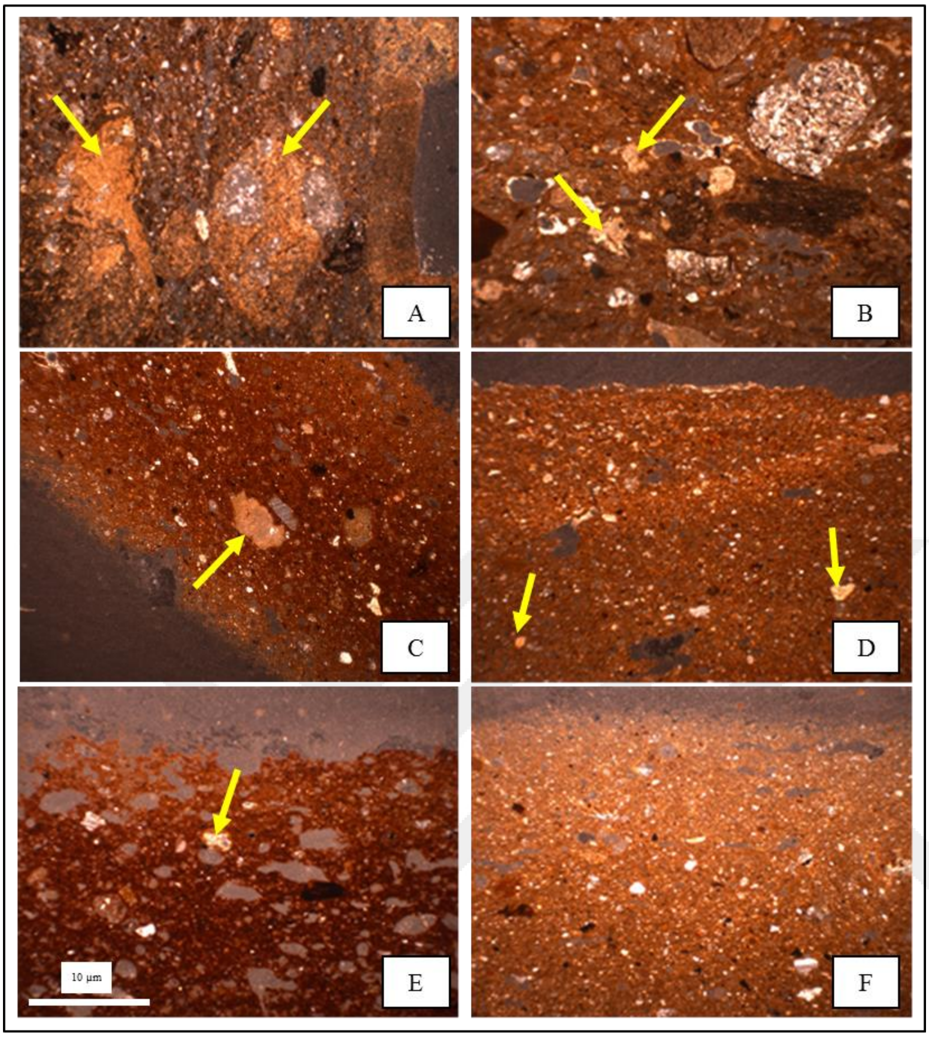


Figure 3.1. Limestone fragments observed in coarsewares K209 (A) and K218 (B); glazed and unglazed pottery samples K204 (C) and K227 (D); biscuit-fired sample K174 (F) and tripod stilt K162 (E). Scale is valid for A to F.

Calcite mineral which is the main constituent of limestone was identified in eight coarsewares, eighteen glazed and unglazed pottery and one biscuit-fired sample with its characteristic diffraction line at 3.03 Å around 29° with XRD analysis. Calcite and other crystalline phases identified with XRD analysis is given in Appendix E. 3.03 Å line which belong to calcite mineral are more visible and sharper in diffraction spectra of coarsewares compared to other samples, possibly the result of relatively low firing temperature of coarsewares. Calcite peaks disappear due the decomposition at high temperature. [156] One example is given in Figure 3.2 to show better signal to noise ratio corresponding to calcite mineral peak at 3.03 Å (29°) of coarsewares compared to that of other samples.

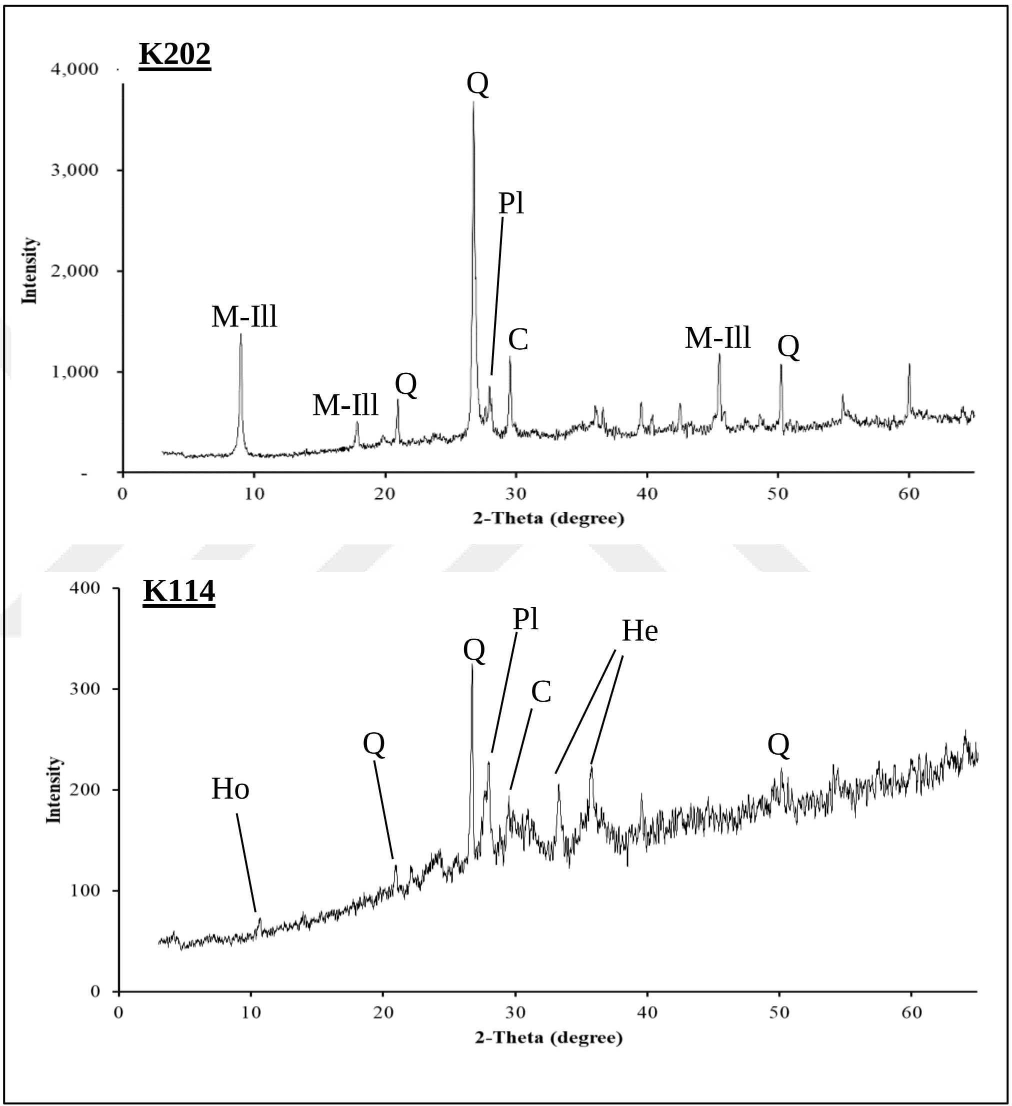


Figure 3.2. XRD spectra of samples K202 (coarseware) and K114 (glazed pottery). (M-Ill: Mica-Illite; Q: Quartz; Pl: Plagioclase; C: Calcite; He: Hematite; Ho:Hornblende)

The presence or absence of calcite has generally been used in estimation of firing temperature of archaeological pottery, because calcite minerals decompose between 600 °C and 800 °C.[157] Decomposition of calcite produces free-lime which may react with silicates from clay decomposition and then, calcium alumina-silicates are formed such as gehlenite, anorthite, diopside and wollastonite.[156, 158–160] Calcite decomposition and formation of these new phases occur at the periphery of calcite grains called as reaction rims.[157] These reaction rims were observed in two samples (K162 and K164) during thin section examination as shown in Figure 3.3.

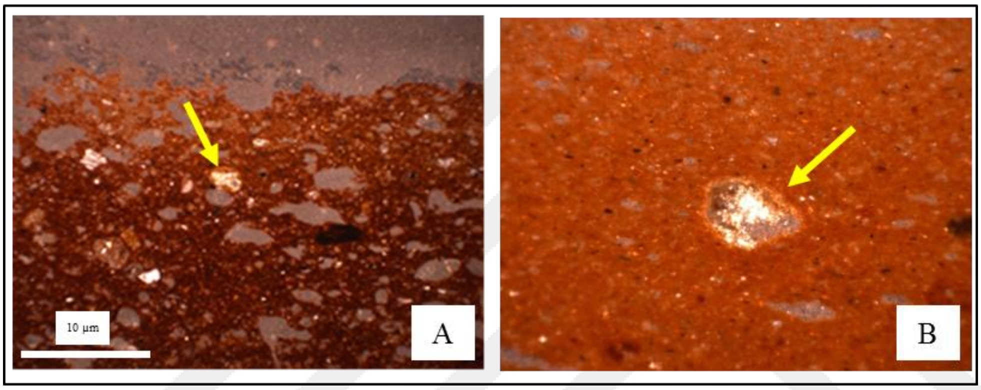


Figure 3.3. Reaction boundaries (rims) around calcite grains in glazed pottery samples, K162 (A) and K164 (B). Scale is valid for both A and B.

Dolomite is calcium magnesium carbonate ($CaMg(CaO_3)_2$) mineral. Dolomite was detected only with XRD analysis in one coarseware and one tripod stilt sample with the presence of diffraction line at 2.88 Å around 31° (2θ). As an example, XRD spectrum of sample K134 is given in Figure 3.4.

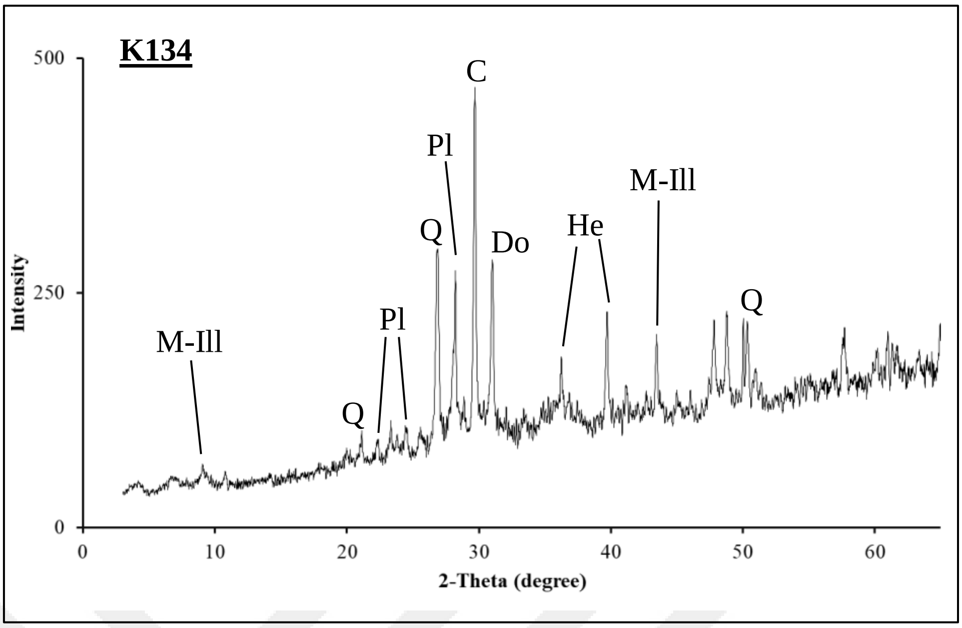


Figure 3.4. XRD spectrum of sample K134 (coarseware). (M-Ill: Mica-Illite; Q: Quartz; Pl: Plagioclase; C: Calcite; Do: Dolomite; He: Hematite; Ho: Hornblende)

Feldspar group minerals are one of the major rock forming minerals which are present 41% in the earth crust.[7] Polycrystalline metamorphic rock fragments composed of quartz and feldspar minerals were observed in thin sections of fourteen coarsewares, twenty six glazed and unglazed potteries, five biscuit-fired samples, five tripod stilt and twenty six test tile samples during microscopic examination. Feldspar group minerals were identified in almost all samples with their characteristic two d-lines at 3.18-3.20 Å (27.8 – 28°) and at 4.03 Å (22°).[155] XRD spectrum of one representative sample was given in Figure 3.5. While coarseware samples have large metamorphic rock fragments, other samples have small fragments. Optical images of representative examples to these fragments are given in Figure 3.6.

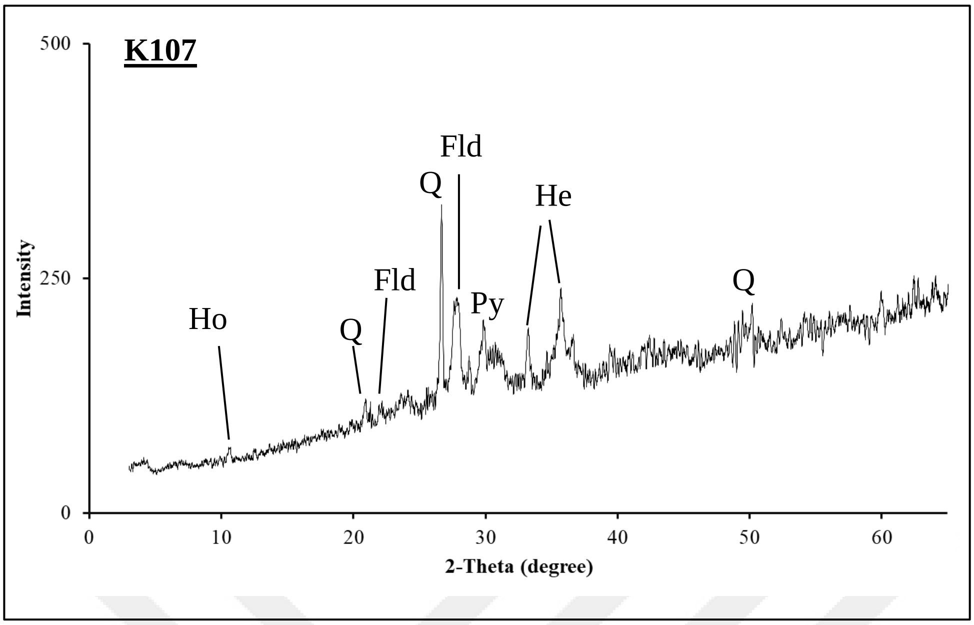


Figure 3.5. XRD spectrum of sample K107 (glazed pottery). (Ho: Hornblende; Q: Quartz; Fld: Feldspars; Py: Pyroxene; He: Hematite)

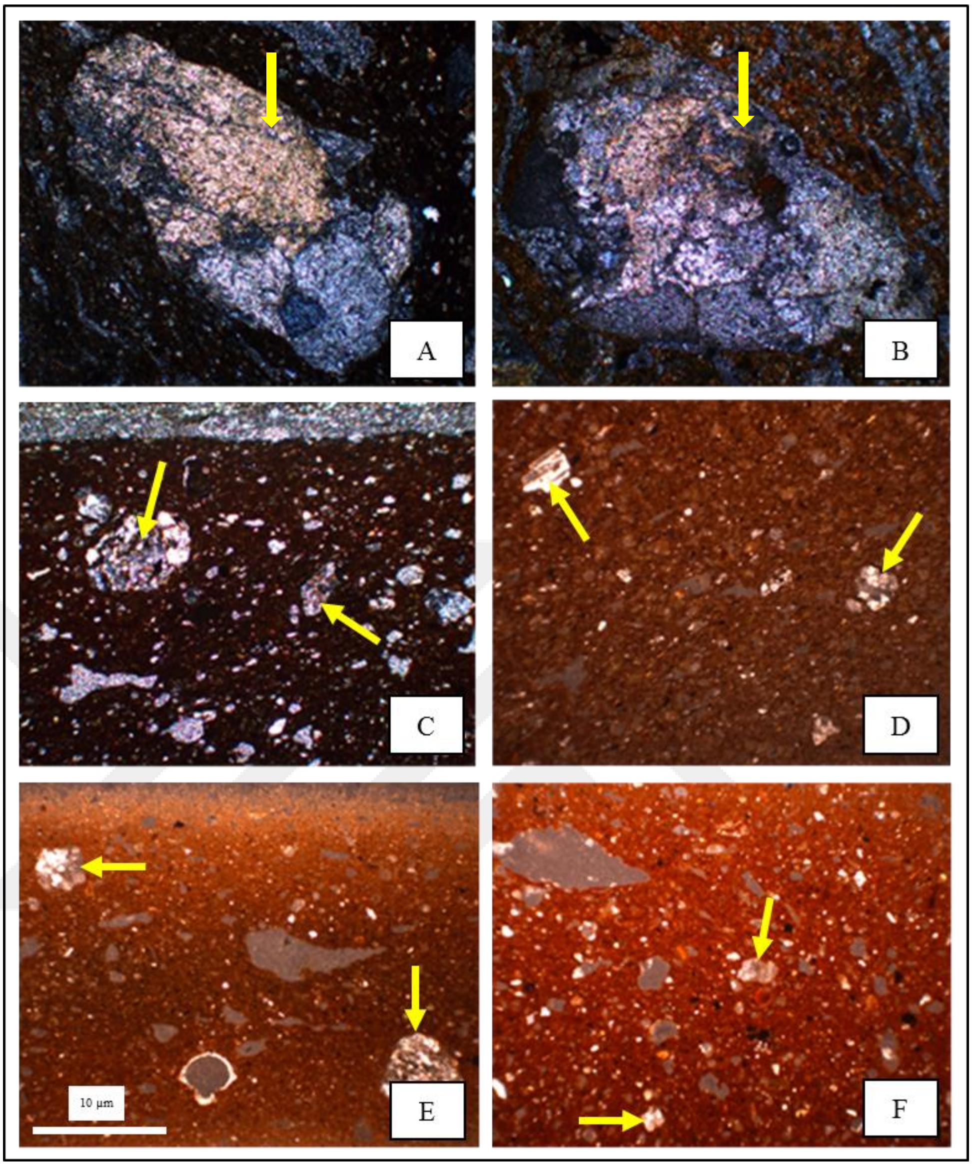


Figure 3.6. Metamorphic rock fragments in coarseware samples K135 (A) and K142 (B); glazed pottery samples K154 (C) and K168 (D); biscuit-fired sample K196 (E) and tripod stilt K163 (F). Scale is valid for A to F.

Plagioclases are a subgroup in the feldspar minerals. Plagioclase mineral group is defined solid solution series with end members of calcium rich anorthite ($CaAl_2Si_2O_8$) and sodium rich albite ($NaAlSi_3O_8$) minerals.[161] Polysynthetic twinning is a distinctive optical property which is helpful in characterization of plagioclase minerals.[20, 161] Plagioclase minerals were detected in one coarseware, ten glazed and unglazed pottery samples, four biscuit-fired and three tripod stilt samples and three test tiles. Optical images of two glazed and unglazed pottery samples samples are given in Figure 3.7. Presence of plagioclase minerals in all of the samples with the identification of characteristic peaks at 6.39 (13.8°), 3.68 (24.1°) and 3.19 Å (27.9°). XRD spectrum of one representative sample is given in Figure 3.4.

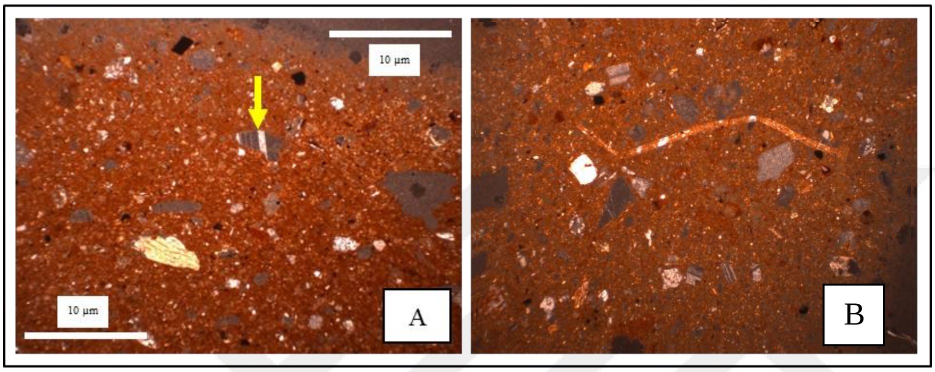


Figure 3.7. Plagioclase minerals in pottery samples samples K171 (A) and K173 (B). Scale is valid for A and B.

Phyllite is a metamorphic rock composed of quartz and chlorite with mica flakes. The existence of phyllite fragments in pottery as a temper was reported by Day and cowerkers.[115] Phyllite fragments were detected in ten coarseware, six glazed and unglazed pottery, five tripod stilt and four test tile samples. Optical images of examples for each type are given in Figure 3.8. The presence of phyllite was confirmed with identification mica in all phyllite containing samples with XRD analysis. Optical image of one example (K219) is given in Figure 3.10. Fragments were generally larger in size in coarsewares, but smaller in glazed and unglazed pottery and tripod stilts. Geological surveys showed that schist and phyllite rocks are main rock types in Tokat Metamorphics which is the dominant rock formation in the region mentioned in Section 1.5. The presence of pyllite fragments in test tiles produced from clay samples shows an indication of the possibility of local pottery production in Komana. However, there is no direct evidence for the use of phyllite fragments as a temper in Komana medieval pottery. Phyllite fragments observed are sub-rounded, in other words, not angular as in mineral fragments formed due to grinding prior to using as a temper.

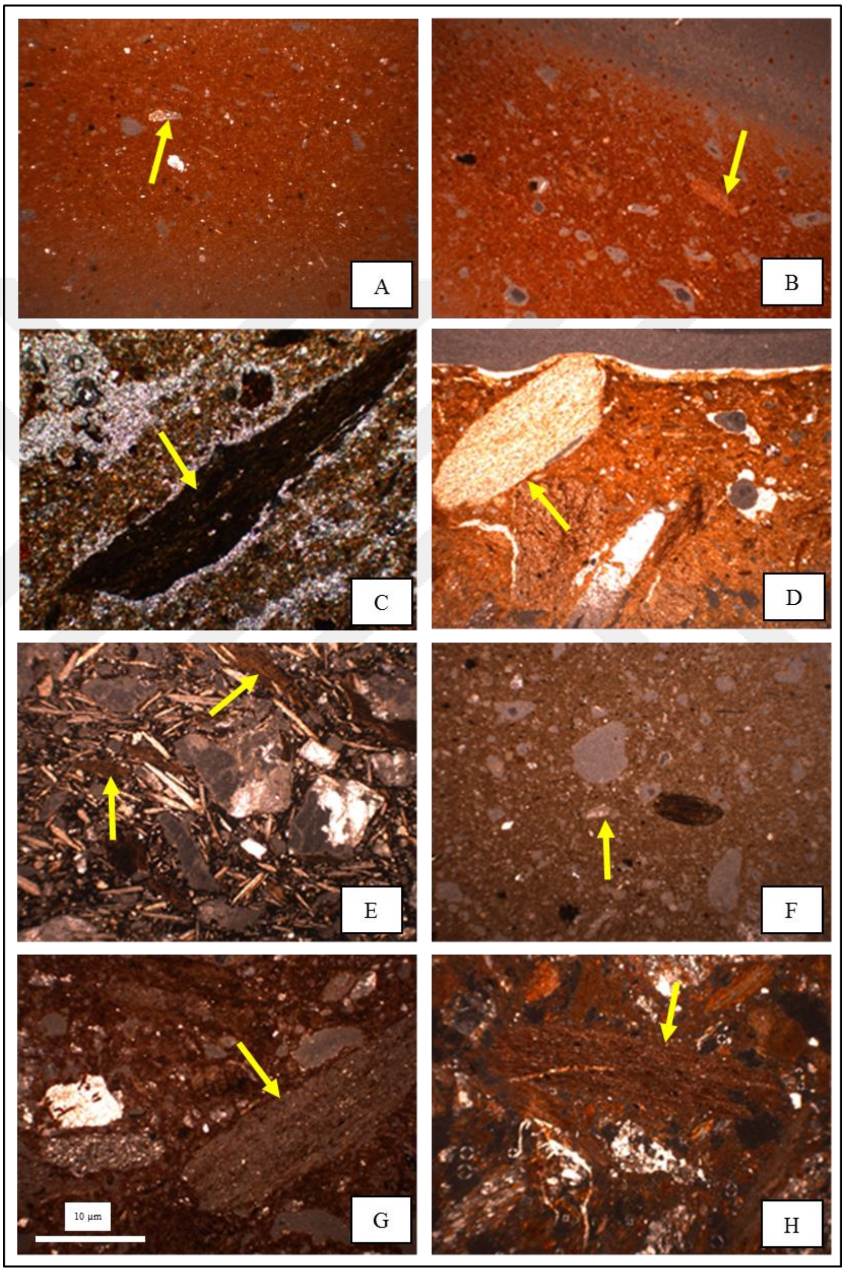


Figure 3.8. Phyllite fragments in glazed and unglazed pottery K168 (A) and K200 (B); in coarsewares K134 (C), K214 (D) and K219 (E); tripod stilt K179 (F); test tile samples S9 (G) and S26 (H). Scale is valid for A to H.

Mica is a mineral family of phyllosilicate minerals showing layered structure. The unit structure consists of one octahedral sheet between two opposing tetrahedral sheets. This gives to mica group minerals a characteristic feature “perfect [001] cleavage”, which is a distinctive property of mica mineral.[161] Mica minerals were identified in four cooking pot, one glazed and unglazed pottery and one tripod stilt samples under optical microscope. Mica was identified in ten coarseware, eight glazed and unglazed pottery and three biscuit-fired samples with XRD analysis. Mica minerals identified with d-spacing value of 9.95-10 Å (8.8 – 9°). Petrographic examination and XRD analysis showed that coarseware samples (K202 and K219) have unique mineralogical composition dominated by mica flakes as shown in Figure 3.9 and Figure 3.10, respectively. Mica mineral was identified in fewer samples in thin section analysis compared to XRD analysis.

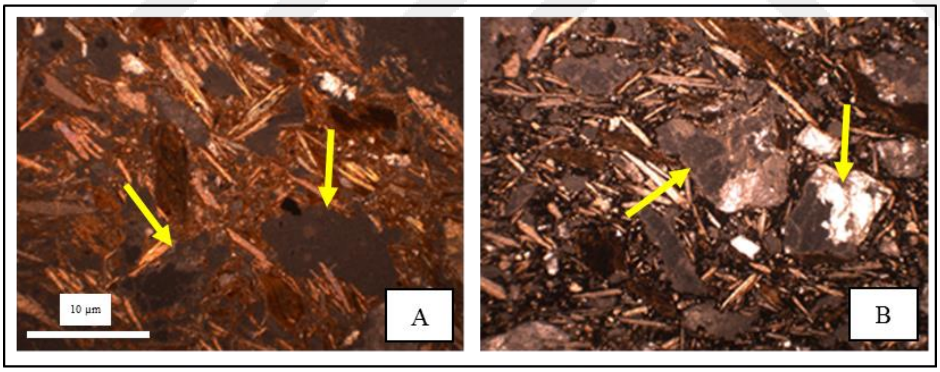


Figure 3.9. Photomicrographs of coarseware samples K202 (A) and K219 (B). Scale is valid for A and B.

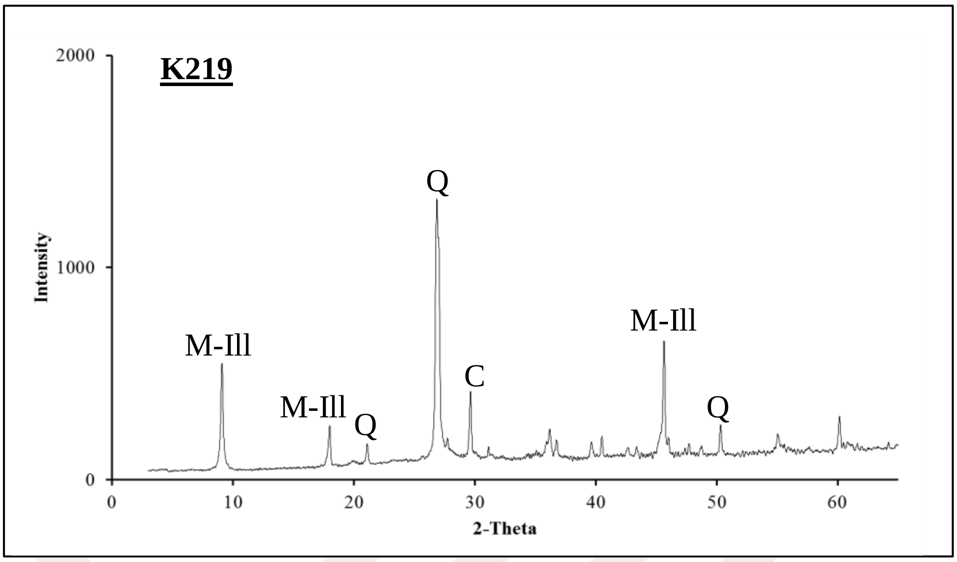


Figure 3.10. XRD spectrum of coarseware sample K219. (M-Ill: Mica-Illite; Q: Quartz; C: Calcite)

Quartz is a phase of silica (SiO_2) and one of the most common minerals in the earth’s crust. It presents in nearly all silica rich sedimentary, igneous, and metamorphic rocks. Quartz is highly resistant to weathering environment and quartz grains have fresh surfaces. Quartz was found in nine cooking pot, eleven glazed and unglazed pottery, one biscuit-fired and nine test tile samples. Presence of quartz was identified in all samples with its characteristic peaks of 4.26 Å (20.8°), 3.34 Å (26.6°), 1.81 Å (50.3°). Optical image of one example is given in Figure 3.10.

The use of quartz as a temper in the pottery paste has been reported in different publications.[162–164] Even though quartz grains were commonly found as unsorted small grains in most of the samples analsyed in this study, only presence of well sorted angular quartz grains dispersed in the matrix of only sample K225 indicates the use of quartz as a temper as shown in thin section photomicrograph in Figure 3.11.

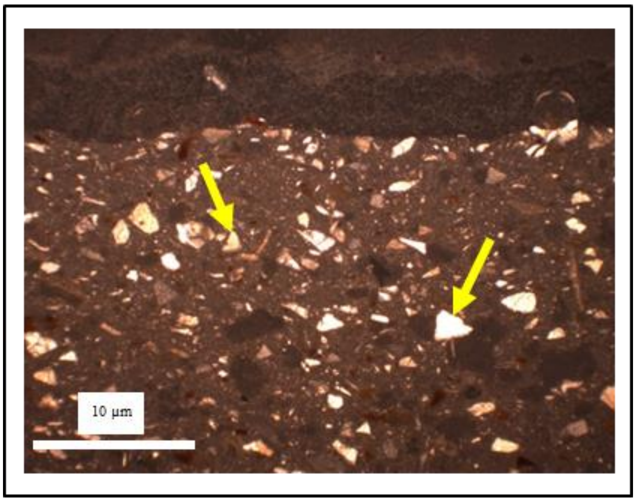


Figure 3.11. Photomicrograph of K225 (glazed pottery) showing quartz grains in the clay matrix

Hornblende is a mineral group of inosilicates but generally refers to dark amphiboles. Chemical formula of hornblende is $(Ca,Na)_{2-3}(Mg,Fe,Al,)_5Si_6(Si,Al)_2O_{22}(OH)_2$.[161] Hornblende is widely distributed as rock forming mineral in igneous and metamorphic rocks. Hornblende is characterized with its greenish pleochroism under polarized light. Hornblende grains were observed in one coarseware and seventeen glazed and unglazed pottery samples in this study. Thin section optical images of two representative samples are given in Figure 3.12. Hornblende was identified at 8.30 Å (10.65°), 3.10 Å (28.7°) and 2.70 Å (33.1°) diffraction lines in four coarseware, thirty two glazed and unglazed pottery and one biscuit-fired samples. XRD spectra of two examples showing the presence of hornblende mineral are given in Figure 3.13.

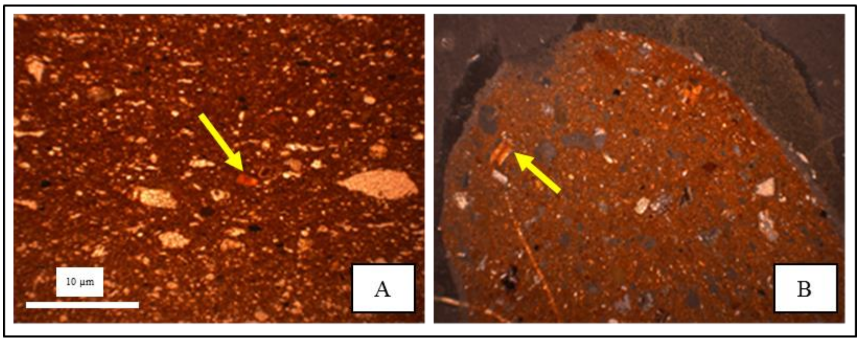


Figure 3.12. Photomicrograph of hornblende grains in pottery samples K170 (A) and K173 (B). Scale is valid for A and B.

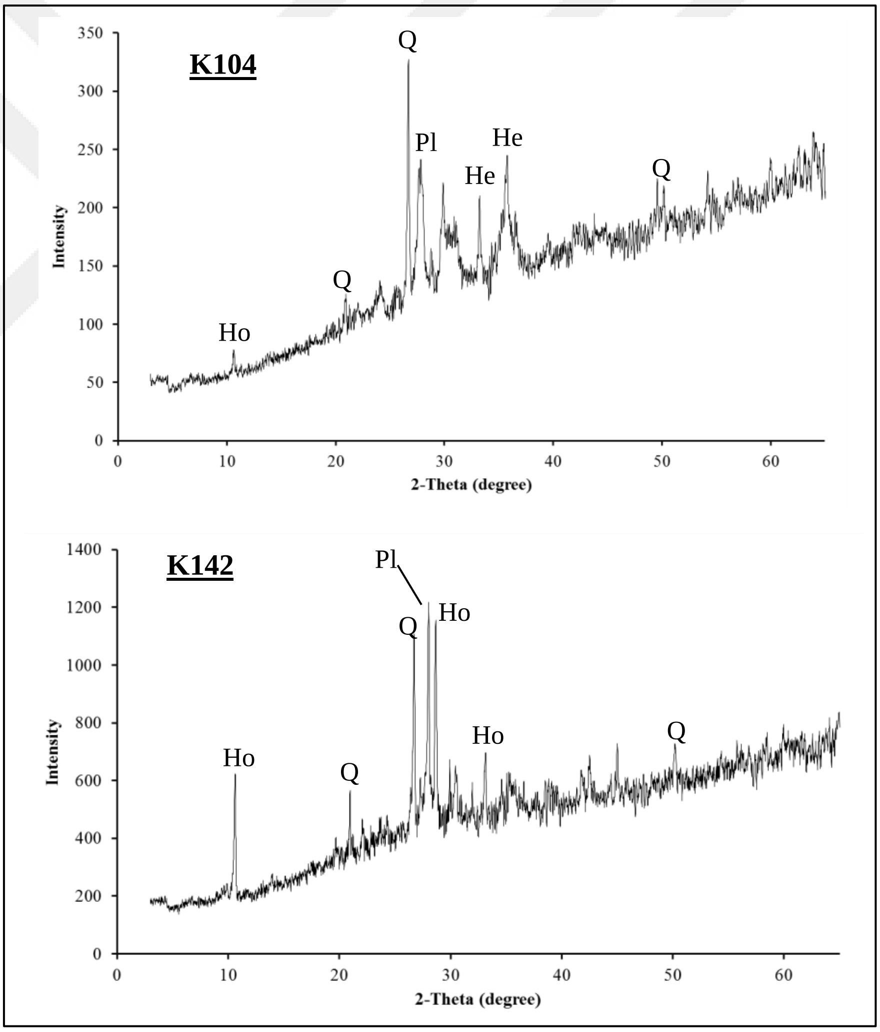


Figure 3.13. XRD diffraction spectra of a pottery sample K104 and a coarseware samples K142 showing hornblende mineral (Ho: Hornblende, He: Hematite, Pl: Plagiclase, Q: Quartz).

Hematite is an iron oxide mineral (Fe_2O_3). It is one of the common minerals found in rocks and soils. The colour of clay paste depends on the presence of iron content in raw material and formation of iron oxides during manufacturing processes.[165] Oxidizing conditions and temperature around 750 °C during firing cause hematite formation which turns the colour of the sample to reddish-brown.[166, 167] Hematite grains were detected in seven coarseware, twenty six glazed and unglazed pottery, ten biscuit-fired and four tripod stilt samples with microscopic examinations as shown in Figure 3.14. Hematite was identified with its characteristic d-lines of 2.69 Å (33.2°) and 2.52 Å (35.5°) in seven coarseware, seventy six glazed and unglazed pottery, eighteen biscuit-fired and eleven tripod stilt samples with XRD. XRD spectrum of one representative example (K104) is given in Figure 3.13.

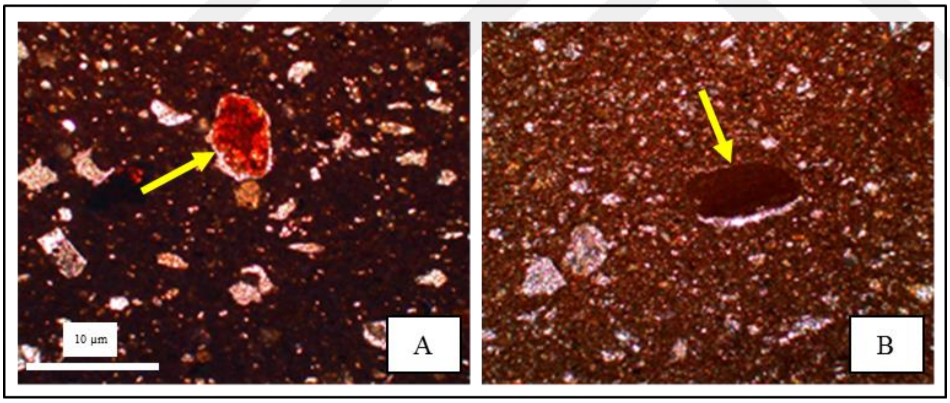


Figure 3.14. Representative photomicrograph of hematite grains in glazed and unglazed pottery samples K132 (A) and K144 (B). Scale is valid for A and B

The chemical composition of pyroxenes is expressed as XYZ_2O_6. X, Y and Z are cations occupying the tetrahedral sites in pyroxene structure.[161] Pyroxene group minerals are generally represented through the $CaSiO_3$-$MgSiO_3$-$FeSiO_3$ system. Pyroxene group minerals such as diopside ($CaMgSi_3O_6$) and augite ($(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$) and pyroxenoid minerals such as wollastonite ($CaSiO_3$) have been commonly found in archaeological pottery samples. These minerals are the products of phase transformations taking place at elevated temperatures.[160, 168, 169] Pyroxene group minerals were detected with the presence of peaks between 29.80° and 31.00° (2Θ) in seven coarseware, seventy two glazed and unglazed pottery, seventeen biscuit-fired and ten tripod stilt samples. However, pyroxene minerals could not be identified individually due to low signal to noise ratio and resolution of diffraction spectra of some of samples as shown in Figure 3.15.

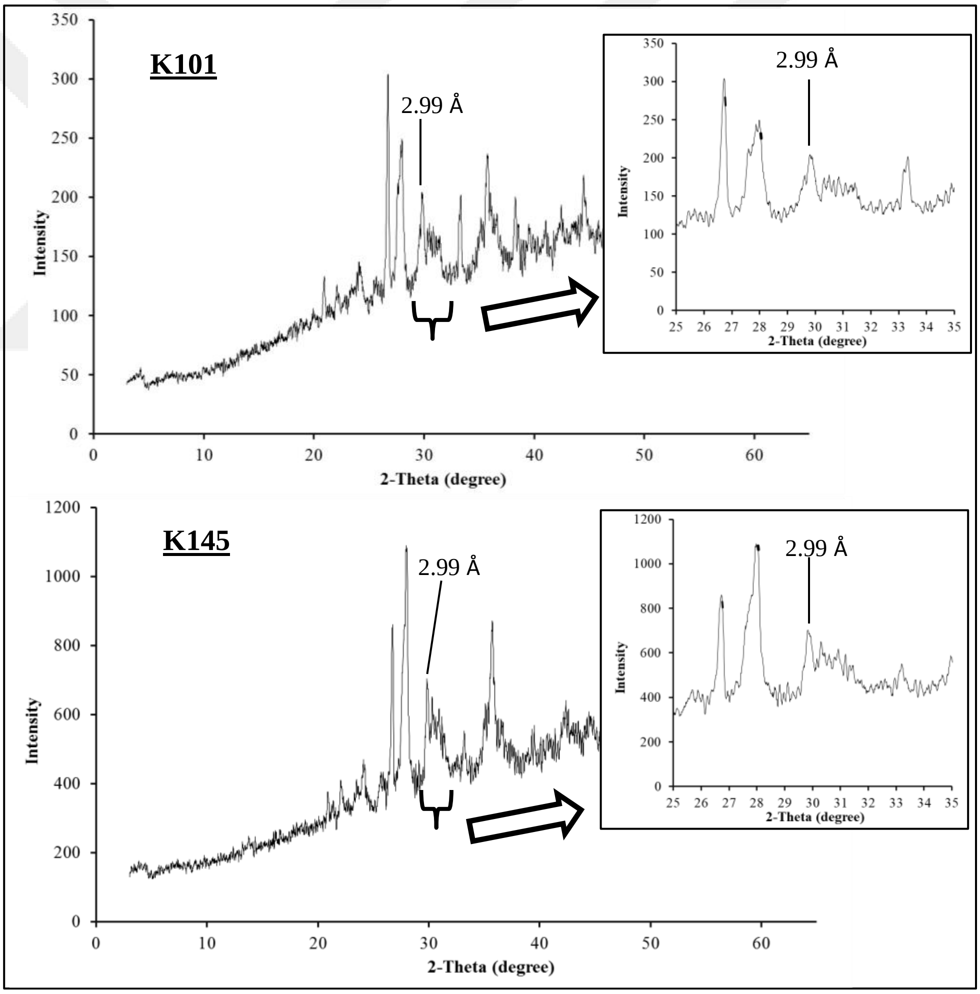


Figure 3.15. XRD spectra of glazed and unglazed pottery samples K101 and K145. Spectra in small boxes on the right side shows low signal to noise ratios for the peaks of pyroxene minerals in 25-35° two theta range.

Smectite/chlorite and illite minerals were identified in four coarseware samples and three glazed and unglazed samples. Representative XRD spectra of two coarseware samples K136 and K224 are shown in Figure 3.16. Diffraction line at 13.5 Å (6.5°) was attested to smectite and diffraction lines at 9.8 Å (9°) and 5 Å (17.85°) were assigned to illite.[14] Intense diffraction line at 3.32 is belonged to quartz but also contributed by mica/illite.

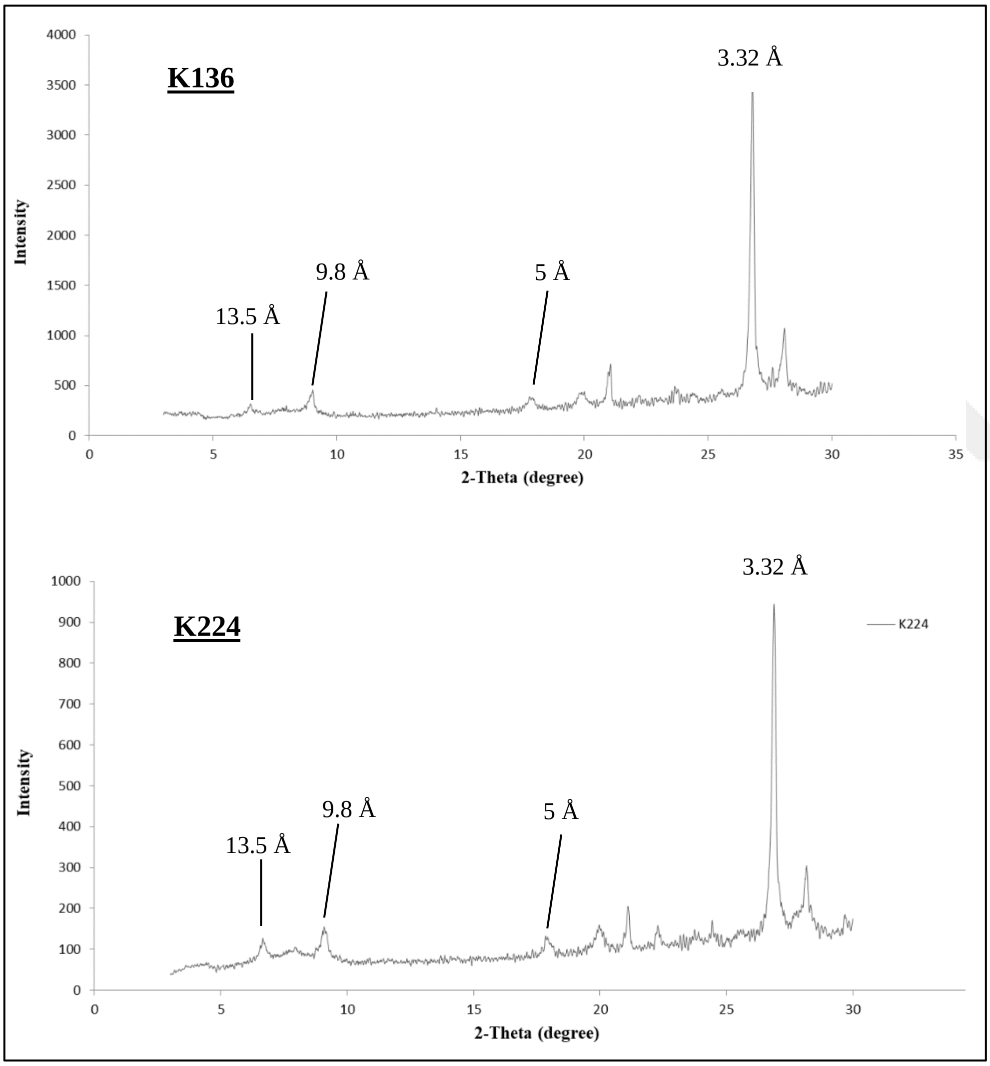


Figure 3.16. Diffraction lines showing the presence of smectite and illite in coarseware samples K136 and K224.

3.1.2. Pottery Fabrics

Pottery samples were assessed according to characteristics of grains, clay matrix and pores (voids) which are the three main components of fabric. The methodology to characterize pottery fabric samples was adopted from the study of Quinn.[20] Selected parameters characterizing grains, matrix and pores are given in Table 3.3.

Grains are aplastic part distributed in the clay matrix. Size, sorting and grain abundance (grain %) were used to characterize types of grains. Grain size is defined as average size of grains distributed dominantly in the matrix. The parameters are divided into three groups including three size ranges. Grain sorting is a measure of how similar sized grains present in the sample. Grain abundance or sometimes called as grain/matrix ratio is the total area covered by grains. The charts given in Figure 3.17 were used to classify the samples according to their grain sorting and abundance.[20, 170] The table given in Table 3.3 were used in order to classify the samples depending on their grain size, sorting of grains, grain abundance, matrix colour, degree of homogeneity, pore size and shape.

Table 3.3. Parameters used to characterize pottery fabric

	Parameters	Classification	
Grain	Grain size	Small	Grain size < 5µm
		Medium	5µm < Grain size < 10µm
		Large	10µm < Grain size
	Sorting of grains	Very poorly/ Poorly/ Moderately/ Well (Grain shape chart in Figure 3.17A)	
	Grain abundance	Low Abundance	Abundance < 1%
		Medium – Low Abundance	5%< Abundance <10%
		Medium Abundance	10%< Abundance <20%
		Medium-High Abundance	20%< Abundance <40%
		High Abundance	40%< Abundance
		(Grain abundance chart in Figure 3.17B)	
Matrix	Matrix colour	Orange/Reddish/Brown/Grey/Black	
	Degree of homogeneity	Slightly/Moderately/High	
Pore	Pore size	Small	Pore Size < 5µm
		Medium	5µm < Pore Size < 10µm
		Large	10µm < Pore Size
	Pore shape	Spherical/Elongated	

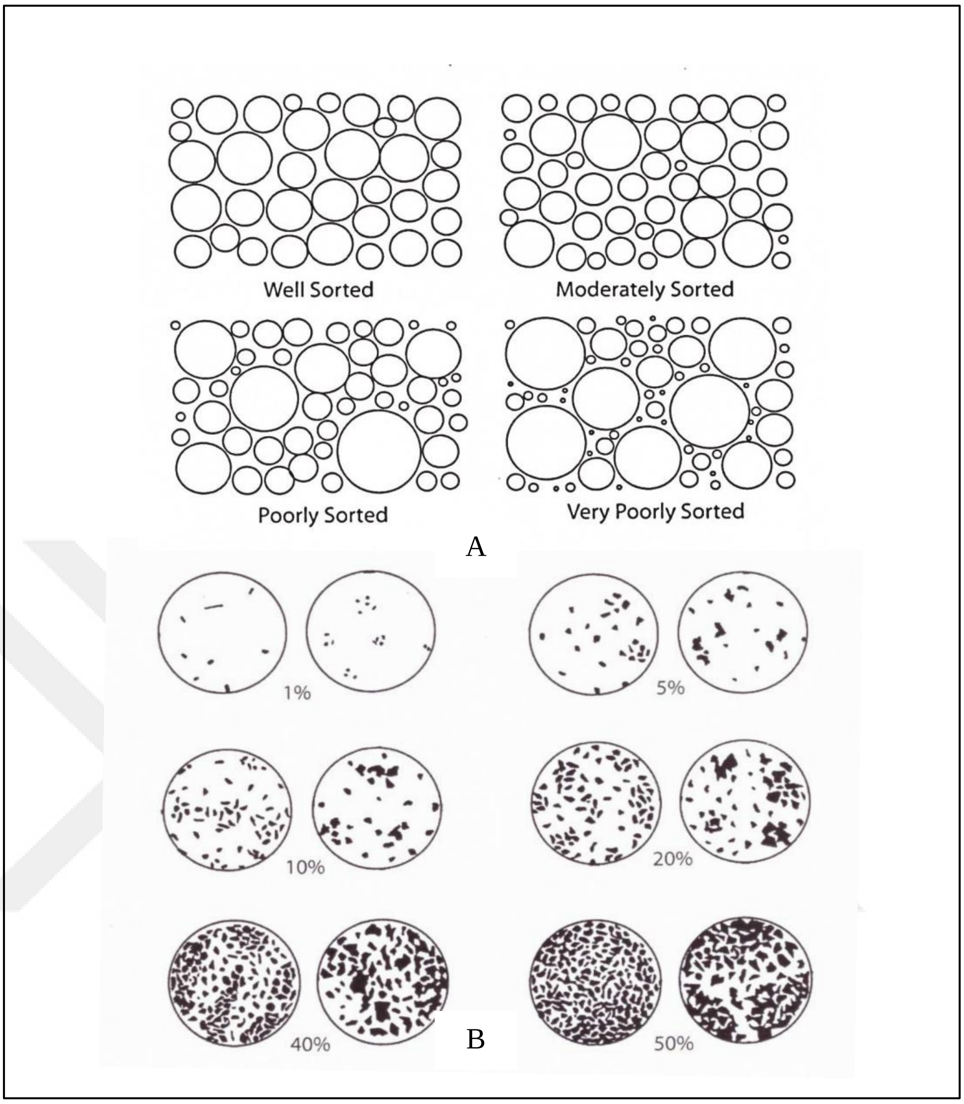
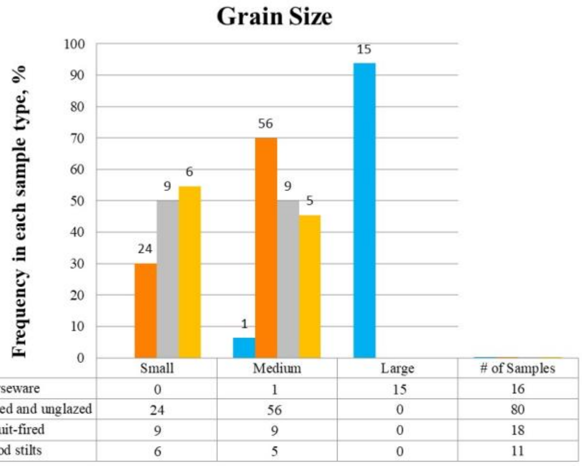
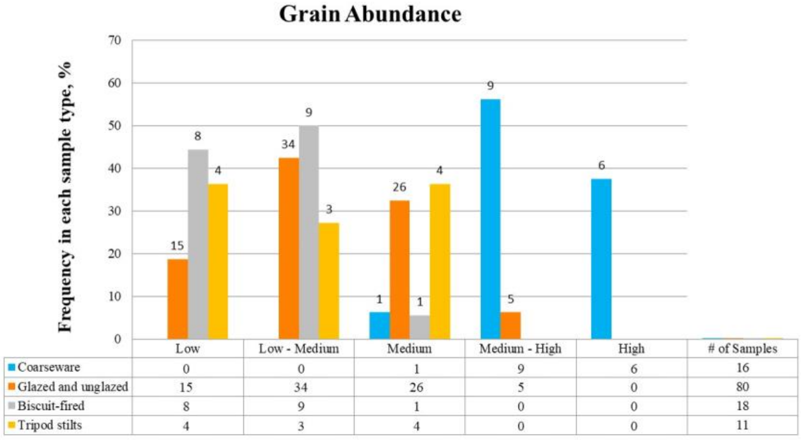


Figure 3.17. Comparison charts for grain sorting (A), and grain abundance (B)

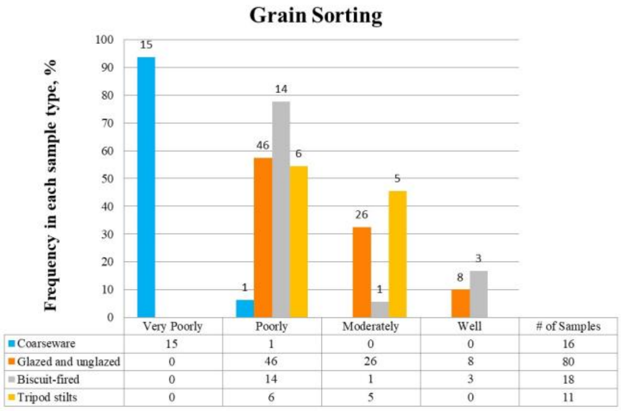
The variation of parameters defining the grains, clay matrix and pores of each sample type is illustrated as bar charts in Figure 3.18, Figure 3.19 and Figure 3.20, respectively. Frequency of a parameter for a sample type is given as percentage in graphs to ease the comparison of sample types among each other.



	Small	Medium	Large	# of Samples
■ Coarseware	0	1	15	16
■ Glazed and unglazed	24	56	0	80
■ Biscuit-fired	9	9	0	18
■ Tripod stilts	6	5	0	11

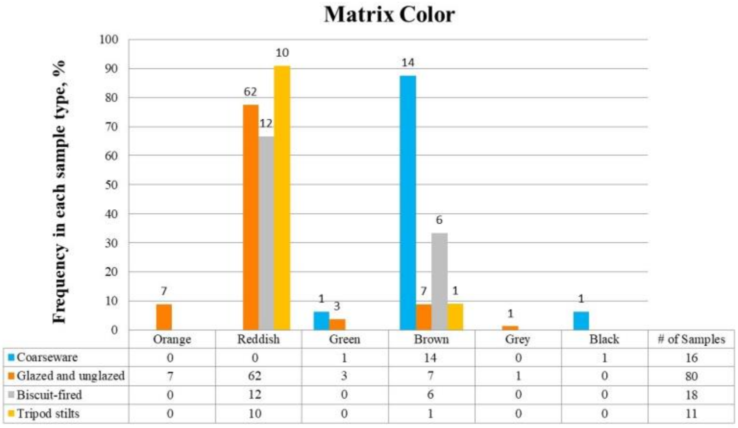


	Low	Low - Medium	Medium	Medium - High	High	# of Samples
■ Coarseware	0	0	1	9	6	16
■ Glazed and unglazed	15	34	26	5	0	80
■ Biscuit-fired	8	9	1	0	0	18
■ Tripod stilts	4	3	4	0	0	11

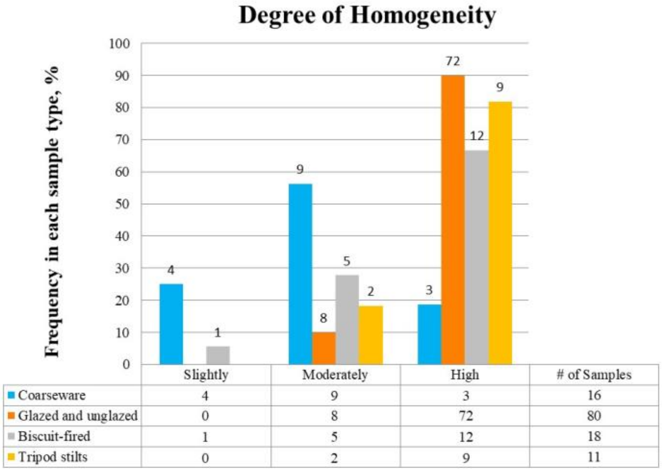


	Very Poorly	Poorly	Moderately	Well	# of Samples
■ Coarseware	15	1	0	0	16
■ Glazed and unglazed	0	46	26	8	80
■ Biscuit-fired	0	14	1	3	18
■ Tripod stilts	0	6	5	0	11

Figure 3.18. Bar charts showing parameters defining size, abundance and sorting of grains in the paste of pottery samples

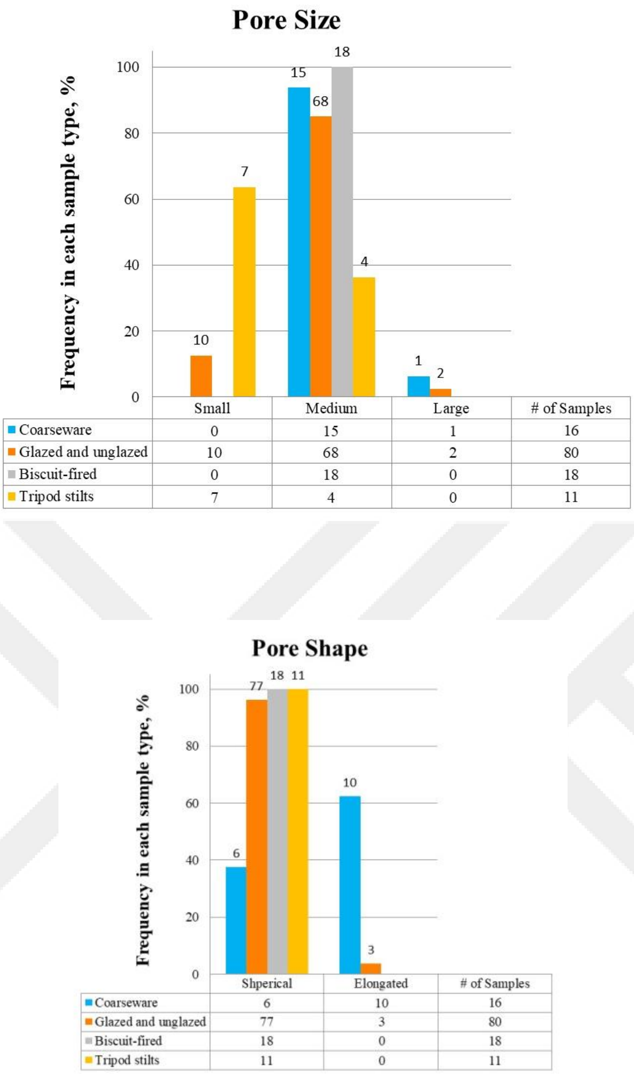


	Orange	Reddish	Green	Brown	Grey	Black	# of Samples
■ Coarseware	0	0	1	14	0	1	16
■ Glazed and unglazed	7	62	3	7	1	0	80
■ Biscuit-fired	0	12	0	6	0	0	18
■ Tripod stilts	0	10	0	1	0	0	11



	Slightly	Moderately	High	# of Samples
■ Coarseware	4	9	3	16
■ Glazed and unglazed	0	8	72	80
■ Biscuit-fired	1	5	12	18
■ Tripod stilts	0	2	9	11

Figure 3.19. Bar charts showing parameters defining matrix characteristics of pottery samples



	Small	Medium	Large	# of Samples
■ Coarseware	0	15	1	16
■ Glazed and unglazed	10	68	2	80
■ Biscuit-fired	0	18	0	18
■ Tripod stilts	7	4	0	11

	Shperical	Elongated	# of Samples
■ Coarseware	6	10	16
■ Glazed and unglazed	77	3	80
■ Biscuit-fired	18	0	18
■ Tripod stilts	11	0	11

Figure 3.20. Bar charts showing parameters defining pore characteristics of pottery samples

According to the grain size, abundance and sorting values given in Figure 3.18, more than 80% of the coarseware samples have large grains that are poorly sorted in the clay matrix. These large grains are dispersed abundantly in the moderately homogeneous dark brown clay matrix. Grains are generally calcite, polycrystalline metamorphic rock and phyllite fragments as previously shown in Figure 3.1, Figure 3.6 and Figure 3.8, respectively. One representative example to thin section image to show grain size distribution, matrix colour and pore size and shape is given in Figure 3.21. In Figure 3.21, varying sized calcite and phyllite fragments and small sized feldspar grains marked by the *green arrow* are dispersed in clay matrix of coarseware sample, K209. Dark colour of clay samples indicates reducing firing atmosphere at the lack of oxygen in the kiln. Elongated pores probably caused by shrinkage during drying or firing, are also marked with *blue arrows* in the same figure.

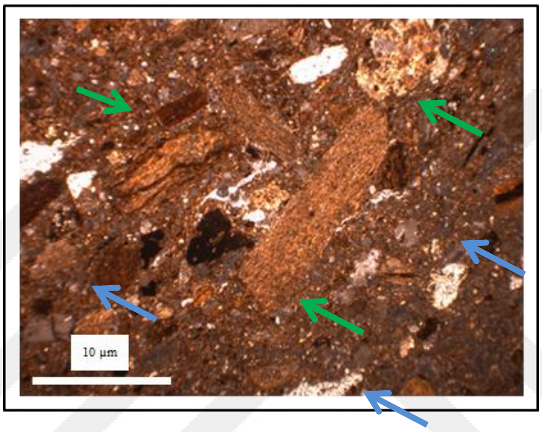


Figure 3.21. Photomicrograph of coarseware sample K209 showing mineral grain distribution, matrix and pores

Glazed and unglazed pottery samples contain poorly sorted small and medium sized grains which are not abundantly (low to medium abundance) dispersed in the clay matrix. The grains are generally calcite, plagioclase and unidentified feldspar grains. Photomicrograph of two samples given in Figure 3.22 has very fine texture (Figure 3.22A) however the other one (Figure 3.22B) includes large sized grains. Thirty percent of glazed and unglazed pottery samples have very fine texture containing no detectable grains. This very fine texture may indicate the use of highly effective clay fractionation methods. [20] Reddish clay matrix is highly homogenous and has medium sized spherical pores. Reddish colour is an indication of oxidizing atmosphere in the kiln. These pores were probably existed after calcite decomposition and shrinkage during firing process as shown previously in Figure 3.3.

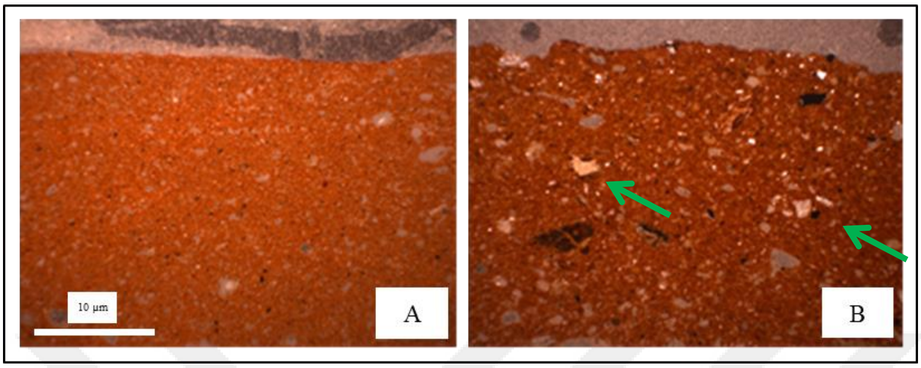


Figure 3.22. Photomicrograph of two glazed and unglazed pottery samples K210 (A) and K211 (B). Scale is valid for A and B.

Similar textural difference was existed within biscuit-fired samples as it was seen in glazed and unglazed pottery samples (Figure 3.23). A biscuit-fired sample, K197 given in Figure 3.23A, contains medium sized limestone and metamorphic rock fragments with small feldspar grain dispersed in the matrix, when the other sample K195 with very fine texture (Figure 3.23B). Colour of clay matrix is red and highly homogeneous. Pores are generally medium sized and spherical as it can be seen in Figure 3.23B.

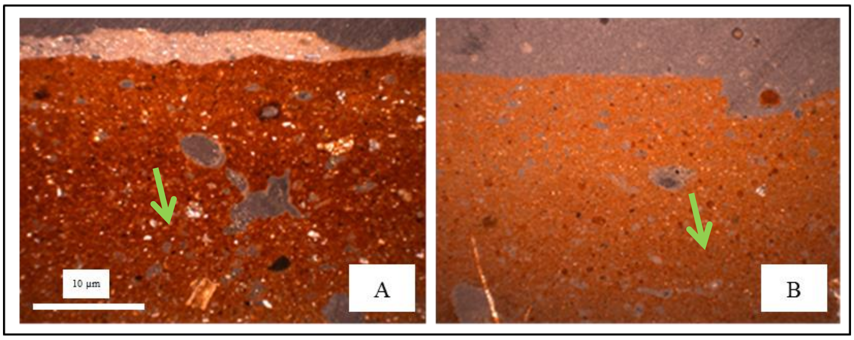


Figure 3.23. Photomicrograph of two representative biscuit-fired samples, K197 (A) and K195 (B) showing textural differences. Scale is valid for A and B. The green arrows show pores in thin sections.

Tripod stilt samples contain poorly and moderately sorted small and medium sized grains as shown in representative sample K180 in Figure 3.24. Grain abundance is changing from low to medium grade. Clay matrix is dense, reddish and highly homogeneous. Small and medium sized are mostly spherical and not connected with each other (Figure 3.24).

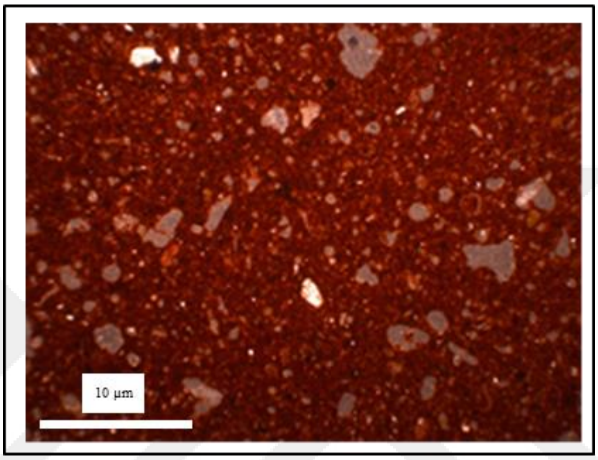


Figure 3.24. Photomicrograph of tripod stilt sample K180

3.1.3. Petro-Mineralogical Grouping of Pottery Samples

Pottery samples were grouped according to their mineralogical and petrographic properties as listed in Appendix D and E. Five groups are defined and named as A, B, C, D and E. Number of samples from each sample type in petro-mineralogical groups is given in Table 3.4.

Table 3.4. Sample groups based on petrographic – mineralogical analysis

Group Name	**Glazed and unglazed pottery**	**Coarseware**	**Biscuit-fired samples**	**Tripod stilt**
Group A	18	0	7	1
Group B	57	0	11	10
Group C	1	13	0	0
Group D	3	1	0	0
Group E	0	2	0	0

Group A samples contain small polycrystalline metamorphic rock fragments, partially decomposed limestone grains surrounded by reaction rims, small feldspar including plagioclase grains probably detached from metamorphic rocks, few quartz and hornblende grains. Small hematite grains were observed in thin section analysis. Pyroxene (probably wollastonite) formation was confirmed based on the presence of major pyroxene peaks between 2.85 and 2.98 Å. The most distinctive observation for Group A is low and low – medium grain abundance. The clay matrices have reddish – orange colour and are highly homogeneous in Group A samples. Pores are spherical and isolated pointing out formation after calcite decomposition and shrinkage during firing. The firing temperature was estimated around 800 – 850 °C because of the formation of pyroxene minerals in the samples of this group. Mostly glazed and unglazed pottery and biscuit-fired samples belongs to Group A.

Group B samples contain fragments of polycrystalline metamorphic rocks, phyllite and limestone; small – medium sized plagioclase and feldspar grains; hornblende and hematite grains dispersed in the clay matrix. Limestone fragments and feldspar grains were abundantly dispersed in the clay matrix compared to Group A samples. Therefore, grain percentage changes between low – medium and medium. Mica/illite peaks at 10 Å and 5 Å were identified in some of the samples in Group B because of the presence of mica containing phyllite fragments. Major pyroxene peaks were also detected in most of the samples. Colour of highly homogeneous clay matrices are brown, green, orange and reddish. Pores are spherical and isolated formed by calcite decomposition. The firing temperature was estimated around 800 – 850 °C because of the formation of pyroxene minerals in this group. Glazed and unglazed pottery, biscuit-fired and tripod stilt samples are major samples present in Group B.

Group C samples contain large fragments of metamorphic rocks, phyllite, calcite rocks; medium sized quartz, plagioclase, feldspar grains. Mineral grains and rock fragments are abundantly present in different sizes (poorly sorted) in the clay matrix. Small grains were generally fragments of large rock pieces. Characteristic mica/illite peaks at 10 Å and 5 Å which can be related to phyllite rock were observed in most of the samples. Hornblende, hematite and pyroxene were detected in XRD spectra of only few samples. 13.5 Å diffraction line at 6.5° was attest to the presence of smectite in few samples. Colour of moderately homogeneous matrix is dark brown. Dark colour of pottery fabric was attested to reducing firing atmosphere. Elongated and spherical pores are present in most of the samples. The firing temperature was estimated around 600 – 800 °C because of the presence of calcite mineral in samples of this group. Coarseware samples dominate in Group C.

There are few samples in Group D containing metamorphic rock fragments, feldspar grains fragmented from metamorphic rock, and hematite and quartz grains. Samples K165 and K166 have similar low grain abundance when other two samples have high grain abundance. Feldspar and quartz minerals are abundantly dispersed in K206, K223 and K225 samples. Green clay matrix is highly homogeneous. Medium sized pores are spherical in shape.

Two coarseware samples (K202 and K219) in Group E contain large fragments of polycrystalline metamorphic rock fragments, calcite and phyllite. Feldspar grains and mica flakes are dispersed abundantly in the clay matrix. Grain abundance is very high for these samples. Colours of highly homogeneous clay matrix for these two samples are brown and black.

3.1.4. Soil Samples

Clay and non-clay minerals in soil samples were identified with XRD analysis. Clay minerals could not be identified with optical microscope due to small grain size. The non-clay minerals were also identified in the test tiles prepared from soil samples. Oriented clay fractions (clay sized samples separated from soil samples) were used to identify clay minerals after the application of heat and ethylene glychol treatments in XRD analysis. XRD spectrum of oriented clay fractions of a representative sample (S16) is given in Figure 3.25. Kaolinite, chlorite, illite and expanding clay minerals (interstratified illite-smectite) were identified in the oriented clay fractions of soil samples; quartz, plagioclase, alkali feldspars, mica, calcite, dolomite and hornblende were detected as non-clay minerals in bulk soil samples. Types of minerals in soil samples and in oriented clay fractions are given in Table 3.5. Relative abundances of minerals in soil samples were determined using intensity of peaks.

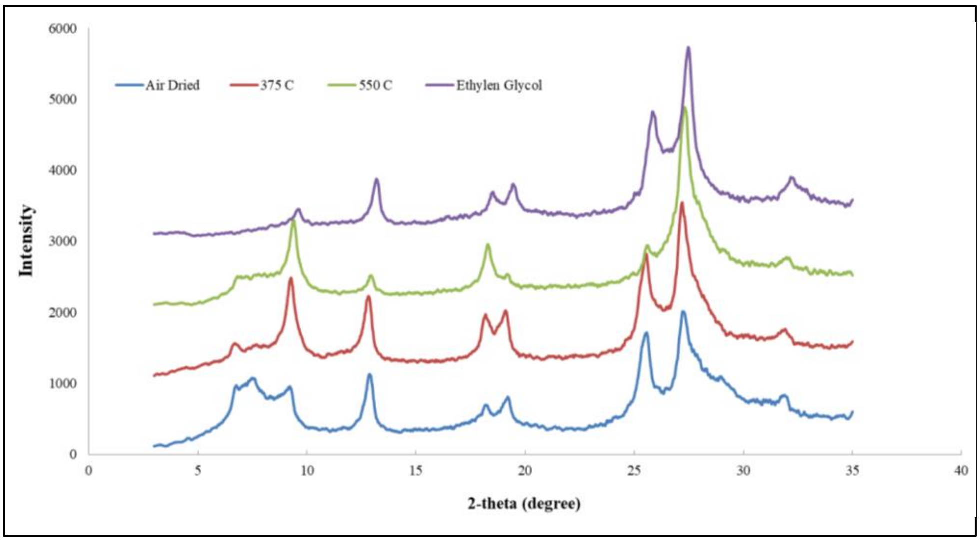


Figure 3.25. Diffraction spectra of soil sample S16

Table 3.5. Types of clay and con-clay minerals identified in soil samples (Quartz: Q; Plagioclase: Pl; Alkali Feldspar: Al-F; Chlorite: Cl; Kaolinite: K; Mica: M; Expanding clays: Ex-Cl; Calcite: Ca; Dolomite: Do, Hornblende: Ho), X represents the degree of relative abundance determined by peak intensities.

	Clay Minerals*				**Non-Clay Minerals****						
Sample	**K**	**Cl**	**Ill**	**Ex-Cl**	**Q**	**Pl**	**Al-F**	**M**	**Ca**	**Do**	**Ho**
S01	XXX	-	X	-	XX	X	-	X	X	-	-
S02	X	-	-	XXX	XX	-	-	-	XX	-	-
S03	-	-	-	XXX	XX	X	-	X	-	X	-
S04	XXX	-	XX	-	XX	X	-	X	-	-	-
S05	-	-	-	XXX	XX	X	-	-	-	-	-
S06	-	XXX	-	X	XX	X	-	-	XX	?X	-
S07	XX	-	XXX	X	XX	X	-	XX	-	X	-
S08	XX	-	XXX	-	XX	-	X	X	-	-	?
S09	X	X	XXX	-	XX	X	-	X	X	-	-
S10	-	-	X	XXX	XX	X	-	-	-	-	X
S11	X	X	-	XXX	XX	XX	-	-	XX	X	X
S12		X	-	XXX	XX	XX	-	-	-	-	?
S13	X	-	X	XXX	X	-	-	-	XX	XX	-
S14	-	-	X	XXX	-	-	-	-	-	XX	-
S15	X	X	XX	X	X	X	X	X	XX	-	X
S16	X	X	XXX	-	XX	XX	-	XX	X	-	X
S17	X	-	XXX	X	XX	X	-	XX	XX	-	-
S18	XX	X	XX	X	XX	X	-	X	X	-	-
S19	X	X	XX	XXX	XX	XX	-	-	XX	-	XX
S20	-	-	-	XXX	X	X	-	-	XX	-	-
S21	XX	-	X	XXX	XX	X	-	X	X	-	-
S22	XXX	X	XX	X	XX	X	-	X	-	-	-
S23	XXX	X	X	-	X	-	-	X	-	-	-
S24	X	-	XX	XX	XX	X	-	X	-	-	X
S25	X	-	XXX	X	XX	X	-	X	X	-	-
S26	XX	X	XXX	X	XX	X	-	X	X	-	-
S27	X	-	X	XXX	XX	X	-	X	X	XX	X
S28	-	-	X	XXX	X	XX	-	-	-	-	-
S29	X	-	X	XXX	X	XX	-	-	-	X	-
S30	-	-	X	XXX	XX	XX	-	-	XX	-	-

*Clay minerals were identified with XRD analysis of oriented samples.
**Non-clay minerals were identified with XRD bulk analysis of soil samples.

Soil samples were grouped depending on relative sampling location to Komana center as listed in Table 3.6. These four sampling locations can be seen in Figure 2.1.

Table 3.6. Soil sample groups according to the location

Group Name	Samples
Northwest samples	S1, S2, S3, S4, S5, S6, S28, S29, S30
South samples	S7, S8, S9, S10, S25, S26, S27
East samples	S13, S14
Northeast samples	S11, S12, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24

Nortwest samples including S1, S2, S3, S4, S5, S6, S28, S29 and S30 were sampled from the slopes of hills in northwest of Komana. Mineralogical composition of these samples represents the geological material eroded from northwestern hills. Samples S2, S3, S5, S28, S29 and S30 were clustered due to high content of expanding clay. Samples S1 and S4 are rich in kaolinite, illite and mica. S6 contain chlorite and calcite minerals.

South samples including S7, S8, S9, S10, S25, S26, and S27 were sampled in two small valleys at the south of Komana. S10 and S27 samples contain expanding clay minerals and hornblende. The rest of the samples in this group (S7, S8, S9, S25 and S26) contain illite and kaolinite as clay minerals, mica and calcite.

East samples including S13 and S14 were sampled from a hill called Killiktepe at the east of Komana. These two samples composed of dolomite and expanding clays.

Northeast samples including S11, S12, S15, S16, S17, S18, S19, S20, S21, S22, S23 and S24 were sampled at the north eastern part of Komana. S11 and S12 were sampled at the slopes of eastern hills. These two groups of samples consist of expanding clays. S15, S17, S18 and S19 were sampled from the slopes of northern hill. These samples consist of mostly illite but also contain kaolinite, chlorite and expanding clays with mica, calcite and hornblende minerals. S16 which were sampled from alluvial deposits consists of illite, mica, calcite and hornblende. S20 and S21 samples were taken from two small hills in alluvial plain consist of expanding clay and calcite. S22, S23 and S24 were sampled from the slopes of the valley at northern side are micaceous soils containing illite and kaolinite clays.

Presence of calcite, mica and hornblende minerals in pottery samples was identified both with thin section and XRD analyses. Expanding clay minerals are not suitable for pottery production due to their high shrinkage rate increasing risk of cracking during drying and firing. Therefore, presence of calcite, mica and hornblende with non-expanding clay minerals was selected as the main expected sources for potential local raw materials.

3.2. ICP-MS Analysis Results

3.2.1. Analysis of Standard Reference Material (SRM)

NIST Standard Reference Material 2710a Montana I Soil was chosen as SRM for ICP-MS analysis because it has similar matrix to the pottery and the soil samples analysed in this study.

Two parallel samples of SRM were dissolved with borate fusion technique. One hundred mg SRM were mixed with 500 mg fusing agents including 400 mg lithium metaborate and 100 mg lithium tetraborate. The mixture were fused in muffle furnace at 1100 °C. Fused samples were dissolved with HNO_3 and 10, 100 and 1000 times diluted samples were prepared after filtering with quantitive grade filter paper Some part of silica could not be dissolved by fusion method applied in this study. Therefore, each sample was filtered before each analysis. The solid phase was analysed using EDX-SEM and only Si peaks were measured and it was concluded that the dissolution method can be applied to the samples collected in this study due to similar matrix of SRM and the samples collected in this study.

Internal standards have commonly used to overcome instrumental drifts during ICP-MS measurements. Elements selected to be used as internal standard should have mass number and ionization potential close to the analyte elements.[171] Be and Li elements have commonly used for low mass, In, Re and Rh elements for middle mass, and Bi for high mass ranges as internal standards in geochemical analysis.[172–175] Even though Be, Li, In, Rh Ho, Tb and Lu were selected to be used as internal standard, only Rh and In were used in ICP-MS experiments because Be, Li, Ho, Tb and Lu were also present in all samples. Therefore, In and Rh were added as 10 ng/mL to each solution as internal standards for ICP-MS measurements.

Ionization potential were the main decision parameter for internal standard corrections. Therefore, the signals of Mg, V, Cr, Fe, Mn, Co, Ni, Cu and Cd were corrected with internal standard Rh and signals of Al, Ti, Ce, and U were corrected with Indium. Standard deviations were calculated from the measurements of 1000, 100 and 10 dilutions of parallel samples. The internal standards were used in the samples as it was used in SRM.

Concentrations were given in Table 3.7 were acquired after analysis of SRM. Student’s t-test was used to check the concentration values obtained by borate fusion technique and certified values. Both values were found to be in agreement with each other at 95% confidence level after comparing t-scores of each element and t-critical value (12.7).

Table 3.7. Results of the Analysis of Standard Reference Material (NIST Standard Reference Material 2710a Montana I Soil)

Element	**Unit**	**Certified Value**	**This Study**	**IS used**	**t-score**
Al	%w/w	5.95 ± 0.05	5.8 ± 0.3	In	0.001
Cu	%w/w	0.342 ± 0.005	0.3 ± 0.1	Rh	3.28
Fe	%w/w	4.32 ± 0.08	4.6 ± 0.1	Rh	2.87
K	%w/w	2.17 ± 0.13	2.2 ± 0.3	-	1.18
Mg	%w/w	0.734 ± 0.038	0.8 ± 15	Rh	0.23
Mn	%w/w	0.214 ± 0.006	0.2 ± 0.1	Rh	15.99
Ba	mg/kg	792 ± 36	770.2 ± 68	-	-2.45
Cd	mg/kg	12.3 ± 0.3	12.2 ± 0.1	Rh	-2.02
Ce[b]	mg/kg	60	59.5 ± 4.1	In	0.49
Co	mg/kg	5.99 ± 0.14	4.6 ± 0.3	Rh	-5.36
Cr[a]	mg/kg	23 ± 6	17 ± 1	Rh	-11.42
Dy	mg/kg	3	3.4 ± 0.5	-	1.34
Eu[a]	mg/kg	0.82 ± 0.01	0.9 ± 0.1	-	9.34
La	mg/kg	30.6 ± 1.2	26.6 ± 2.1	-	-2.85
Nd[a]	mg/kg	22 ± 1	21.9 ± 2	-	0.48
Ni[a]	mg/kg	8 ± 1	7.8 ± 3.4	Rh	-0.13
Sm[a]	mg/kg	4.0 ± 0.2	3.9 ± 0.1	-	1.35
Sr	mg/kg	255 ± 7	254 ± 25	-	-1.42
Th[a]	mg/kg	18.1 ± 0.3	17.5 ± 1.2	-	-0.72
U	mg/kg	9.11 ± 0.30	12.1 ± 1.1	In	5.66
V	mg/kg	82 ± 9	83 ± 9	Rh	0.55
Yb[b]	mg/kg	2	2.3 ± 0.1	-	36.86

[a] Reference values: Reference values for all elements except chromium, nickel, samarium, and vanadium are based on results from one analytical method at NIST

[b] Information values: Information values for elements based on results obtained from one NIST method.

3.2.2. Chemical Analysis of Samples

Concentrations of major elements (Na, Mg, Al, K, Ti, Mn and Fe), minor elements (V, Cr, Co, Ni, Cu, Zn, Sr, Ba and Pb) and trace elements (Y, Zr, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th and U) in all samples are given for each sample in Appendix F and for each sample group in Appendix H.

3.2.3. Interpretation of Chemical Analysis Data

Elemental concentration data was evaluated with statistical and geochemical methods. Analytical figures of merit including mean, median, standard deviation and coefficient of variation of element concentrations were calculated to get information about the overall precision of the data including sampling and measurement variations. *Independent 2-sample T Test* and *Mann-Whitney U Test* were applied in order to test compositional similarity between biscuit-fired pottery and tripod stilt samples. The elemental concentration of biscuit-fired pottery and tripod stilt samples represents at least one local compositional pattern. Cluster and principal component analysis (PCA) methods were applied to identify local and import pottery groups. Rare earth element distribution patterns were drawn to identify the possible clay sources used for the preparation of pottery.

3.2.4. Data Exploration

The data set consists of element concentration values obtained for each sample. However, concentration data was evaluated under five groups based on the types of samples (biscuit-fired pottery, tripod stilts, soil samples, glazed and unglazed pottery and coarsewares).

Major Elements

Major elements (Na, Mg, Al, K, Ti, Mn and Fe) are distributed as percentage concentration in soil, clay and ceramics. According to calculated parameters given in the Table in Appendix H (Statistics for elements), it was determined that mean concentration of Na is at around 1% when Mg is 3 - 5%, Al is 10 - 15%, K is 1 - 2%, Ti is 1 - 5%, Mn is 0.1 - 0.2% and Fe 5 - 10% ranges. Major elements Al and Si (Silicon was not reported in this study) come quantitatively from clay and non-clay alumina-silicates. Na and K concentrations are controlled by feldspar group minerals while concentration of Mg is controlled by dolomite ($CaMg(CaCO_3)_2$) and pyroxene group minerals.[160, 169, 176] Although not measured in this study might be caused by high blank signal and poly atomic interferences , the amount of Ca is one of the most frequently selected parameters for classifying the raw material used in production as calcareous or non-calcareous.[112, 177]

Feldspars are defined as rock forming minerals which are one of the most common minerals in the soil. The sum of Na and K concentrations represents the amount of feldspar in pottery samples.[116] The mean concentration of Na in biscuit-fired and tripod stilt samples was 1.2%, while it was between 0.7 - 0.9% in other sample groups. Similarly, the concentration of potassium has mean value of approximately 2.0% in biscuit-fired and tripod stilt samples, while in other sample groups it was between 1.0 - 1.5%.

The high concentration of Mg indicates dolomitic, and pyroxene rich raw materials, as well as clay formed from mafic rocks.[158] Strong positive correlation between Mg and Ca and elevated concentrations of Mg and Ca can be used to control the presence of dolomite.[169, 178] Mean concentration of Mg was determined between 3 - 5% for all samples. It is at 4.5 - 5% range for biscuit-fired and tripod samples while 3.5 - 4.5% range for the other groups.

Aluminium in ceramic paste mainly comes from the clay minerals and other aluminium silicates in the soil. Thus, Al concentration is correlated with the clay content in the raw material.[179] The mean concentration of Al concentration was found to be between 13 - 15% for all type of samples.

The mean concentration of Ti ranges from 1 to 1.5% for all samples. It was calculated around 1.5% in the glazed and unglazed pottery which is the highest concentration compared to other sample groups.

Fe is the element which is the main constituent determining the colour of paste of pottery.[166, 167, 180] Oxidation state of iron determines the paste colour. Oxidizing atmosphere causes red colour (Fe^{3+}) when it turns to darker colours (Fe^{2+}) in the lack of oxygen. The average Fe concentration is 9-10% for all samples except coarseware samples which have 5% Fe.

Mn concentration in clay bearing rocks is reported to be coming mostly from carbonated rocks.[116] Mean concentration of Mn is higher in biscuit-fired and tripod stilt samples (0.22%) than other sample groups (0.15%), as in other major elements.

Na, Mg, K, Mn and Fe concentrations in biscuit fired and tripod samples are higher than that of glazed and unglazed pottery, coarseware and soil samples. The difference between range (minimum and maximum) and central tendency (mean and median) of major elements for biscuit fired and tripod stilt samples is below 10%. Coefficient of variation (C_{Var}) is between 10 and 20% for biscuit-fired and tripod stilt samples while that of other samples groups are higher than 40%. This shows that major elements in biscuit-fired and tripod stilt samples have similar distributions.

Minor elements (V, Cr, Co, Ni, Cu, Zn, Sr and Ba)

The mean concentration of V is 200 – 300 mg/kg, Cr is 450 – 600 mg/kg, Co is 40 – 70 mg/kg, Ni is 200 – 250 mg/kg, Cu'ın 200 – 600 mg/kg, Zn is 100 – 150 mg/kg, Sr is 100 – 200 mg/kg and Ba is 300 – 400 mg/kg range.

The high concentration of Cr, Co and Ni in the clay is an indication that the clay is composed of a mafic and an ultra-mafic rock.[112, 119, 177] The Cr/V, Co/V and Ni/V ratios provide data for the mafic/felsic nature of the rocks from which the clay is formed.[181] Strontium concentration is controlled by carbonated rock fragments in the raw material.

The mean concentration values of V in biscuit-fired, tripod and soil samples are around 300 mg/kg, while it decreases around 200 mg/kg for glazed and unglazed pottery and coarsewares. C_{Var} of V concentration is calculated as 50 – 60% for coarseware and glazed and unglazed pottery samples, and 15 – 20% for biscuit-fired and tripod stilt samples.

High concentration values of Cr, Co and Ni in pottery than average upper crust have been considered as a sign of mafic and ultramafic source of clay.[112, 119, 177] Concentrations of Cr (124.50 mg/kg), Co (25.70 mg/kg) and Ni (58.00 mg/kg) in NASC (North American Shale Composite) selected as reference values.[116, 182] The mean concentration of Cr varies between 450 and 600 mg/kg, Co varies between 40 and 70 mg/kg and Ni varies between 200 and 250 mg/kg for all samples. Biscuit-fired and tripod stilt samples had 10 - 20% C_{Var} for these three elements, while C_{Var} values of other sample groups were higher than 30%.

Mean concentrations of Cu changes between 200 to 600 mg/kg in all sample groups. The mean concentration of Zn is in the range of 100 - 150 mg/kg. Copper and zinc concentration was below LOD in 89 samples and 88 samples, respectively. Since the concentrations of these elements were below LOD in these samples, so Cu and Zn were excluded from the statistical evaluation in the following sections.

Strontium concentration in pottery is controlled by carbonate rocks and plagioclase minerals in the raw material.[116] The mean concentration of Sr in all samples changes between 100 and 200 mg/kg. Glazed and unglazed potteries have higher Sr concentration (200 mg/kg) than other sample groups which have 100 - 150 mg/kg Sr in their composition. The C_{Var} value for Sr is around 20% for biscuit-fired and tripod stilt samples and higher than 40% for other sample groups.

Concentration of Ba in soil is controlled by feldspar minerals [116]. The mean concentration of Ba is 300 – 400 mg/kg for all samples except for soil sample group having 200 mg/kg Ba concentration.

Trace Elements (Y, Zr, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th and U)

In this study, rare earth elements (REEs) and Y, Zr, U and Th were found in trace concentrations in the samples. Rare earth elements are the elements placed between 57 (La) and 71 (Lu) atomic number in periodic table. Elements in REE group with similar chemical properties and low geochemical mobility have been frequently selected as indicator elements in provenance studies. [116] Ytterbium shows similar chemical properties with rare earth elements and is therefore mostly evaluated with REEs. The other immobilized element, Zr, is also included in the trace element group. Thorium and uranium elements are classified as HFSE (high field strength elements) and present in trace levels in soil and clay samples.

Mean concentrations of rare earth elements for all sample groups were calculated as follows: 20 mg/kg for La, 60 – 80 mg/kg for Ce, 4 – 5 mg/kg for Pr, 15 – 20 mg/kg for Nd, 3 – 4 mg/kg for Sm, 1 – 1.5 mg/kg for Eu, 0.5 – 1.0 mg/kg for Tb, 3.5 – 4.5 mg/kg for Dy, 0.6 – 0.8 mg/kg for Ho, 2.0 – 2.5 mg/kg for Er, 0.2 – 0.3 mg/kg for Tm, 1.5 – 2.5 mg/kg for Yb, 0.2 – 0.3 mg/kg for Lu. The mean concentrations of other trace elements were 20 – 25 mg/kg for Y, 40 – 150 mg/kg for Zr, 5 – 7 mg/kg for Th, and 2 – 3 mg/kg for U.

The mean concentrations of REE in all sample groups except soil samples have similar values. The difference between the means is approximately 20%. The mean REE concentration in soil samples is approximately 30% less than other groups (except Ce and U). The C_{Var} values are around 20% for trace element concentrations in biscuit-fired and tripod stilt samples, while 30 - 50% for other group samples.

Distributions of the element concentrations in type-based sample groups were examined. One of the most striking observations is that the C_{Var} values of biscuit-fired and tripod stilt samples are around 20%. According to Harbottle, the variance of a homogeneous and archaeologically meaningful class can be defined as the sum of the variances come from sampling, analytical and natural factors.[8] In the some of examples, element variation was recorded 2 - 7% for Greek pottery from Bronze Age, and 4 - 9% for compositional pottery groups from Roman and Middle East regions.[183, 184] Kennett stated that element variations in compositional groups were generally between 10 and 20%.[185] Biscuit-fired and tripod stilt samples from Komana samples have element variations change between 10 – 20%. Accordingly, these values may suggest that two groups should be considered as a compositional group representing single production. In order to test this argument, mean and median of the sample groups were compared with *t-test* and *Mann-Whitney u-test* in the next section.

It was determined that the C_{Var} values of the elements in glazed and unglazed pottery and coarseware sample groups were above 40% for major and minor elements and around 30% for trace elements. The high C_{Var} value gives information about the heterogeneity of the sample composition. Beside that different production technologies such as different combinations of temper and clay have been reported to increase the value of C_{Var}.[186, 187] C_{Var} were recorded 50% and above for all elements in soil samples. This expected result may represent the heterogeneous composition of soil samples taken from four sites around Komana.

3.2.5. Characterizing Local Reference Samples

Elemental concentration of biscuit-fired samples and tripod stilt samples which are direct evidences of local pottery production in Komana, represent at least one production in the site. These types of samples have been used as *stricto sensu* in pottery analysis.[71, 124]

In the data exploration step (Chapter 3.2.4), the difference between mean concentrations of major, minor and trace elements in biscuit-fired and tripod stilt samples is less than 10% and C_{Var} values of element concentrations are generally at 10 – 20% range. Independent two-sample t-test and Mann-Whitney u-test were performed in order to evaluate these two sample groups as a single local reference group representing production of pottery in Komana region.

According to test of normality table in Appendix G, concentrations of Na, K, Ti, Cu, Zn, Ba, Y, La, Ce, Pr, Sm, Dy, Er, Yb, Lu, Th and U which have signifance level (p) higher than 0.05 (that means accepting H_0), have normal distribution while Mg, Al, Mn, Fe, V, Ni, Sr, Zr, Nd and Tm concentrations are not normally distributed for sample groups at 95% confidence level.

Two sample t-test results showed that major elements, Na, K and Ti; minor elements Cu, Zn and Ba; trace elements Y, La, Ce, Pr, Sm, Dy, Er, Yb, Lu, Th and U concentrations were not significantly different than that of biscuit-fired and tripod stilt samples at 95% confidence level. The result of Mann-Whitney u-test represents that the element concentrations of major elements Mg, Al, Mn and Fe; minor elements V, Ni and Sr; and trace elements Zr, Nd and Tm shows no significant difference between the biscuit-fired and tripod stilt sample groups at 95% confidence level.

Statistical tests showed that tripod stilt and biscuit-fired sample groups were evaluated as a single compositional group which was defined in this study as "local reference group". The local reference group is assumed to be a reference to a single pottery production in Komana.

3.2.6. Multivariate Analysis of Concentration Data

Hierarchical cluster analysis (HCA) and *principal components analysis (PCA)* techniques were used to recognize the patterns in the element concentration dataset.

Hierarchical Cluster Analysis (HCA)

Cluster analysis yielded six different results according to input data transformed by different methods. The concentration data were used after being standardized by z-score standardization, and transformed by log-ratio method using three elements (Al, Ti or U) as denominator, natural log (or log) and ranking methods.

Al_2O_3 is one of the main constituent of clay minerals. Thus, Al presents in percent range in the pottery. Titanium is a transition metal and presents around 0.5 – 1.5% ranges and U is a high field strength element and presents at trace concentrations in clay. These three elements were selected to understand the effect of denominator having different concentration ranges in the samples. Dendrograms obtained by cluster analysis are given in Appendix I. The results obtained generally show one or two major groups and a small minor group, except the analysis performed by ranking transformation.

At least one branch of major groups contains local reference samples. In three dendrograms produced with standardized and transformed with ranking and log-ratio (by using Ti) methods, local reference samples present in one cluster and together. Concentration of elements in local reference samples generally have coefficient of variations (C_{Var}) of less than 20% explains this agglomeration. In dendrograms generated by the data which was transformed by log and log-ratio methods using Al and U as the denominator, local reference samples were also scattered to other groups, albeit to lesser extent. After six dendrograms were examined, the dendrogram produced by log-transformed data provided interpretable results.

After the logarithmic transformation, the dendrogram can be divided into 4 main groups; L1, L2, L3 and M. The letter “L” was used to indicate the sample groups estimated as local production.

The group L1 includes twenty one local reference samples (K162, K163, K174, K176, K177, K178, K180, K181, K182, K183, K186, K187, K188, K189, K191, K192, K193, K194, K197, K198 and K205), twenty three glazed pottery (K101, K107, K108, K111, K112, K113, K113, K114, K115, K119, K128, K129, K130, K144, K148, K161, K166, K169, K200, K215, K220, K221 and K226) and three moulded ware samples (K121, K126 and K227). L1 group also contains nine coarseware samples (K134, K135, K136, K137, K141, K202, K214, K218 and K219) and eleven soil samples (S01, S04, S07, S08, S09, S16, S17, S18, S24 and S26). In group L1, local reference samples are more correlated with glazed pottery, while coarsewares are more distinct from other samples. Presence of glazed and unglazed pottery and coarsewares as separate groups in group L1 could be the result of raw material processing of similar raw material. Different production techniques such as clay fractionation or tempering might change element concentrations in pottery.[188] According to the presence of soil samples in group L1, eleven soil samples might be used for production of local pottery.

The L2 group contains seven local references (K175, K179, K195, K196, K207, K208 and K217), fifty one glazed pottery samples (K102, K103, K104, K105, K106, K109, K110, K117, K118, K122, K124, K125, 132, K146, K147, K149, K150, K151, K152, K153, K154, K155, K156, K160, K165, K167, K168, K170, K185, K199, K201, K203, K204, K210, K211 and K212), and one glazed pottery with white paste (K165). The group also contains two coarseware (K138 and K209) and four soil samples (S10, S15, S19 and S21). It is clear that this group is dominated by pottery samples. Although there are not many samples as in L1, the presence of local samples in this group may indicate that the glazed and unglazed pottery in group L2 may have been produced from local resources. The soil samples in this group are potential raw materials used in the production of pottery.

The L3 group includes fourteen glazed pottery (K131, K133, K143, K145, K158, K159, K164, K171, K172, K173, K184, K213, K222 and K228) and two moulded wares (K120 and K216), five coarseware (K139, K140, K142, K206 and K224) and seven soil samples (S02, S11, S20, S23, S25, S27 and S29). Although there are no local reference samples in the L3 group, the presence of coarseware in this group and linking at initial stages of clustering with the L2 group suggests that the samples in this group may also be locally produced pottery.

The M group contains two turquoise glazed pottery samples with white paste (K223 and K225) and nine soil samples (S03, S05, S06, S12, S13, S14, S28 and S30). The dendrogram of the M group is located far from the other groups. In addition, there are neither local reference samples pointing to local production nor coarseware samples assumed local. Therefore, it is thought that M group represents the import group consisting of turquoise glazed pottery K223 and K225. The soil samples present in this group might not be used for production.

Principal Component Analysis (PCA)

PCA is a multivariate analysis technique commonly used to develop models to describe experimental data. PCA creates new and fewer variables from the old variables (in this case old variables are concentration of elements). These new variables have a linear correlation with the old variables and helps to interpret the compositional data to provide the archaeologically meaningful results.[144, 145]

As hierarchical cluster analysis, PCA is also a scale dependent analysis. In order to remove scale dependency and comparable results, the same data (log transformed) used in cluster analysis was also used in PCA analysis.

Table 3.8 represents the extraction rates of initial variables. Al, K and Zr have an extraction value below 0.6, indicating that these elements had less effect on new components. On the other hand, V, Mn, Ba, Ce, Pr, Nd, Sm, Ho, Er and Yb elements have more contribution to new variables with having extraction values higher than 0.8. New components were assessed with regard to the extraction rates of old variables.

Table 3.8. Extraction rates of initial variables

Communalities		
	Initial	Extraction
Na_log	1.000	0.636
Mg_log	1.000	0.744
Al_log	1.000	0.541
K_log	1.000	0.571
Ti_log	1.000	0.621
V_log	1.000	0.887
Mn_log	1.000	0.854
Sr_log	1.000	0.718
Zr_log	1.000	0.509
Ba_log	1.000	0.849
La_log	1.000	0.679
Ce_log	1.000	0.878
Pr_log	1.000	0.916
Nd_log	1.000	0.939
Sm_log	1.000	0.910
Eu_log	1.000	0.784
Dy_log	1.000	0.763
Ho_log	1.000	0.863
Er_log	1.000	0.919
Tm_log	1.000	0.699
Yb_log	1.000	0.873
Lu_log	1.000	0.626
Th_log	1.000	0.759
U_log	1.000	0.646

As can be seen in Table 3.9, accounted variances for components 1 and 2 are 46% and 13% of the total variance. First four components cover the majority of the total variance (75%) in the data set. These components were investigated in order to reveal the patterns in elemental concentration data.

Table 3.9. Cumulative variance and eigenvalues of PCA

Total Variance Explained						
Comp.	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %
1	11.138	46.409	46.409	11.138	46.409	46.409
2	3.244	13.517	59.926	3.244	13.517	59.926
3	2.574	10.724	70.650	2.574	10.724	70.650
4	1.227	5.111	75.761	1.227	5.111	75.761
5	0.998	4.160	79.921			
6	0.779	3.245	83.166			
7	0.635	2.646	85.812			
8	0.560	2.334	88.146			
9	0.502	2.092	90.239			
10	0.421	1.752	91.991			
11	0.368	1.533	93.524			
12	0.346	1.440	94.964			
13	0.263	1.098	96.062			
14	0.220	0.918	96.980			
15	0.152	0.632	97.612			
16	0.132	0.549	98.161			
17	0.101	0.421	98.582			
18	0.094	0.392	98.974			
19	0.068	0.283	99.257			
20	0.054	0.224	99.481			
21	0.048	0.201	99.682			
22	0.033	0.139	99.821			
23	0.028	0.118	99.940			
24	0.015	0.060	100.000			

As shown in component matrix in Table 3.10, component 1 contains positive loadings from Al, K, Ti, Ba, Th, U and rare earth elements. Correlation table in Appendix J shows that there is a very strong positive correlation (if Power>0.5) between REEs (Rare earth elements; La to Lu). K and Ba of LILE (large ion lithophile elements), Th and U of HFSE (high field strength elements) also contributed to positive loading of component 1.

Component 2 has strong positive loadings from Mg, V and Mn and small positive contributions from Ti and Zr. There are strong correlation between Mg, V and Mn. Al and Ti which have positive loading on both component 1 and 2. These elements are located between REEs and Mg, V and Mn in the loading plot given in Figure 3.26.

Component 3 has a strong positive loadings from Zr and small positive loadings from La, Ce, Th and U whereas Na and whereas HREEs have negative contribution. There is positive correlation between Na and HREEs, and between Zr, V and Mn.

Component 4 has strong positive loadings only from Sr which does not have any correlation with other elements.

Table 3.10. Component matrix

Component Matrix				
	Components			
	1	**2**	**3**	**4**
Na_log	0.326	0.128	-0.661	0.276
Mg_log	0.052	0.769	0.200	0.332
Al_log	0.658	0.305	-0.067	-0.103
K_log	0.605	-0.349	0.118	0.264
Ti_log	0.550	0.543	0.149	-0.036
V_log	0.294	0.891	0.084	-0.004
Mn_log	0.259	0.871	0.131	0.105
Sr_log	0.101	-0.013	-0.040	0.840
Zr_log	-0.013	0.444	0.513	-0.221
Ba_log	0.831	-0.210	0.196	0.276
La_log	0.712	-0.209	0.360	-0.005
Ce_log	0.790	-0.052	0.489	-0.113
Pr_log	0.906	-0.166	0.260	-0.019
Nd_log	0.948	-0.114	0.160	-0.036
Sm_log	0.950	-0.046	0.046	-0.050
Eu_log	0.873	0.126	0.057	-0.058
Dy_log	0.825	0.014	-0.280	-0.051
Ho_log	0.817	0.021	-0.398	-0.190
Er_log	0.901	0.058	-0.322	-0.019
Tm_log	0.658	-0.082	-0.507	0.047
Yb_log	0.850	0.028	-0.379	-0.074
Lu_log	0.658	0.077	-0.396	-0.172
Th_log	0.727	-0.283	0.386	0.007
U_log	0.530	-0.362	0.463	0.140

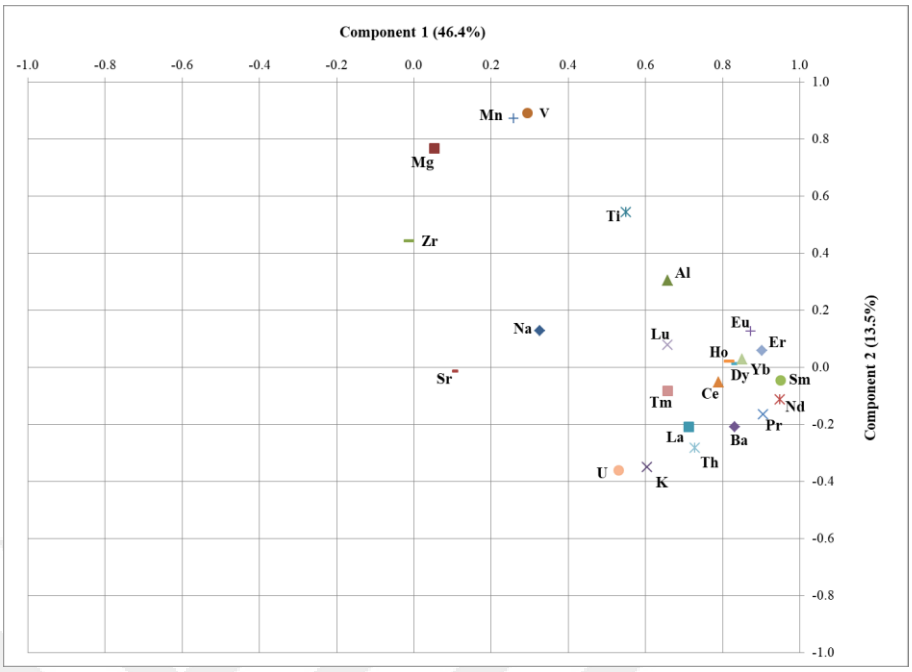


Figure 3.26. Loading of variables on component 1 and 2 (Accounted variances are given in percentages)

First two components contribute maximum to the total variance in PCA and also also provide the most valuable data for grouping the samples.[144] According to component 1 versus component 2 scatter diagram given in Figure 3.26, most of the samples are clustered, except for some of soil samples and a small number of glazed and unglazed pottery and coarseware samples. This shows compositional similarity between the glazed and unglazed pottery, local reference and coarseware samples whereas soil samples are scattered.

Turquois glazed pottery samples (K223 and K225) and coarseware samples (K134, K135, K136 and K137) are distinctly separated from the main group as shown in Figure 3.27. In addition to these samples, K202 and K219 and K142 can be classified as a separate group of samples.

Concentrations of Mg, V and Mn which have positive loading on component 2 are main factors for the separation of the samples.

Concentrations of these elements in K223, K225 and K134, K135, K136 and K137 samples forming separate subgroups and Mn and V in K202 and K219 samples are below the average of all main samples. Concentrations of Mg, V and Mn in coarseware samples K134, K135, K136 and K137 are 0.2 – 0.5%, 20 – 30 ppm, 100 – 170 ppm lower than 3 – 5%, 200 – 300 ppm, 100 – 200 ppm which are means of all samples, respectively. Low concentrations of Mg, V and Mn in coarsewares K202, K206, K219 and turquois glazed pottery K223 and K225 samples were also seen in Mg – V diagram given in Figure 3.28. Since Mg concentration indicates dark coloured Mg-rich basic rocks, the results obtained for K223 and K225 samples with whitepaste is expected.

As seen in component 1 - component 2 scatter plot in Figure 3.27, soil samples are highly scattered compared to other sample groups. The C_{Var} values of the element concentrations in the soil samples higher than 50% is compatible with the scatter of soil samples in the diagram. Thirteen soil samples (S2, S3, S5, S6, S11, S12, S13, S14, S20, S27, S28, S29 and S30) are separated from the other samples in the scatter plot given in Figure 3.27.

Consistent with the previous findings, K223 and K225 are separated from the main group and the same fourteen soil samples are scattered around the main group on the component 1 – component 3 scatter diagram in Figure 3.29.

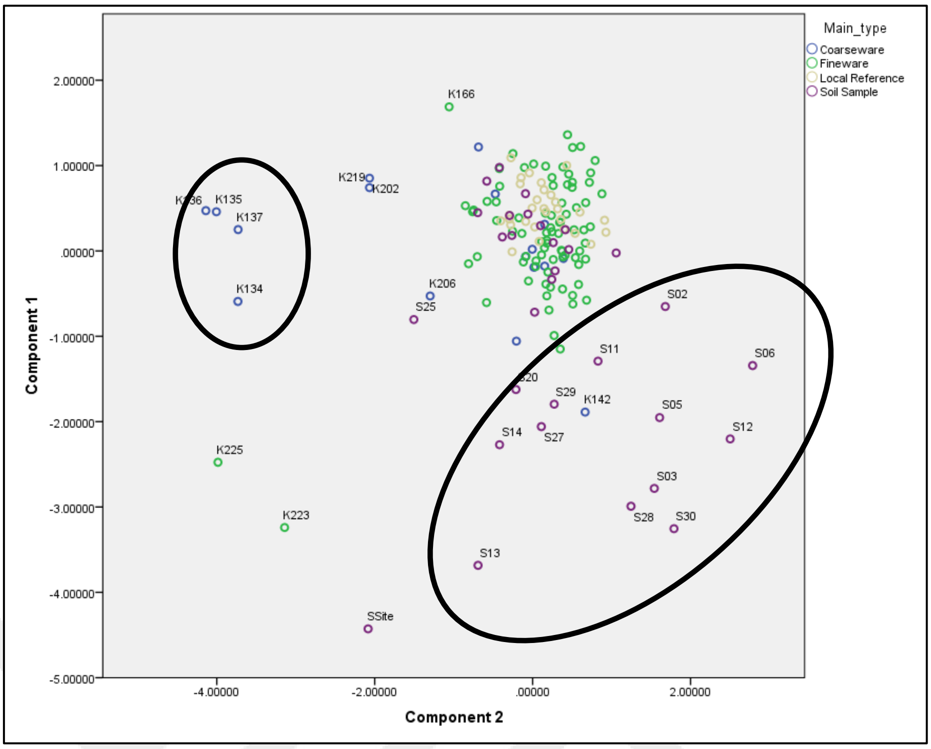


Figure 3.27. Component 1 vs component 2 scatter diagram

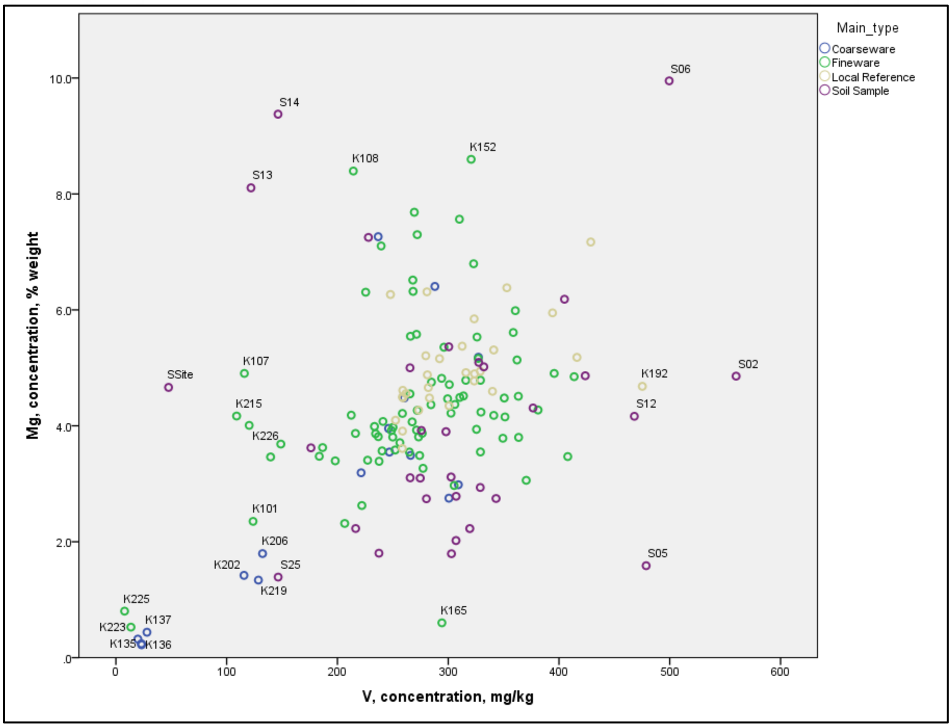


Figure 3.28. Mg-V scatter diagram

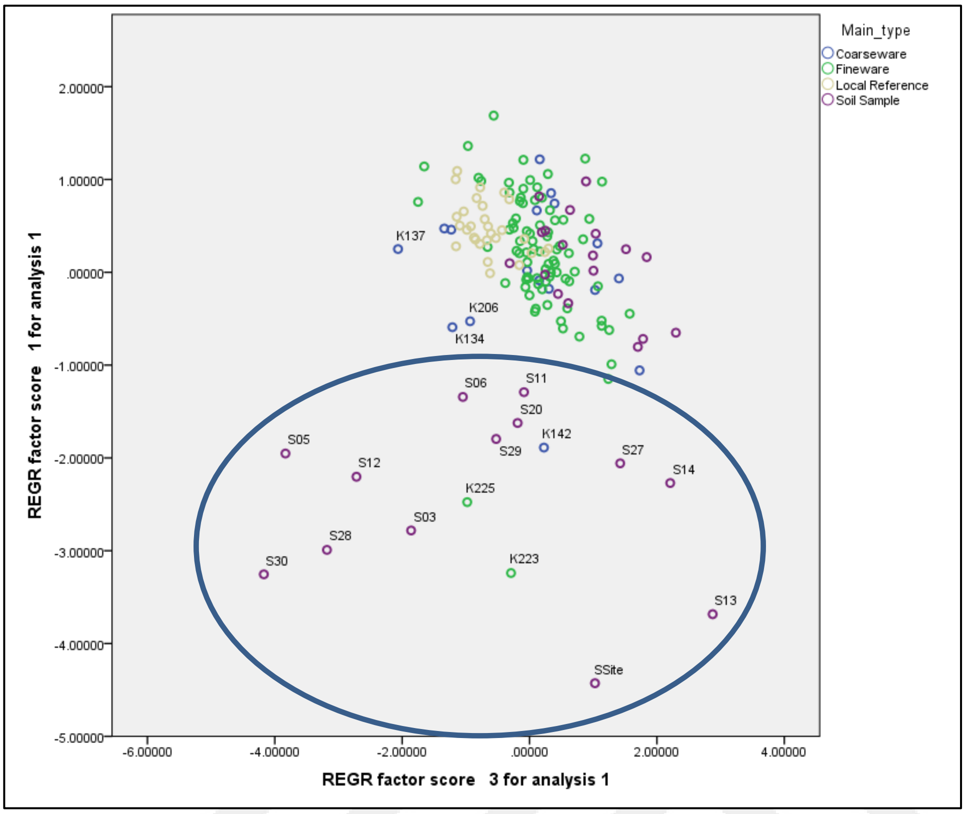


Figure 3.29. Component 1 – Component 3 scatter diagram

3.2.7. REE Distribution Patterns

From the dendrogram generated by cluster analysis, glazed and unglazed pottery samples mostly fall into L1 and L2 groups also containing local reference samples. PCA confirms the presence of one large cluster containing most of the pottery samples. *REEs distribution patterns*, *fractionation* and *Eu anomaly* ratios of the samples have been examined to contribute the groupings of multivariate analyses.

Concentrations of REE (rare earth elements) are used in the source analysis of rocks and sediments. Due to low solubility, mobility and very low concentration of REE elements in river and sea water, solid contents in sediments are the main source of REE in sediments. Thus, REE concentrations reflect the chemical properties of the source of particulate matter in the sediments.[116]

REE elements with *even atomic number* are more stable and more abundant in nature than the ones with having *odd atomic number*. This phenomenon causes zig-zag pattern in composition diagrams of REE elements. Variations in concentration of REE in the samples are presented in concentration versus atomic number diagrams, usually called *REE distribution patterns*. Trends on REE diagram can be referred to as REE "patterns" and the shape of an REE pattern is of considerable petrological interest.[116] The concentration values are given as logarithmic ratios of sample concentration to chondrite standard concentrations (chondrite normalization). Chondrite meteorites are condensed samples of undifferentiated cosmic matter.[189] They can also be described as the oldest known rocks and their components formed during the birth of the solar system ca. 4.5 billion years ago.[190] The normalization removes the natural zig-zag pattern and makes the patterns more recognizable and provides normalized values to identify REE fractionation in the samples.[116]

C1 chondrite values in Table 3.11 were used for chondrite normalization.[191] REE distribution patterns were drawn after chondrite normalization. In order to identify the enrichments and depletions of REEs in the samples, reference values of element concentrations in North American shale composite (NASC), European shale and upper crust average were used.[182, 192, 193] Because of the repeated erosion cycle in environment, concentrations of elements in fine grained sedimentary rocks from different parts of the world represent similar.[116] The concentration of REEs in these reference values is given in Table 3.11. The REE patterns of these NASC, European shale and upper crust represent enrichment of light REEs over heavy REEs as given in Figure 3.30. These patterns were used to classify the REE patterns of the samples.

Table 3.11. C1 Chondrite, NASC, European shale and upper crust values used in normalizing REE

REE	**Chondrite (mg/kg)**	**NASC (mg/kg)**	**European Shale (mg/kg)**	**Upper Crust (mg/kg)**
La	0.24	31.10	41.10	30.00
Ce	0.64	67.03	81.30	64.00
Pr	0.096	-	10.40	7.10
Nd	0.47	30.40	40.10	26.00
Sm	0.15	5.98	7.30	4.50
Eu	0.06	1.25	1.52	0.88
Tb	0.04	0.85	1.05	0.64
Dy	0.254	5.54	-	3.50
Ho	0.056	-	1.20	0.80
Er	0.17	3.28	3.55	2.30
Tm	0.025	-	0.56	0.33
Yb	0.17	3.11	3.29	2.20
Lu	0.03	0.46	0.58	0.32

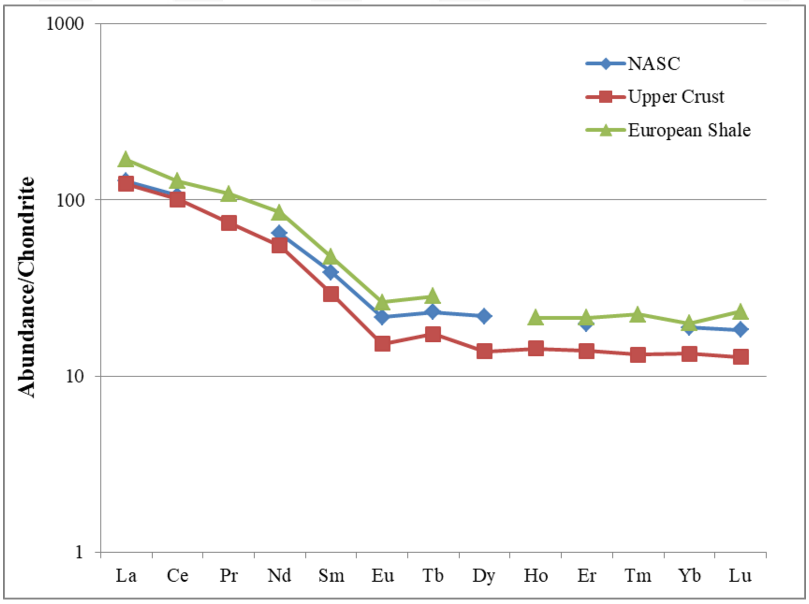


Figure 3.30. REE pattern of NASC, European shale and upper crust.

Eu anomaly is a natural phenomenon occurs especially in felsic magma. When plagioclase solidifies in felsic magma, Eu^{2+} ion compatible with plagioclase, substitutes quantitatively with Ca^{2+} in plagioclase. This causes the relative decrease quantitatively in Eu^{3+} to the other REEs in the melt and is detectable in REE distribution patterns.[116]

Eu_n^* in Eu anomaly ratio (Eu_n/Eu_n^*) was calculated with the help of the Equation 3.1 given below where Sm is the concentration of Sm and Tb is the concentration of Tb.[194] Eu anomaly ratio higher than 1.0 indicates positive Eu anomaly when the ratio smaller than 1.0 indicates negative Eu anomaly.[116]

$$Eu_n^* = \sqrt[3]{(Sm_n^2 * Tb_n)} \qquad \text{Equation 3.1}$$

REE fractionation is the relative abundance of REE groups (light and heavy) over one another. REE fractionation is quantified by the La_n/Yb_n ratio. The ratio higher than 1.0 indicates the enrichment of light rare earth elements (LREE) over heavy rare earth elements (HREE). La_n/Yb_n ratio was used to differentiate felsic and mafic source of sediments.[116, 195]

Samples with similar shape of the REE distribution patterns were grouped beforehand and then intra- and inter-group values of Eu anomaly (Eu/Eu* ratio) and REE fractionation (La_n/Yb_n) given in Table 3.12 were checked to establish the reliability of groupings. All samples were eventually divided into nine groups (LG1, LG2, LG3, LG4, PG1, PG2, PG3, SG1 and SG2). Abbreviations; LG, PG and SG correspond to the groups containing **l**ocal reference and pottery samples, only **p**ottery samples and only **s**oil samples, respectively. Thirteen samples (K139, K140, K142, K143, K158, K166, K202, K202, K212, K221, K223, K224 and K225) and six soil samples (S03, S05, S20, S26, S28 and S30) which have unique REE patterns and extreme Eu anomaly and La_n/Yb_n ratio were grouped as ungrouped pottery (UP).

Table 3.12. Eu anomaly and REE fractionation values

Group Name	**Eu anomaly**	**La_n/Yb_n**
LG1	1.1	5.5
LG2	1.2	6.3
LG3	0.9	6.6
LG4	0.8	5.6
LG - average	**1.0**	**6.0**
PG1	1.1	7.2
PG2	1.0	7.3
PG3	-	5.5
PG - average	**1.0**	**6.7**
SG1	1.1	5.8
SG2	0.9	7.8
SG - average	**1.1**	**6.0**
UP	**1.0**	**9.4**
US	**1.0**	**4.7**

Local group (LG) and pottery samples were divided into four subgroups (LG1-LG4) Depending on variation of pattern shapes mainly caused by concentrations of Tb and Tm. LG1 (27 samples), LG2 (18 samples), LG3 (28 samples) and LG4 (9 samples) groups contain totally eighty two samples.

The mean of Eu-anomaly value of 1.1 indicates that there is no Eu-anomaly for LG group samples. The mean of La_n/Yb_n ratio of all samples in LG groups was calculated as 6.1 showing light REEs are enriched over heavy REEs in these groups. Intense positive anomaly of Ce present in all subgroups of LG. Strong positive anomaly is associated with the siliceous clays.[196] Even though, shapes of the right side of the pattern where heavy REEs present can be described as flat as the patterns of NASC. European shale and upper crust, subgrouping of LG is primarily based on anomalies of

Tb and Tm as shown in Figure 3.31, Figure 3.32, Figure 3.33 and Figure 3.34. The association of the anomalies of middle REEs including Tb and Dy with the hornblende mineral were supported with identification of hornblende with XRD analysis and partly thin section analysis. The clay pastes containing varying amounts hornblende crystals were used for production might cause Tb anomaly in the patterns of samples in LG group.

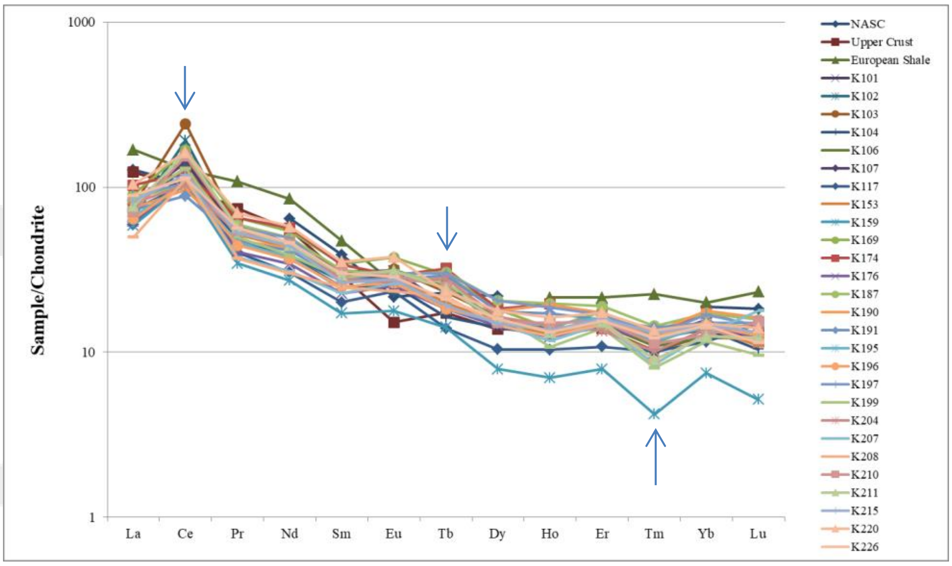


Figure 3.31. REE patterns of LG1 samples. Arrows mark Ce, Tb and Tm showing anomalies.

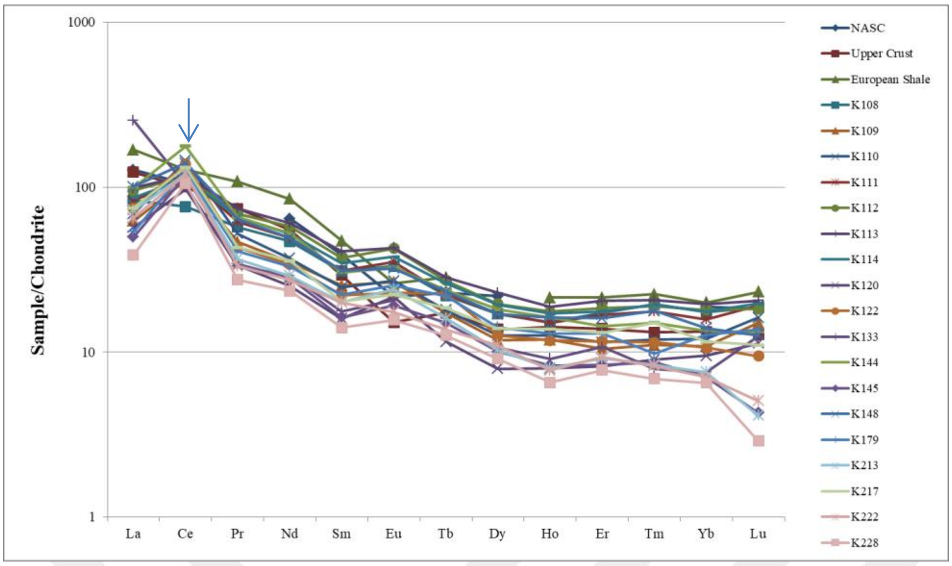


Figure 3.32. REE patterns of LG2 samples. The arrow marks Ce showing anomaly

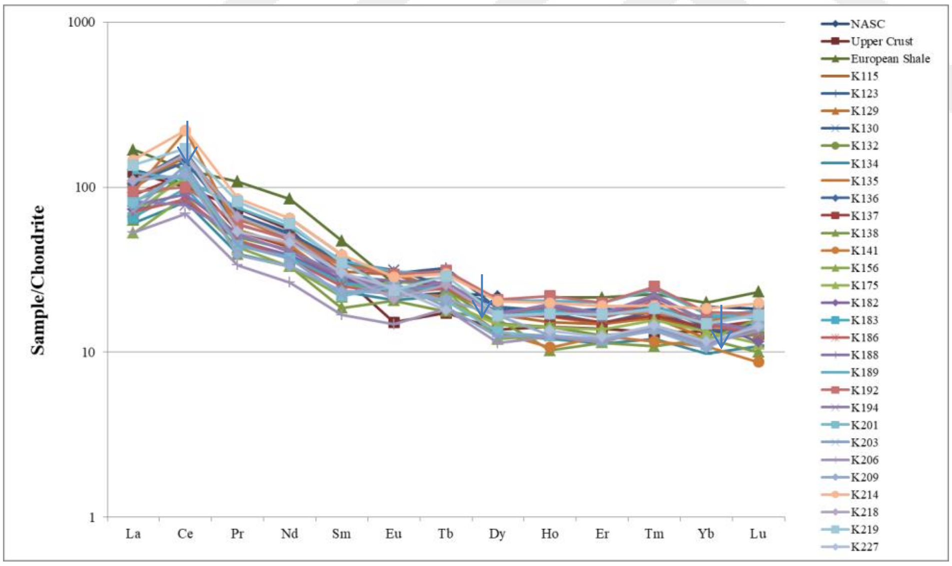


Figure 3.33. REE patterns of LG3 samples. Arrows mark Ce, Tb and Tm showing anomalies

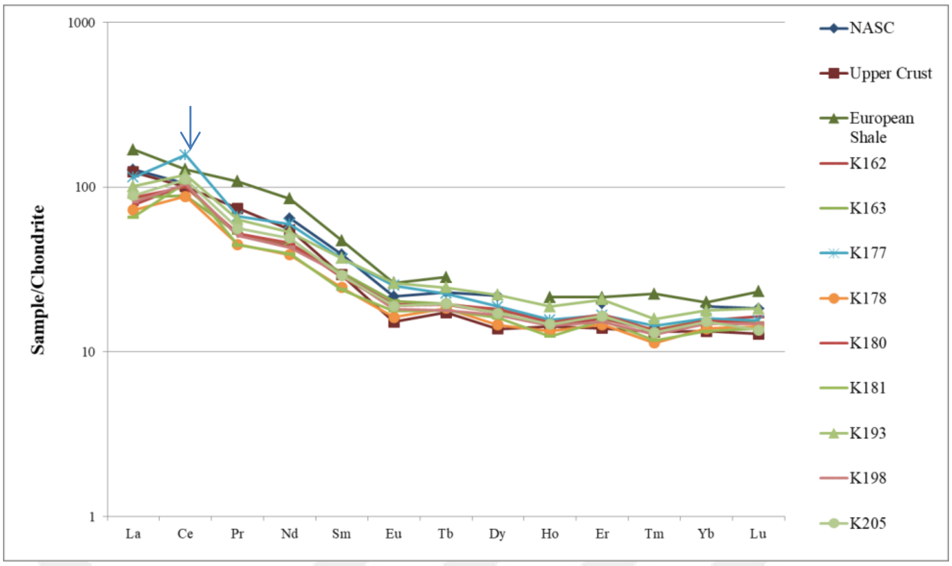


Figure 3.34. REE patterns of LG4 samples. The arrow marks Ce showing anomaly

Thirty one glazed and unglazed pottery samples were classified in PG1, PG2 and PG3 groups according to the shape of REE patterns as given in Figure 3.35, Figure 3.36 and Figure 3.37.

Calculated mean of Eu anomaly around 1.0 for the samples in PG groups shows that there is no Eu anomaly in PG groups. The Eu anomaly could not be calculated for fifteen samples in which Tb concentration could not be determined since its concentration was below LOD (LOD for Tb 4.44 µg/kg). Mean La_n/Yb_n ratio of PG samples was calculated as 6.7, showing the enrichment of light REEs over heavy REEs. The Eu anomaly and REE fractionation values are almost same as LG groups. This may indicate the same source of raw materials. Strong positive anomaly of Ce present in the patterns of the samples in PG group as observed in LG groups. The positive and negative anomalies of Tb and Ho elements in the patterns are remarkable. These could be caused by the variation in hornblende mineral content in the clay paste, as it is for LG groups.

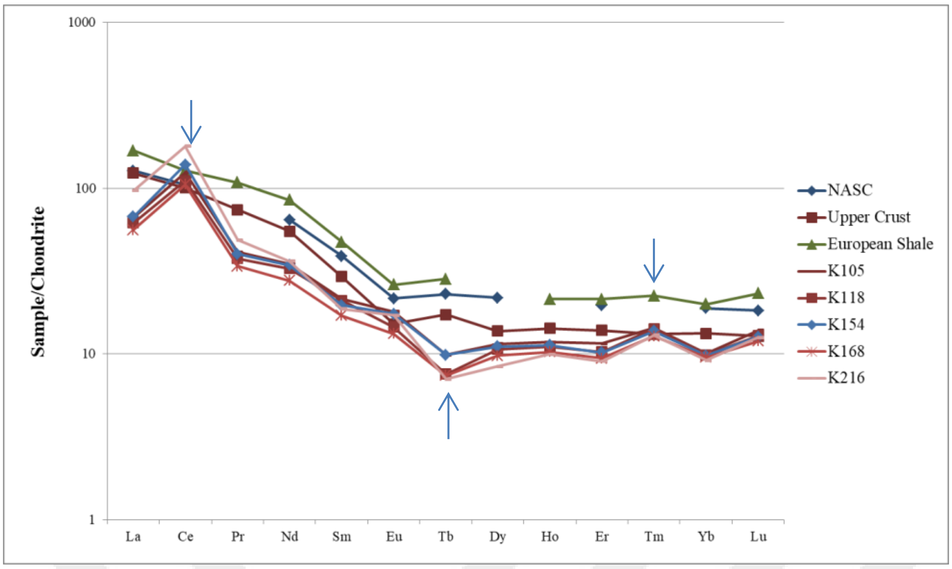


Figure 3.35. REE patterns of PG1 group samples. Arrows mark Ce, Tb and Tm showing anomalies.

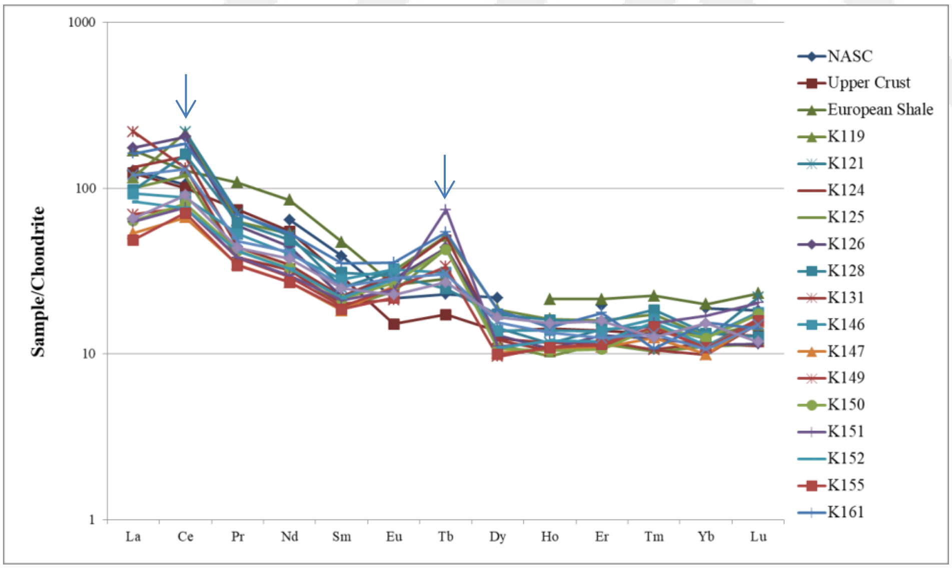


Figure 3.36. REE patterns of PG2 group samples. Arrows mark Ce and Tb showing anomalies.

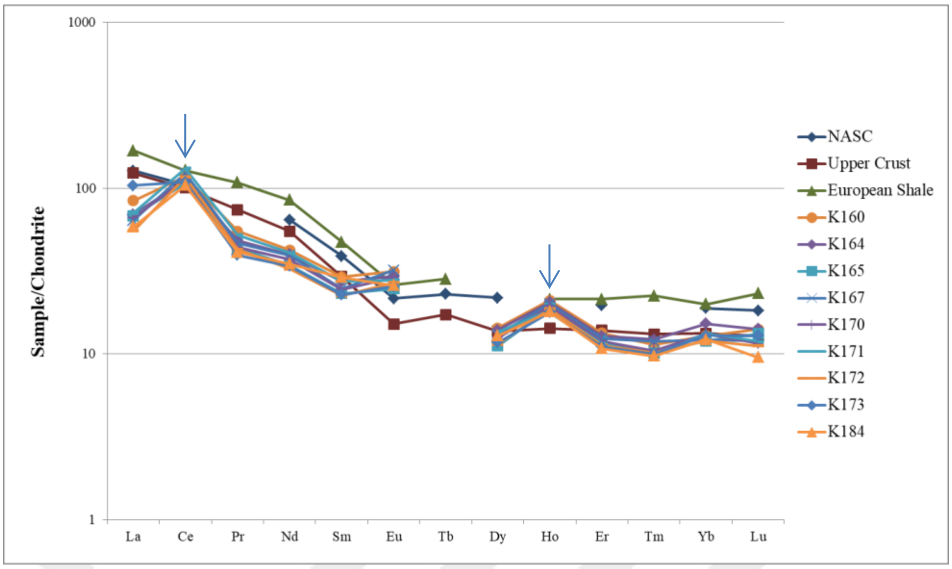


Figure 3.37. REE patterns of PG3 group samples. Arrows mark Ce and Ho showing anomalies.

Soil samples were classified into two groups (SG1 and SG2) by the anomaly of Tm element in REE distribution patterns (Figure 3.38 and Figure 3.39). Patterns of soil group SG1 (eighteen samples) is containing strong negative anomaly compared to that of SG2 samples (six samples). Means of Eu-anomaly (1.1) and La_n/Yb_n ratio (6.0) are very similar to LG and PG groups.

Six samples were classified as ungrouped soils (US) and thirteen pottery samples were grouped as ungrouped pottery (UP) and both groups have discrete REE distribution patterns which are very dissimilar to the other samples are given in Figure 3.40 and Figure 3.41.

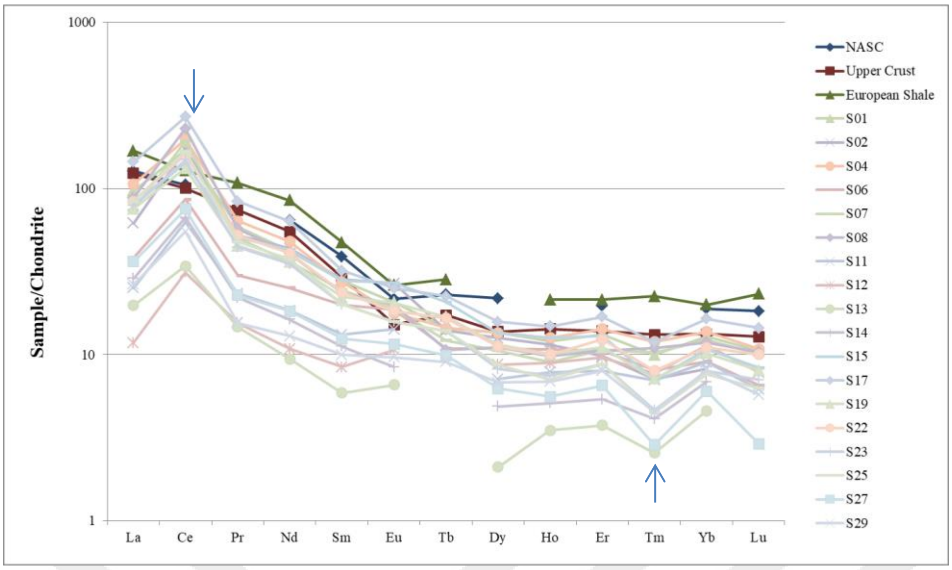


Figure 3.38. REE patterns of SG1 samples. Arrows mark Ce and Tm showing anomalies.

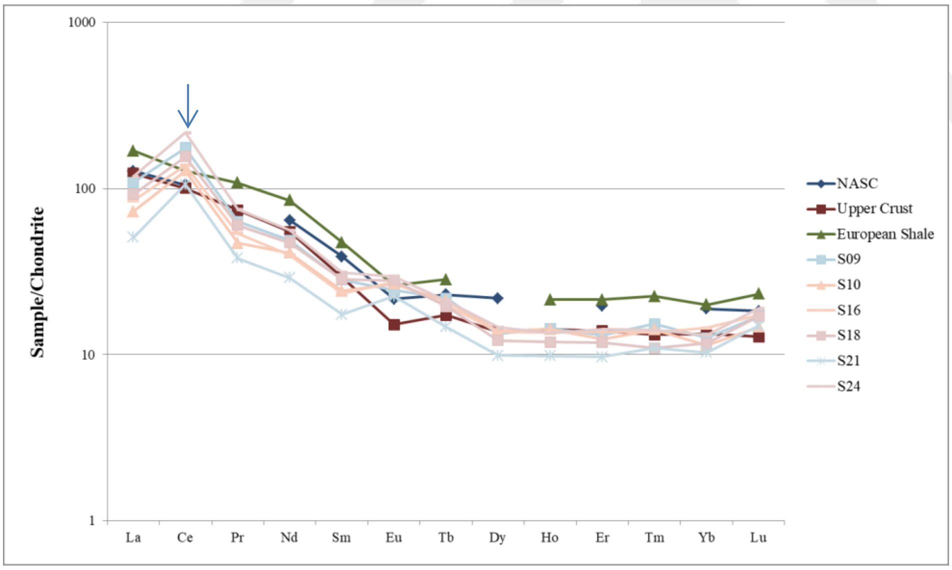


Figure 3.39. REE patterns of SG2 samples. The arrow marks Ce showing anomaly.

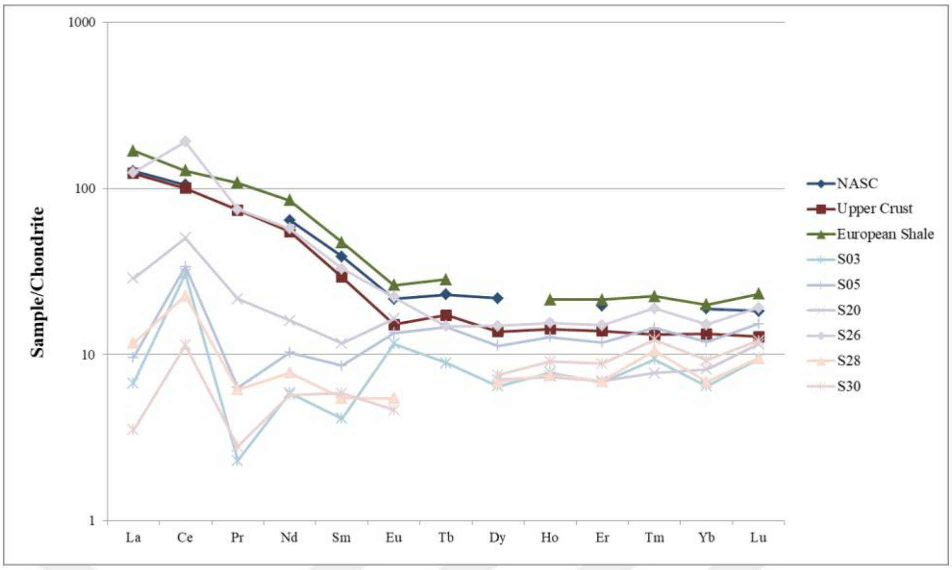


Figure 3.40. REE patterns of ungrouped soil samples

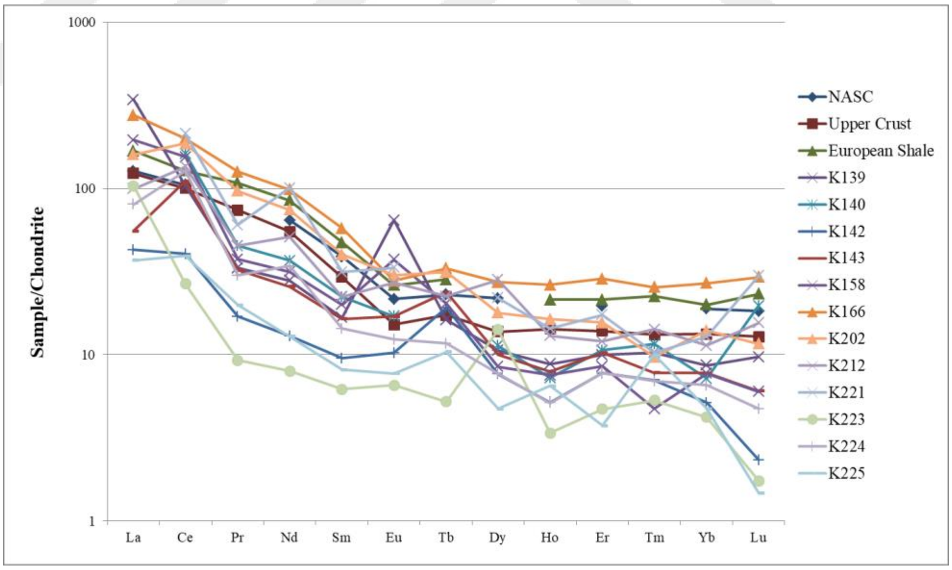


Figure 3.41. REE patterns of ungrouped samples

Concentrations of REEs in all samples were evaluated with the shape of the REE pattern, Eu anomaly and REE fractionation to contribute the multivariate analyses as a complimentary method.

Samples were classified into three main groups and two discrete groups based on the shape of REE patterns. Three main groups showed light rare earth element enrichment over heavy REEs and provided remarkable Ce-anomaly. La_n/Yb_n values between 5.5 and 7.5 indicated the light REE enrichment. Means of Eu anomaly of each group in the range of 0.8 – 1.2 represented the absence of Eu anomaly for the samples in these groups. As a result, these common features for LG, PG and SG samples indicate that these samples (one hundred thirteen pottery and local reference samples and twenty four soil samples) are from the same clay source. However, the source of Tb, Ho and Tm anomalies probably caused by the variations of hornblende in the clay paste.[116]

3.3. Summary of Compositional Groups in Komana Pottery

The samples were grouped separately by petrographic, XRD and ICP-MS analyses and these groups were combined to define pottery compositional groups. Semi-finished and tripod samples were taken as references in deciding local productions.

The pottery which have used for servicing food were divided into five groups in terms of decoration type and typology: *1) incised decorated glazed pottery*, *2) undecorated glazed pottery*, *3) glazed pottery with white paste*, *4) unglazed moulded ware* and *5) unglazed pottery*. Apart from pottery with service function, coarsewares (cooking vessels and storage jars) were selected for analysis in order to represent local clay. Coarsewares occasionally are assumed to be local production and they are used as local references in provenance analyses especially when local reference samples are absent in the archaeological context.[131]

Visual investigation showed that almost all of glazed pottery samples have red, dense and homogenous paste with few visible grains. However, sample K166 is an exception to these samples since it has white paste which is remarkable with its very porous white paste including black additives. Generally, the pastes of glazed pottery are covered with white slip decorated with incised decoration techniques such as sgraffiato technique which is the most common technique used on the interior and exterior surfaces of glazed pottery occasionally with champlevé technique; or on only interior surfaces of the samples which have slip painting decoration on the exterior surfaces. In addition to incised and slip painting techniques, there are also undecorated glazed pottery samples. Although the decoration patterns are generally floral and geometric, there are two pottery samples with bird figure. The glaze colours are mostly monochrome green and yellow but brown and blue was also used in few samples. There are few glazed pottery samples having polychrome glaze composed of brown, green and yellow.

Pottery samples were divided into five groups according to their petrographic properties and mineralogical composition as *A, B, C, D and E* (Section 3.1.3). According to petro-mineralogical grouping, local reference samples present in A and B groups; glazed – unglazed pottery are in A, B and D and coarsewares are in C, D and E groups. Thin sections of test tiles produced from soil samples and bulk mineralogy of soil samples were compared with archaeological samples in order to check the potential of local clay source. From the provenance perspective, Group B and Group C were found to contain schist – phyllite and polycrystalline metamorphic rock fragments classified as local rocks with geological literature and test tiles representing local clay as well.[83] It is difficult to interpret thin section of the samples in Group A which was produced from very fine clay. Group D samples consist of white paste samples while Group E contains coarsewares made of mica-tempered clay.

The concentrations of major, minor and trace elements in the samples were determined by ICP-MS and interpreted with statistical methods.

The similarity in elemental concentration between biscuit-fired pottery samples and tripod stilts which are defined as local reference in this study, were tested by t-test and Mann-Whitney u-test. The result showed that element concentrations in these two sample groups are very similar (Section

3.2.5). If in-group variations of element concentrations are less than 20%, then local reference samples can be attested to a single source.[185] Thus, the local reference samples were defined as references of single production in Komana.

The samples were divided into four groups (L1, L2, L3 and M) due to similarity in elemental concentrations in the samples using cluster analysis. Pottery samples in L1 and L2 were attested as local pottery since these groups contain all local reference samples (biscuit-fired and tripod stilt samples). The pottery samples in the group L3 consist of only pottery and soil samples. The group M includes discrete (K223 and K225) samples and possibly unpreferable soil samples (S03, S05, S06, S12, S13, S14, S28 and S30).

PCA analysis produced four new components having linear correlation with original variables which are elemental concentrations. The elemental concentration results in the entire sample were interpreted through scatter plots drawn with new components which contain information came from concentrations of elements (Section 3.2.6). The scatter plots show that samples in groups L1, L2 and L3 formes a single large cluster, whereas concentrations of element in the samples in M group (K223 and K225) are differed significantly from the rest of the samples. Cooking pot samples K134, K135, K136 and storage jar K137, cooking pot sample K206, samples K202 and K219 and glazed pottery K166 were also separated as subgroups from the single large cluster. The presence of K202 and K219 in the petrographic group E and K166, K206, K223 and K225 samples in the petrographic group D indicate that the chemical and mineralogical composition of these samples are different from the samples in single large cluster.

Samples were grouped into seven groups based on REE patterns as explained in Section 3.2.7. LG1 to LG4 encoded samples contain local reference samples, while PG1 to PG3 groups contain only pottery samples.

These seven sample groups were found to have generally similar REE patterns. The samples which did not match with these seven sample groups were named as ungrouped pottery samples including K139, K140, K142, K143, K158, K166, K202, K212, K221, K223, K224 and K225.

Compositional groups were defined by combining the results obtained from the pottery typology and elemental and mineralogical analyses in this study. The sample percentages in each sub-group of main compositional group are given in Figure 3.42. Pottery samples in compositional groups are given in Table 3.13. In-group variation of elemental concentrations is given Appendix K.

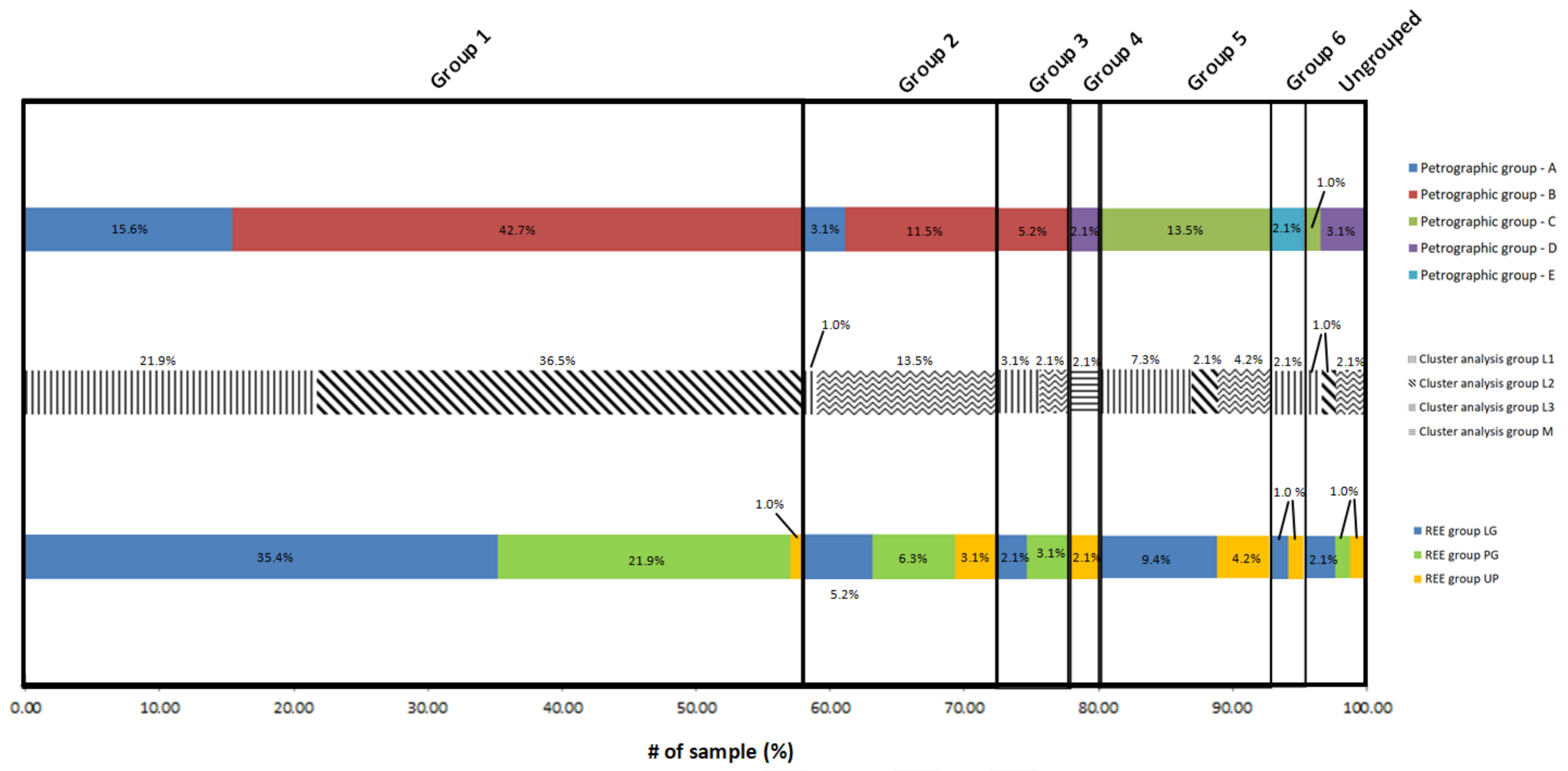


Figure 3.42. The chart showing sample percentages in each sub group (petrographic, cluster and REE) of final compositional groups

Table 3.13. Pottery samples in the compositional groups

Compositional Groups	**Samples**
Group 1 - Local Glazed Pottery	K101, K102, K103, K104, K105, K106, K107, K108, K109, K110, K111, K112, K113, K114, K115, K117, K118, K119, K122, K123, K124, K125, K128, K129, K130, K132, K144, K146, K147, K148, K149, K150, K151, K152, K153, K154, K155, K156, K160, K161, K167, K168, K169, K170, K185, K199, K200, K201, K203, K204, K210, K211, K212, K215, K220, K226
Group 2 - Glazed Pottery	K131, K143, K145, K158, K159, K164, K171, K172, K173, K184, K213, K222, K228, K221
Group 3 - Moulded Wares	K120, K121, K126, K216, K227
Group 4 - Turquoise Glazed Pottery	K223, K225
Group 5 - Local Common Coarsewares	K134, K135, K136, K137, K138, K139, K140, K141, K142, K209, K214, K218, K224
Group 6 - Mica Tempered Coarsewares	K202, K219
Ungrouped Samples	K133, K165, K166, K206

Group 1 – Local Glazed Pottery

Group 1 is mostly consisted of samples in the L1 and L2 groups defined by cluster analysis. Fifty six glazed ceramic samples, eighteen biscuit-fired pottery and eleven tripod samples are present in Group 1. Similarity of elemental composition among group 1 samples was also approved by scatter diagram of components of PCA. The group was attested as local since it contains local references.

Petrographic analysis revealed the presence of two clay pastes (fine and coarse pastes) used for glazed pottery production. Glazed potteries which were produced from very pure clay without grains and rock fragments are classified in petrographic group A, while coarse ones containing rock fragments and mineral grains originated especially from metamorphic rocks and calcite grains are classified in petrographic group B. Presence of two local clay pastes indicates that there are more than one step in fractionation process of clays. The feldspar grains and polycrystalline metamorphic rock fragments, small deformed phyllite/schist fragments were detected in the local glazed pottery are consistent with local rock types and test tiles. Firing temperature was estimated around 800 – 850 °C due to the presence of pyroxene minerals formed at this temperatures.[160, 168, 169] The presence of deformed primary calcite grains in local glazed pottery indicates that firing temperature was not high enough to decompose the calcite totally. Thus, firing temperature can be estimated around 800 °C for the local glazed pottery produced with coarser paste. Presence of hematite minerals suggests that the pottery samples in this group were fired in oxidizing atmosphere.[166]

Local glazed pottery of Komana has dense red paste covered with white-cream slip layer. The majority of samples were decorated with incised techniques such as sgraffiato and champlevé on both surfaces; but slip painting technique was used to decorate the exterior surfaces of few samples. Undecorated glazed pottery samples (K144, K151, K152, K161 and K210) were also found in Group 1 with regard to their mineralogical and elemental compositions. Monochrome and polychrome sgraffiato wares which are similar to Komana local glazed pottery have been found in wide geography including Anatolia, Iraq, Iran, Syria and Egypt between the 9th – 14th centuries.[77] The origin of this decoration technique was probably from China where it has been used between 7th – 9th centuries. Sgraffiato decorated glazed pottery became widespread in Anatolia during the Byzantine and its contemporary Seljuk period.[77] Spread of this type of pottery in such a large area may indicate that pottery production was carried out in different locations.

Chemical and mineralogical analyses indicate that the local glazed pottery of Komana was produced from single clay source. Among the local samples, the grain/matrix ratio in one group was quite low, while the grain/matrix ratio in the other group was high and the determination of calcite mineral indicated that clay fractionation and firing temperature were variable in locally produced potteries. This variation might be existed because of clay fractionation skills of different potters worked in same or different workshops in Komana.

Group 2 – Glazed Pottery

Group 2 consists of fourteen glazed pottery decorated with incised (sgraffiato and champlevé) and slip painting techniques in L3 group of cluster analysis. Majority of these samples presents in petrographic group B. The red and dense pastes of glazed pottery paste containing visible white additives (probably calcite) were covered with white slip layer and mostly green glaze, except five samples having yellow – brown glaze (K164, K171, K172 and K173).

The results of XRD and petrographic analyses suggest that the mineralogical compositions of these samples are similar to the local glazed pottery group (Group 1). Although the evaluation of the components produced by PCA analysis indicated that Group 2 samples had similar element concentrations as Group 1 samples, this group was not classified as local since there was no local reference sample in L3 group after cluster analysis.

Group 3 – Moulded Wares

There are five unglazed pottery samples made by moulding technique. In cluster analysis, K121, K126 and K227 samples were included in the L1 group with local references, and K120 and K216 samples were in the L3 group. Similarly, scatter diagram drawn with component 1 and 2 shows the connection between moulded wares and local glazed pottery (Group 1) as shown in Figure 3.27.

XRD analysis revealed that moulded wares have mineralogical composition consisting of mica, calcite, hematite, feldspar and quartz. Besides quartz and feldspar which are commonly found in soil; mica, calcite and hematite minerals provided information about provenance and production techniques of moulded wares. The presence of mica mineral in the pastes of these samples with XRD and thin section analyses indicates the use micaceous clay for moulded wares. Local lithology and mineralogical analyses of soil samples and test tiles showed that the mica-containing phyllite-schist rocks are frequently found around Komana (Section 3.1.3). Identification of fragments of phyllite-schist in a moulded ware (K227) in petrographic analysis reinforces the possibility of local origin of moulded ware. The presence of calcite grains in moulded wares in XRD analysis makes it possible to estimate firing temperature for the moulded wares between 600 and 800 °C which is slightly lower than that of the local references.

Although there are no archaeological findings such as mould pieces or production wastes related to the production of mould wares in Komana, the results of mineralogical and chemical analysis indicated that these wares might be locally produced in Komana.

Group 4 – Turquoise Glazed Pottery

Two samples (K223 and K225) with unslipped white paste covered with blue – turquoise glaze are quite different visual properties such as glaze and paste colour from other pottery types. PCA and cluster analyses clearly revealed the difference in element concentration between these two samples and other pottery types. Petrographic analysis showed that calcareous clay matrix tempered with angular quartz grains in these samples. The presence of quartz and undecomposed calcite were also detected in the XRD spectra of these samples. Presence of calcite grains showed that firing temperature of these samples can be estimated as around 600 °C, thus two samples can be classified as low-fired potteries. These two turquoise glazed potteries represent different production technologes and raw materials in the sample collection in this study.

There are only few turquoise glazed pottery samples found in Komana and they do not provide any information about under or over glaze decoration. Similar type of pottery samples were found in the kiln and dump site contexts in the Ahlat excavations.[60] It is reported that this type of pottery found in Ahlat are connected to the pottery productions in Syria and Iran.[60]

The fact that these two samples have a very different chemical and mineralogical composition than that of the other pottery groups and soil samples suggesting that these samples may have been imported to Komana.

Group 5 – Local Common Coarsewares

Samples of coarsewares are lid, handle and body parts of cooking pots and storage jars. It is generally assumed that coarsewares, especially cooking pots were made by using available clay sources around settlements. Coarsewares were divided into three groups according to their petrographic - mineralogical characteristics. Petrographic group C including mostly coarsewares contains large polycrystalline metamorphic rock, phyllite – schist and limestone fragments. Similar mineralogical composition was observed in the most of test tiles artificially produced from soil samples gathered around Komana. The mineralogical analyses showed that coarsewares were fired in a reducing atmosphere between 600 – 800 °C which is not enough to decompose calcite grains in the clay.[157] Rock fragments and mineral grains are naturally present in the clay.

Thin section analysis showed that coarsewares were made of gritty clay containing large grains. The presence of grains in the clay not only modifies the workability of the clay, but also increases the thermal shock resistance of the final product.[7] Although there is no direct evidence that rock fragments and mineral grains were intentionally added to the paste, the presence of these grains in clay was undoubtly a technological choice of the potter.

In cluster analysis, the most of the coarsewares were clustered in L1, L2 and L3 groups. PCA results confirmed the similarity in elemental composition between the local reference samples and coarsewares. Analytical results indicated that the most of coarsewares were probably produced from local raw clay around Komana.

In some of the previous provenance studies, coaserwares were selected as local reference.[131] Although the clay used to produce coarsewares is different from the raw materials of local glazed ceramics, the analysis of coarseware samples provided successful identification of the available clay around Komana.

Group 6 – Mica Tempered Coarsewares

Two coarseware samples (K202 and K219) were differentiated from local common coarsewares (Group 5) with their paste intensively tempered with mica minerals which are visible even to the naked eye.

Thin sections of these samples represent mineralogical composition included mica flakes deliberately added to clay paste containing metamorphic rock fragments. The presence of mica mineral was also determined by intense characteristic mica-illite peaks around 9.95-10 Å (8.8 – 9°) in XRD spectra of K202 and K219 samples.

Statistical analyses showed that chemical compositions of these two samples are similar to that of the local coarsewares. It is known that mica minerals have been deliberately added to the pottery pastes and slips since it provides shiny surface. Although these two samples appear to be in local groups due to similar chemical compositions, there is no doubt that they have manufactured through a different production technology because of mica tempering.

Ungroupped Samples

Three glazed and unglazed pottery samples and one coarseware having different chemical and mineralogical compositions compared to other samples were classified as ungrouped samples. the petrographic analysis results showed that three samples (K165, K166 and K206) are in group D and one sample (K133) is in group C.

K165 and K206 samples in group D have green - buff pastes while K166 has a white paste tempered with black inclusions. The mineralogical composition of K165 and K206 are similar. Sample K166 which is similar to Group 4 turquoise glazed pottery with its calcareous white paste, but differs from this group with its black inclusions and very porous structure. Although these samples were similar to the local ceramics in the grouping with cluster analysis, PCA analysis results showed that the samples K166 and K206 elemental compositions are quite different than that of local raw materials.

The mineralogical composition of the sample K133 in Group C, which is thought to be used for service purposes, is similar to local coarseware samples. Cluster and PCA analysis results showed that this sample has similar chemical composition to that of the local raw material.

3.4. Soil Samples and Raw Materials around Komana

Clay, water and fuel are three necessary raw materials to prepare pottery paste. Apart from these required raw materials, tempers in the clay paste controlling the plasticity of clay, colouring agents used in paints and various oxides used in glazing are some of the other raw materials required for ceramic production in this period. Provenance studies showed that the raw materials used for production should not be far from the workshop.[10]

The quantity of biscuit-fired sherds and tripod stilts indicated the presence of at least one active workshop in Komana between 12th – early 14th centuries. Pottery workshop/s in Komana which is located on the banks of

Yeşilırmak and surrounded by mountains and large forests, should be easily supplied with fuel and water required for ceramic production. In this study, searching for raw material was focused on clay used for pottery paste. One of the main objectives of this thesis was to locate and characterize available clay sources used for paste preparation.

The lithological characteristics of the Yeşilırmak basin in which Komana is located were explored through previous publications and geological maps.[83, 85] It was revealed that Komana and surroundings are largely covered by lithological unit called Tokat metamorphics composing of schist – phyllite, marble, crystallized limestone and metabasic rocks (Section 1.5). Therefore, the clay used in ceramic production in Komana region is expected to contain fragments of these rocks. Petrographic analysis revealed that group B and C contain rock fragments which are compatible with local lithology (Section 3.1.3). In particular, the presence of large metamorphic rock fragments in local coarsewares group (Group 5) indicated that mineralogical composition of local coarseware group and local rock types are very similar to each other.

In order to locate the available clay sources, thirty soil samples were taken in 7 km zone from the center of Komana. Soil samples were classified into four regions according to sampling locations: northwest samples, south samples, east samples and northeast samples (Table 3.6). All samples were sieved by passing through a 2 mm sieve to get rid of the coarse material. XRD and ICP-MS analyses were carried out on the specimens taken from on powdered and sieved samples. Thin sections were prepared from the test tiles produced from sieved soil samples.

The results of thin section analysis showed that the mineralogical composition of most of the soil samples consisted of phyllite-schist type and feldspatic metamorphic rocks with limestone (Figure 3.43). While the mineralogical composition can be clearly detected in coarseware samples containing coarse grains, the comparison between tableware and test tiles could not be easily made through thin section analysis, because very fine paste of tablewares produced from fractionated clay fired at elevated temperatures. The rocks and mineral grains observed in thin sections are consistent with the local lithology mentioned in the geological survey in the region.

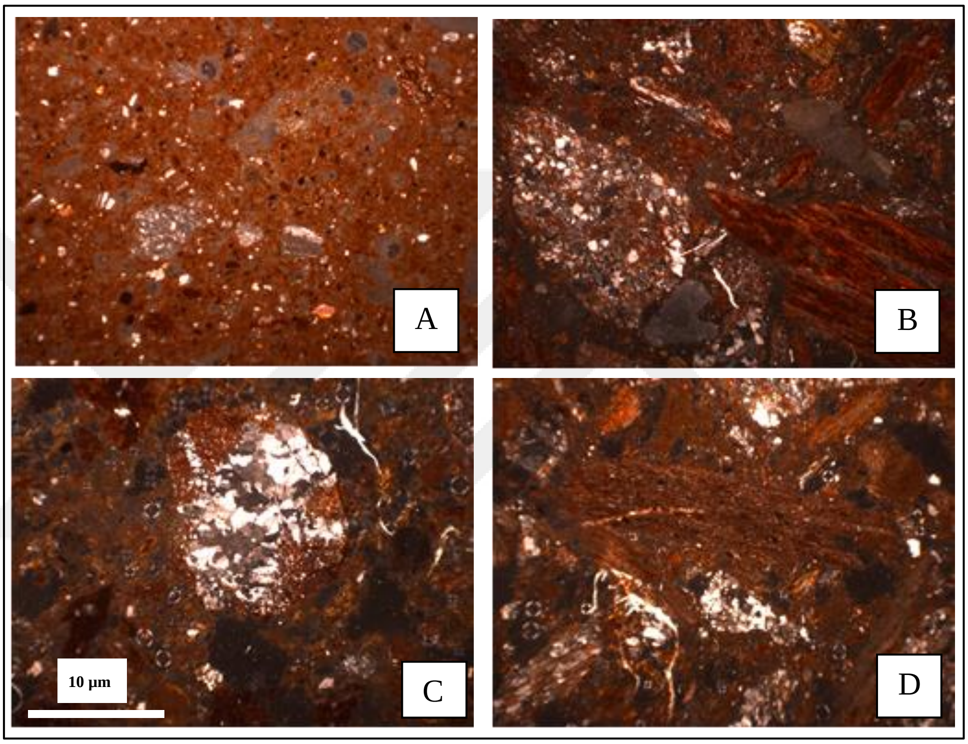


Figure 3.43. Thin section photomicrograph showing feldspar grains dispersed in clay matrix in S16 (A), large polycrystalline metamorphic rock and phyllite fragments in S18 (B), S21 (C) and S26 (D) soil samples. Scale is valid for A – D.

Clay and non-clay minerals in soil samples were identified with XRD analyses of bulk and oriented clay fractions in soil samples (Section 3.1.4). Kaolinite, chlorite, illite and expanding clay minerals (smectite, etc.) were identified in the oriented samples, as well as quartz, plagioclase, mica, calcite, dolomite and hornblende were detected in bulk soil samples (Table 3.5).

Clay-size fractions of six out nine samples (S1, S2, S3, S4, S5, S6, S28, S29 and S30) from the northwest of Komana were composed of swelling clay minerals. Illite and mica were absent or very few in these samples, except kaolinite rich S1 and S4. Two samples (S13 and S14) from Killik Tepe in the east of Komana, were composed of swelling clays and dolomite. Seven samples (S7, S8, S9, S10, S25, S26 and S27) were collected from the south of Komana. The mineralogical composition of S7, S8, S9, S25, S26 samples were composed of illite, kaolinite, mica and calcite with quartz and plagioclase. twelve samples (S11, S12, S15, S16, S17, S18, S19, S20, S21, S22, S23, and S24) were taken from the north east of Komana. S11, S12, S19, S20 and S21 samples contained expanding clay minerals in the clay-fractions. Mineralogical composition of S22, S23 and S24 samples consisted of illite, kaolinite, mica with quartz and plagioclase. S15, S16, S17 and S18 samples included illite, mica and calcite minerals with quartz and plagioclase.

When soil samples were evaluated based on their mineralogical composition, it was realized that samples from north-west and east part of Komana contain mostly swelling clays. This type of clay minerals absorb large amount of water which can cause production failures during its its evaporation from the soil sample. Thus, these clay minerals are not suitable for ceramic production and cause cracking during drying and firing steps in production process. The mineralogical composition of the local pottery groups was found to be composed of mica/illite, calcite and hornblende with quartz and feldspar minerals (Section 3.3). Based on this information, S1, S4, S7, S8, S9, S15, S16, S17, S18, S25 and S26 soil samples were found to have similar mineralogical composition (illite, quartz, plagiclase feldspar, mica, calcite, hornblende) with local reference samples.

PCA and cluster analysis were used to evaluate the element concentrations in soil samples. Based on result of the cluster analysis, S3, S5, S6, S12, S13, S14, S28 and S30 samples were not clustered with local pottery samples (Appendix I). These samples are among the soil samples that contain mostly swelling clay minerals. In the scatter diagram drawn with first two components produced by PCA, S1 and S4 of north western samples; S15, S16, S17, S18, S19, S21, S22 and S24 of north eastern samples and S7, S8, S9, S10 and S26 from the southern samples have similar element compositions with the local reference samples (Figure 3.44).

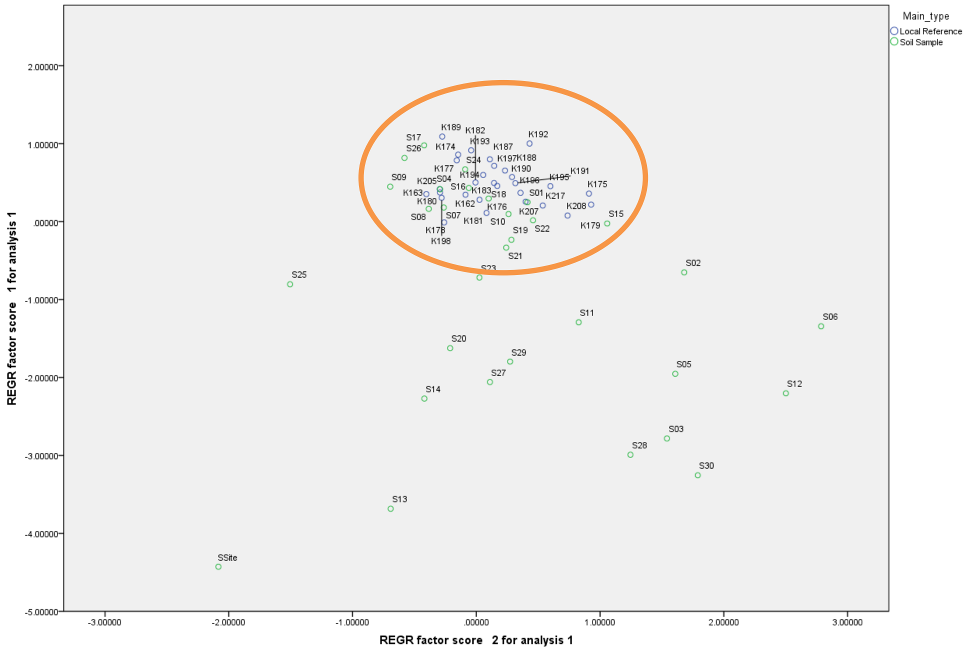


Figure 3.44. Scatter diagram of component 1 and component 2 showing distribution of soil samples and local reference samples

When mineralogical and elemental compositions of soil samples were interpreted together, it was deduced that elemental concentrations of S7, S8, S9, S15, S16, S17, S18, S25 and S26 samples containing mica, illite, calcite and hornblende minerals were similar to the local reference samples. S7, S8, S9 samples were collected from the valley where Ballıdere village is located; S25 and S26 samples were taken from the slopes near the village of Bakışlı. S15, S16, S17 and S18 samples were taken from the points where the hills to the northeast of Komana and the valley floor overlap. It can be said that these four samples represent alluvial deposit (Figure 2.1).

Field survey aiming to discover clay sources for brick productions in 1970s by MTA, one available source found very close to the town of Emirseyit.[197] During the interviews with the villagers from Bula village in the east of Komana, brick production was made 1-2 km east of Komana until 1980s. A villager who worked in the factory mentioned that the production was made using the deposits of the Yeşilırmak River.

Within the scope of this thesis, a field work was conducted to look for workshop/s using traditional methods in Tokat and its vicinity in 2015. An active workshop known from the publications in the town of Emirseyit, 15-20 km west of the city of Tokat was visited.[198] Kâzım Çömlekçioğlu, the potter of this workshop stated that they have used alluvial deposits to prepare clay paste during face-to-face interview with him. The tools, equipments and resting pools used in this workshop were also investigated during this visit.

As a result, petro-mineralogical and chemical analysis results indicated that the illite-rich clays on the slopes of the southern valleys and alluvial deposits of Yeşilırmak have similar mineralogical and chemical composition with local references and these clay sources may have been used in ceramic production in the past. Conversely, the samples containing swelling clay minerals are not likely to be preferred in pottery production. It can be concluded that potters were aware of suitable raw materials to produce pottery paste.

3.5. Limitations of the Study

Potential limitations of this study were sampling bias, analytical performances on different samples and limited number of the previous studies in this region. The details of these limitations and how to minimize the impact of limitations were discussed below.

The general approach on pottery provenance studies is to identify the chemical variations in pottery samples and to compare them with reference samples groups attested to workshops, and directly with the raw materials that potentially used in the production. However, the variations in elemental and mineralogical compositions possibly be changed by geological, cultural, technical and taphonomic factors.[199] These factors should be carefully taken into account in order to obtain elemental subgroups depending on raw material used for the preparation of pottery samples.[200]

This study has potential limitations in the sampling stage. The samples taken for archaeometric analyses aiming especially reconstruction of pottery mobility should be sampled from the stylistically grouped pottery.[71] However, pottery specialists did not start to study pottery collection of Komana when samples were taken for this thesis. With being aware to the common sampling procedure following taking samples from well-defined pottery groups, this study followed taking at least five to ten representative samples reflecting decoration techniques (sgraffiato, champlevé, slip painting decorations or undecorated glazing) and forms from in the glazed pottery and moulded wares and coarsewares in the archaeological layers dated back to Seljuk period. However, this strategy failed at some points such as for monochrome turquoise glazed pottery represented with only two samples and could cause over-sampling from a single production of glazed pottery.

Statistical power analysis is commonly performed to determine the smallest sample size which is necessary to detect the effect of a statistical test at the desired level of significance. The power of a statistical test (1-β) can be defined as avoiding type II error (β) which occurs when the null hypothesis is indeed false, but is not rejected.[143] It depends on three parameters: the significance criterion, the sample size, and the effect size.[201] In this thesis, the sample size had already been determined before chemical analyses. Thus, the statistical power analysis was performed through comparing the means of element concentrations among three groups (glazed and unglazed pottery samples, local reference samples and soil samples) presenting finished products, local reference and raw materials with the two-sample t-test. Gpower© software with version 3.1 was used for analysis.[202, 203] Powerful tests which have power value close to 1.0 are more sensitive to detect a real difference between parameters [201] According to the result of power analysis given in Appendix K, two-sample t-test produced powerful results especially for rare earth elements having power value between 0.5 - 1.0 indicating the analysis is powerful with the given sample size. Power value calculated for the concentrations of major and minor elements is lower than that of rare earth elements. It can be concluded that the concentration of rare earth elements are more useful in differentiating sample groups in terms of provenance of pottery samples.

Mineralogical and elemental compositions of a production attested to a local workshop in Komana was determined with the analysis of local reference samples. Local reference samples which were biscuit-fired and tripod stilt samples, produced from the same clay paste used to produce pottery. Beside undoubtedly local samples or stricto sensu, coarsewares consisting of cooking pot and storage jars have assumed to be produced from clay collected around Komana were also sampled. Coarsewares were used to represent local clay if local reference samples such as biscuit-fired or production waste samples were not available for analysis.[131] In this thesis, mineralogical comparison of the test tiles made from soil samples with coarseware samples showed that both sample types include coarse rock fragments and mineral grains in their paste. Moulded wares, which are characteristic pottery of the Seljuk period as glazed pottery, were also sampled to test the production of unglazed ware types in Komana.

Locating clay sources used for the production of potteries in the past is another problematic part in the provenance studies.[204] The source clay used in the past might be changed, lost and completely exploited. Moreover, potters often fractionated clay with levigation, mixed with different clays or added tempering materials to prepare the paste with desired properties. The effects of changes in elemental composition of pottery caused by such interventions including firing were discussed in some publications.[187, 188]

Kilikoglu reported that the composition of elements were increased after purification and suggested to compare raw clays after treatment with pottery samples. In order to mimic the raw material used for the production of pottery samples, soil samples were sieved and homogenized with agate mortar for ICP-MS analysis, and artificial samples (test tiles) were prepared from the collected soil samples for petrographic analysis.

The other critical step in clay sampling was to sample the soil samples around Komana. In the literature, sampling was made from clay beds used in modern production as in Sagallasos.[111, 205] Unfortunately, no modern clay bed or modern facility of tile or brick production site were identified around Komana with one workshop using traditional methods which is still active in the town of Emirseyit, 25 km west of Komana. The workshop was visited to get information about traditional methods of raw material extraction, fractionation and storage of raw materials and finished products. In accordance with the personal communication with the potter for the availability of clay, the alluvial deposit at the banks of Yeşilırmak was sampled.

Elemental and petrographic analyses are two methods used in the provenance analysis of archaeological pottery. Although there are some strengths and weakness of these methods compared to each other, generally these methods are used as complementary techniques.[120] Petrographic analysis has produced limited data on the mineralogical composition of pottery produced from fractionated clay, defined as “petrographic A” group in glazed pottery. However, the compositional similarities between the thin sections of coarsewares and test tiles containing coarse grains and rock fragments were revealed by petrographic analysis. XRD was used to identify crystal phases having a grain size which was too small to be identified by thin section analysis.

Concentrations of elements in the pottery and soil samples were determined by ICP-MS. The high C_{Var} value around 50% for concentration distributions of elements in coarsewares and soil samples indicated the dispersion and heterogeneous nature of these samples. For glazed pottery and local reference samples, it can definitely be concluded that concentrations of elements especially trace elements are more successful for grouping the pottery samples depending on their origin. However, silica phase could not be dissolved completely therefore silicon concentration in the samples was not reported in scope of this thesis. Concentrations of Co, Ni, Zn, Cr and Sc were below limit of detection in some of the samples. Although concentration of calcium has been frequently used to group pottery produced from calcareous clay in provenance studies, calcium concentration was not determined due to the high concentration of calcium in reagent blanksolutions.[22, 71, 177] Absence of concentration values of Co, Ni, Cr and Sc prevented the identification of source rock using the concentration ratios of such as Co/Th, Co/La or Sc/Th. Since the absence of these elements broke the integrity of the data set, these elements were also removed from the data set examined in PCA and cluster analysis.

This thesis provides the first chemical analyses results for provenance study of pottery samples found in Komana. There are two two published articles in which pottery found in Komana excavation were stylistically evaluated. The first one published by Vorderstrasse in 2015, an evaluation was made on the ceramics sampled from the archaeological context called cesspit.[80] The other study was published by Karasu and Özkul-Fındık examining figured pottery samples dated to Seljuk period.[81] In Turkey, the archaeometric studies on pottery of Seljuk period are also limited and few publications focusing on production technology of pottery from Akşehir and Hasankeyf, both are geographically far from Komana.[206, 207]

CHAPTER 4

CONCLUSION

Within the scope of this thesis, three main aspects of pottery production in Komana were studied with petrographic, mineralogical and elemental analyses. The results of these three methods were used to investigate local glazed pottery and its production technology, locating clay sources used for production and identifying pottery imported from other settlements in this study. In order to find reliable answers to these questions interdisciplinary approach involves an application of a specific sampling strategy, use of complementary techniques (petrographic thin section, XRD and ICP-MS) and using multivariate statistical analyses to interpret the large and diverse amount of data obtained from these techniques. In this thesis, selecting samples from locally produced pottery in Komana which are biscuit-fired pottery and tripod stilts was critical to decide the presence of local production in past. Using analytical techniques, a reference data produced so that mineralogical composition and concentrations of elements in the local reference samples could be used either to localize glazed pottery or to define import wares.

The petro-mineralogical grouping and the results of multivariate statistical analyses using elemental concentration data both came out a single inference that is the most of the glazed pottery being the members of a large local group. Hereby, fifty six glazed pottery samples were defined as local glazed pottery and they were attested to a workshop active in 12th – early 14th centuries in Komana. Even though the local group represented low variation (10 – 20%) in element concentrations and having almost same mineralogical composition (quartz, feldspar, hematite, pyroxene), the presence of undeformed/partly deformed calcites and large feldspars in the pastes were also detected with optical microscope. This indicates presence of deviations during production stages; one in fractionation of clay and the other in firing temperature in the kiln. The craftsmanship of different potters may use different parameters during the pottery production to improve the quality of pottery in each production line.

Samples of coarsewares which were assumed to be produced from gritty clay collected near Komana were specifically selected to understand local lithology and to compare them with test tiles samples. Thin sections of the most of the coarsewares are dominated by the fragments of phyllites-schists and polycrystalline metamorphic rocks and limestones. The presence of two coarseware samples having mica-tempered pastes shows the use of different paste preparation techniques in coarseware production. Petrographic examination produced superior results over elemental analysis for coarsewares with identification of local rock types in the thin sections and shared mineralogical composition in combination with the test tiles of soil samples. The performance of petrographical analysis on fine-grained glazed pottery samples was limited in comparison to the elemental analysis. This shows the importance of using more than one method in such studies.

The pastes of moulded wares were clearly produced from finer clay compared to coarsewares but coarser than glazed pottery. Mineralogical composition of moulded wares composed of quartz, feldspar, calcite, mica/illite and hematite indicated that moulded wares were fired at temperature range of 600 to 800 °C which is lower than that of glazed pottery. Even though statistical analyses showed that the moulded wares were probably produced from local clay, these samples could not be securely localized to Komana due to the lack of local reference samples for this group.

The other aim of this study was to find available clay sources for pottery production. Finding these sources was one of the most difficult part of this study. In order to overcome to the problems related to sampling of clay sources used in the past, traditional production in Tokat were investigated and modern clay deposits were tried to be located before sampling possible clay sources. Unfortunately, traditional production is very limited nowadays and only one workshop found as actively producing potttery and one demolished brick factory was able to be located in Tokat and no modern facilities of clay exploitation for ceramic industry were found. However, chemical and mineralogical analysis of soil samples showed that the most suitable clay for glazed pottery production might be alluvial deposits of Yeşilırmak. The mineralogical composition of the deposit consisting of illite/mica, calcite, quartz, feldspar and hornblende fits with the paste of local glazed pottery.

Unlike all other samples, mineralogical analyses showed that pastes of two monochrome turquoise-glazed potteries were made of calcareous clay tempered with quartz grains fired at low temperatures insufficient to decompose calcite. These samples were classified as imported due to the fact that calcareous clay, which has not been detected in the survey and sampling around Komana, was used in the production of pottery samples and the techniques (quartz tempering and low firing temperatures) used in production were very different than all other samples. Even though the production locations of these turquoise glazed potteries have not known, productions of similar samples in the 12 – 14th centuries were discovered with the archaeological survey in Ahlat in Turkey and Raqqa in Northern Syria.

The studies on distribution of pottery dated to medieval periods when Byzantine, Seljuk and Beylik periods concurrently existed in Anatolia have concentrated on the samples came from the settlements on the Aegean and Mediterranean coasts. There is no study in the literature for this period in the Black Sea region. Komana was located in the region in where cultural, political and economic interactions were intensively existed in 12 – 14th centuries. Undoubtedly, east-west oriented roads in the Central Black Sea region connecting Anatolia to the Caucasus and Iran and important ports in Sinop and Samsun contributed to this interaction. Potential studies in the future on pottery distribution in this region will certainly contribute to the understanding of regional economic, political and cultural interactions.

Glazed pottery is considered to be luxurious rather than daily use consumer product. Numerous pieces of glazed pottery with biscuit-fired ones found in Komana prove the glazed pottery production for luxurious consumption. As it is located in the Central Black Sea region, Komana can be defined as a settlement away from the major centers in western Anatolia. Archaeological studies in settlements such as Komana will certainly contribute to the understanding of production and consumption in rural sites in Medieval Anatolia.

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APPENDICES

A. VISUAL ANALYSIS

Visual properties of pottery samples are given in Table A1. (GP: Glazed pottery, UGP: Unglazed pottery, CW: Coarsewares, TS: Tripod stilt, BF: Biscuit-fired, TW: Tableware, CP: Cooking pot, ST: Storage jar). Question mark (?) used for indecisive situations.

Table A1. Visual Analysis of pottery samples

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K101	GP	TW	13th	Sgraffiato	White	Green	No deco	No slip	Green	Red	White
K102	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green, yellow	Orange	None
K103	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	White	Green	Red brown	White
K104	GP	TW	13th	Sgraffiato	White	Green	Slip painted	White	Yellow	Red	None
K105	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	White	Green	Red	None
K106	GP	TW	12-13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red	None
K107	GP	TW	13th	Champleve, Sgraffiato	White	Green	Slip painted	White	Green	Red	?
K108	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White (few)
K109	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Brown	White
K110	GP	TW	12-13th	Sgraffiato	White	Green	Sgraffiato	White	Green	Red brown	White (few)
K111	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Orange	None
K112	GP	TW	13th	Sgraffiato	White	Yellow	No deco	White	Green	Red brown	White
K113	GP	TW	12-13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White
K114	GP	TW	13th	Sgraffiato	White	Brown, Green	Sgraffiato	White	Green	Red	None
K115	GP	TW	12th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Orange	None

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K117	GP	TW	13th	Slip painted	White	Green	Slip painted	White	Yellow	Red orange	None
K118	GP	TW	12-13th	Sgraffiato	White	Yellow	Sgraffiato	White	Yellow	Red brown	None
K119	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red	Dark
K120	UGP	TW	12-13th	No deco	No slip	No glaze	Moulded	No slip	No glaze	Grey	None
K121	UGP	TW	12-13th	No deco	No slip	No glaze	Moulded	Micaceous slip	No glaze	Orange	None
K122	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	None
K123	GP	TW	12-13th	Sgraffiato	White	Green	Sgraffiato	White	Green	Red brown	?
K124	GP	TW	12-13th	Sgraffiato	White	Green	No deco	White	No glaze	Red brown	?
K125	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	No slip	No glaze	Red brown	?
K126	UGP	TW	12-13th	No deco	No slip	No glaze	Moulded	Traces of slip	No glaze	Brown	?
K128	GP	TW	12-13th	Sgraffiato	White	Yellow	No deco	White	Yellow	Red	White (few)
K129	GP	TW	13th	Sgraffiato, Slip painted	White	Yellow	No deco	White	No glaze	Red brown	White
K130	GP	TW	13th	Sgraffiato	White	Yellow	Champleve, Sgraffiato	White	Green	Red	Dark
K131	GP	TW	13th	Champleve, Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White
K132	GP	TW	13th	Sgraffiato	White	Brown, Yellow	No deco	Traces of slip	No glaze	Red	White

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K133	UGP	TW	12-13th	No deco	No slip	No glaze	No deco	Micaceous slip	No glaze	Brown	White, Black
K134	CW	CP	?	No deco	No slip	No glaze	Incised	Red brown	No glaze	Red brown	White, Black (large)
K135	CW	CP	?	No deco	Red brown	No glaze	No deco	Red brown	No glaze	Red brown	White, Gritty
K136	CW	CP	11-13th	No deco	No slip	No glaze	Corrugated, Incised	Slipped?	No glaze	Grey	White (large)
K137	CW	SJ	12-13th	No deco	No slip	No glaze	Raised deco	Red brown	No glaze	Grey	White
K138	CW	CP	?	No deco	No slip	No glaze	No deco	Light brown	No glaze	Red brown wt grey	White
K139	CW	SJ	?	No deco	No slip	No glaze	No deco	Light brown	No glaze	Brown	Gritty
K140	CW	CP	?	No deco	No slip	No glaze	No deco	Red brown	No glaze	Red brown	White, Black
K141	CW	CP	11-13th	No deco	No slip	No glaze	Corrugated	Red brown	No glaze	Red brown wt dark	Mica, White shells, Black
K142	CW	CP	?	No deco	No slip	No glaze	No deco	Red brown	No glaze	Grey	White
K143	GP	TW	12-13th	Sgraffiato	White	Green, Yellow	Sgraffiato	White	Yellow	Red brown	None
K144	GP	TW	12-13th	No deco	White	Green	No deco	White	Green	Red	None
K145	GP	TW	13th	Sgraffiato	White	Green	Sgraffiato	White	Green	Grey	White (few)
K146	GP	TW	13th	Slip painted	White	Yellow	Slip painted	White	Yellow	Red brown	White
K147	GP	TW	13th	Champleve, Sgraffiato	White	Green	Sgraffiato, Slip painted	White	Green	Red	White

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K148	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White
K149	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White
K150	GP	TW	12-13th	Sgraffiato	White	Yellow	No deco	No slip	No glaze	Red	White
K151	GP	TW	12-13th	No deco	White	Yellow	No deco	No slip	No glaze	Red brown	White
K152	GP	TW	12-13th	No deco	White	Yellow	No deco	White	No glaze	Red	White
K153	GP	TW	12-13th	No deco	white	Green	Sgraffiato	White	Green	Red	White, Dark
K154	GP	TW	13th	Sgraffiato	White	Yellow	No deco	White	Green	Red brown	-
K155	GP	TW	13th	Sgraffiato	White	Green	Slip painted	White	Green, yellow	Orange	Dark
K156	GP	TW	13th	No deco	White	Green	Sgraffiato	White	Yellow	Red brown	None
K158	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	No slip	Green	Red brown	White
K159	GP	TW	13th	Sgraffiato	White	Green	No deco	No slip	Green	Red brown	White
K160	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red	None
K161	GP	TW	12-13th	No deco	White	Green	No deco	No slip	No glaze	Red	White
K162	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Red brown	White
K163	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	Brown, yellow	Orange	White (few)

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K164	GP	TW	13th	Slip painted	White	Yellow	No deco	White	Yellow	Light red	None
K165	UGP	TW	12-13th	No deco	White	No glaze	No deco	White	No glaze	White	None
K166	GP	TW	11th	No deco	No slip	Green	No deco	No slip	No glaze	White	Black
K167	GP	TW	13th	Sgraffiato	White	Green, Yellow	Sgraffiato	White	Green	Red brown	Light
K168	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White
K169	GP	TW	12-13th	Sgraffiato	White	Green	Sgraffiato	White	Green	Red brown	White
K170	GP	TW	13th	Sgraffiato	White	Brown, Yellow	Sgraffiato	White	Green	Red	White
K171	GP	TW	12-13th	Sgraffiato	White	Brown, Yellow	No deco	No slip	No glaze	Red	White
K172	GP	TW	12-13th	Sgraffiato	White	Brown, Yellow	No deco	White	Brown, yellow	Red brown	White
K173	GP	TW	12-13th	No deco	White	Brown, Yellow	No deco	White	Brown, yellow	Red	White
K174	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Brown	White
K175	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	Brown, yellow	Red	White
K176	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Red	White
K177	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Light brown	White
K178	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	Green	Red	White

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K179	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Grey	None
K180	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	Green	Red	White
K181	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	Brown, yellow	Red	White
K182	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Red	None
K183	TS	TS	12-13th	No deco	No slip	No glaze	No deco	No slip	No glaze	Red	None
K184	GP	TW	12-13th	Champleve, Sgraffiato	White	Yellow	No deco	White	Green	Red brown	White
K185	GP	TW	12-13th	Sgraffiato	White	Yellow	No deco	White	Yellow	Red brown	White
K186	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	No slip	No glaze	Red	White
K187	BF	TW	12th	Sgraffiato	White	No glaze	No deco	White	No glaze	Orange	None
K188	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Brown	White
K189	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Brown	None
K190	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Orange	White
K191	BF	TW	12-13th	No deco	White	No glaze	Sgraffiato	White	No glaze	Red brown	White
K192	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	No slip	No glaze	Red brown	White
K193	BF	TW	12th	Sgraffiato	White	No glaze	Sgraffiato	White	No glaze	Red brown wt grey	None

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K194	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Orange	White (few)
K195	BF	TW	12th	Sgraffiato	White	No glaze	No deco	White	No glaze	Orange	None
K196	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	No slip	No glaze	Orange	White
K197	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Red	White
K198	BF	TW	12-13th	No deco	White	No glaze	No deco	White	No glaze	Red	White
K199	GP	TW	13th	Sgraffiato	White	Green	No deco	White	Green	Red	White
K200	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	White	Brown, yellow	Red brown	None
K201	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	White	Green	Red	None
K202	CW	CP	10-11th	No deco	No slip	No glaze	No deco	No slip	No glaze	Red brown	Mica
K203	GP	TW	13th	Sgraffiato	White	Brown, Green, Yellow	No deco	No slip	No glaze	Red brown	White
K204	GP	TW	12-13th	Sgraffiato	White	Green	No deco	White	Green	Red	White
K205	BF	TW	12th	Sgraffiato	White	No glaze	Sgraffiato	White	No glaze	Red	None
K206	CW	CP	10-11th	No deco	White	No glaze	No deco	White	No glaze	White	Dark
K207	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	White	No glaze	Orange	White
K208	BF	TW	12-13th	Sgraffiato	No slip	No glaze	No deco	No slip	No glaze	Red	White

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K209	CW	CP	11-13th	No deco	Red brown	No glaze	Corrugated, Incised	Red brown	No glaze	Grey	White
K210	GP	TW	12-13th	No deco	No slip	Green	No deco	White	Green	Orange	White (few)
K211	GP	TW	13th	Sgraffiato	White	Green, Yellow	No deco	No slip	No glaze	Brown	White
K212	GP	TW	13th	Sgraffiato	White	Green, Yellow	Sgraffiato	White	Green	Orange	White
K213	GP	TW	13th	No deco	No slip	Green	Sgraffiato	White	Green	Red brown	White (few)
K214	CW	CP	10-13th	No deco	No slip	No glaze	Incised	Burned slip	No glaze	Light brown	Black, White, Red
K215	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato, Slip painted	White	Yellow	Red	None
K216	UGP	TW	12-13th	No deco	No slip	No glaze	Moulded	Micaceous slip	No glaze	Orange	None
K217	BF	TW	12-13th	Sgraffiato	White	No glaze	No deco	No slip	No glaze	Brown	None
K218	CW	CP	11-13th	Corrugated, Stamped	No slip	No glaze	No deco	Red brown	No glaze	Red brown wt grey	White, Gritty
K219	CW	CP	10-11th	No deco	No slip	No glaze	No deco	Micaceous slip	No glaze	Black fabric	Mica
K220	GP	TW	13 or early 14th	Champleve, Sgraffiato	White	Brown, Green, Yellow	No deco	White	No glaze	Red brown	White
K221	GP	TW	12-13th	No deco	White	Green	No deco	Red brown wt	No glaze	Light brown	White (few)
K222	GP	TW	12-13th	Sgraffiato	White	Green	No deco	White	Green	Red	?
K223	GP	TW	12-13th	No deco	No slip	Blue, Green	No deco	No slip	No glaze	White	?

Table A1 Continued

				Interior Decoration			Exterior Decoration			Paste	
Sample Code	**Type**	**Function**	**Dating**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Surface Decoration**	**Slip Colour**	**Glaze Colour**	**Colour**	**Inclusions**
K224	CW	CP	11-13th	No deco	Red brown	No glaze	No deco	Red brown	No glaze	Orange	Dark brown, White
K225	GP	TW	12-13th	No deco	No slip	Blue	No deco	No slip	No glaze	White	None
K226	GP	TW	12-13th	Sgraffiato	White	Green	Sgraffiato	White	Yellow	Orange	None
K227	UGP	TW	12-13th	No deco	No slip	No glaze	Moulded	Micaceous slip	No glaze	Orange	None
K228	GP	TW	13th	Sgraffiato	White	Yellow	Sgraffiato	White	Green	Red brown	White

B1. SAMPLE PHOTOGRAPHS

GLAZED AND UNGLAZED POTTERY SAMPLES


K101


K101


K102


K102


K103


K103


K104


K104


K105


K105


K106


K106

K107 K107 K108 K108




K109 K109 K110 K110




K111 K111 K112 K112




K113 K113 K114 K114




K115 K115 K117 K117


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K221

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K223

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K225

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K226

K226

K227

K227

K228

K228

BISCUIT-FIRED SAMPLES


K174


K174


K186


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K205


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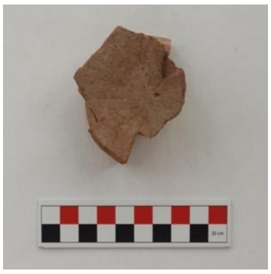
K207


K207



K208

K208

K217

K217

TRIPOD STILT SAMPLES

K162

K162

K163

K163

K175

K175

K176

K176

K177

K177

K178

K178

K179

K179

K180

K180

K181

K181

K182

K182

K183

K183

COARSEWARE SAMPLES

K134

K134

K135

K135

K136

K136

K137

K137

K138

K138

K139

K139

K140

K140

K141

K141


K142


K142


K202


K202


K206


K206


K209


K209


K214


K214


K218


K218


K219

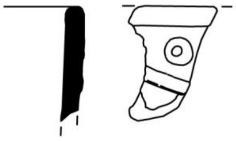

K219

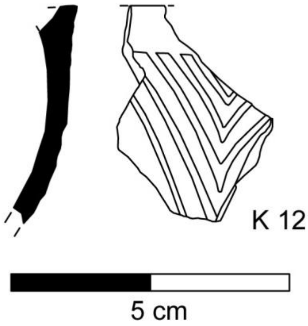

K224


K224

B2. POTTERY DRAWINGS

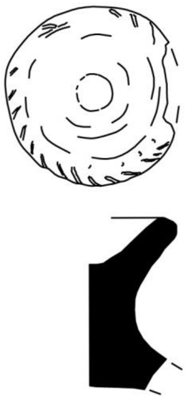
Moulded Wares

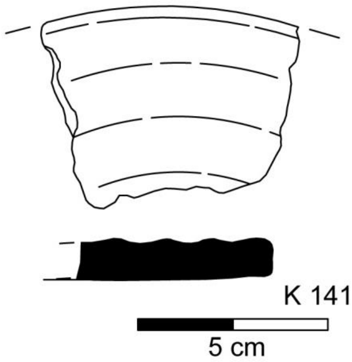

K 120



K 121

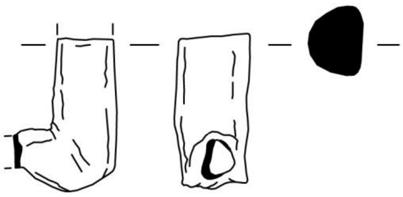
Cooking Pots

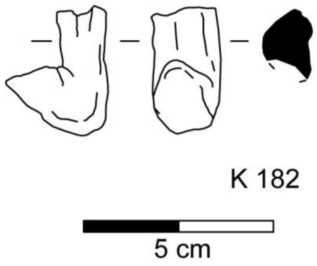

K 134



K 141

Tripods


K 176



K 182

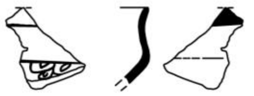
Biscuit-fired Bodysherds

K 192

Biscuit-fired Rims

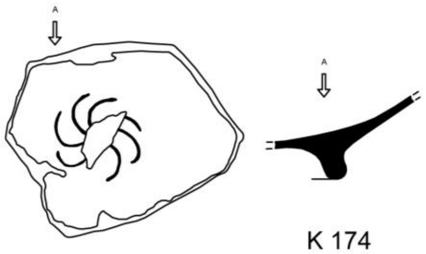
K 191

K 187

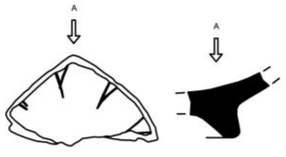


K 188

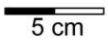
Biscuit-fired Bases



K 174

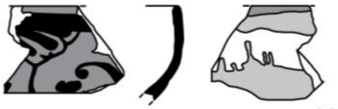


K 196



Glazed Pottery- Rims II

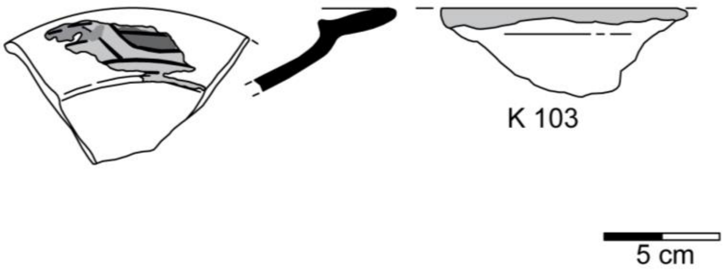

K 106


K 104


K 228

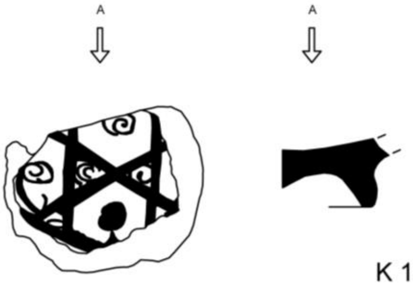

K 108


K 144

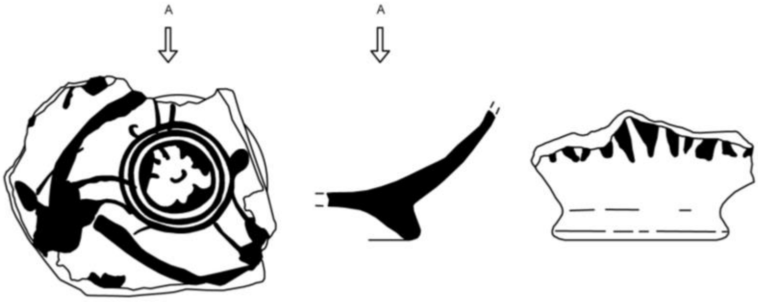

K 103

K 225

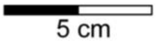
K 223



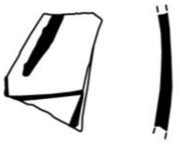
K 128



K 107- base



Glazed Pootery- Body sherds



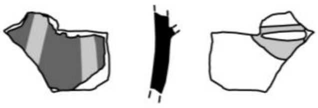
K 220

K 132

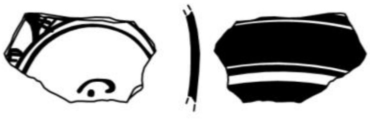
K 226

K 115

K 129



K 164



K 168

5 cm

C. ANALYTICAL FIGURES OF MERIT

Table C1. Limit of detection (LOD), limit of quantification LOQ, linear regression equation and R^2 for elements

Element	m/z	Unit	LOD	LOQ	Linear Regression Equation	R^2
Na	23	mg/kg	4.86	16.20	y=2219.25x-3551	0.9948
Mg	24	mg/kg	3.53	11.78	y=18.95x+116.47	0.9995
Al	27	mg/kg	5.24	17.47	y=10.89x-21.14	0.9941
K	39	mg/kg	3.23	10.77	y=2167.06x-32816	0.9975
Ti	49	mg/kg	1.13	3.75	y=0.86x+0.31	0.9989
V	51	mg/kg	0.52	1.74	y=26.39x+15.52	0.9982
Cr	53	mg/kg	1.56	5.20	y=3.11x-6.47	0.9973
Mn	55	mg/kg	1.18	3.92	y=57x-37.32	0.9983
Fe	57	mg/kg	23.56	78.52	y=1.14x-54.92	0.9848
Co	59	mg/kg	0.63	2.11	y=33.47x+3.53	0.9991
Ni	60	mg/kg	1.04	3.46	y=6.34x-6.02	0.9982
Cu	65	mg/kg	1.95	6.51	y=8.21x-54.41	0.9995
Zn	66	mg/kg	2.01	6.70	y=7.88x+0.68	0.9985
Sr	88	mg/kg	0.24	0.81	y=7611.26x+109	0.9997
Y	89	mg/kg	0.12	0.39	y=9344.57x-1849	0.9996
Zr	91	mg/kg	0.05	0.18	y=9.26x-2.52	0.9992
Ba	137	mg/kg	0.27	0.90	y=1510.17x+843	0.9998
La	139	µg/kg	7.07	23.56	y=10767.07x+317	0.9999
Ce	140	µg/kg	27.30	90.99	y=70.24x-3.83	0.9980
Pr	141	µg/kg	14.04	46.80	y=18433.16x+967	0.9997
Nd	146	µg/kg	15.24	50.81	y=3818.54x+137	0.9999
Sm	149	µg/kg	7.08	23.61	y=3273.32x+241	0.9997
Eu	153	µg/kg	19.32	64.39	y=14553.72x+526	0.9992
Tb	159	µg/kg	12.34	41.12	y=27104.26x+826	0.9993
Dy	163	µg/kg	17.63	58.77	y=7538.81x+205	0.9998
Ho	165	µg/kg	11.45	38.17	y=32907.27x-533	0.9998
Er	167	µg/kg	11.14	37.14	y=7616.69x-204	0.9992
Tm	169	µg/kg	10.05	33.49	y=36539.01x-829	0.9990
Yb	172	µg/kg	13.09	43.65	y=8628.6x-253	0.9990
Lu	175	µg/kg	15.14	50.46	y=38480.73x-779	0.9996
Pb	208	mg/kg	0.66	2.20	y=75.16x+68.1	0.9991
Th	232	µg/kg	9.29	30.96	y=23456.17x+803	0.9997
U	238	µg/kg	20.09	66.95	y=189.01x-10.14	0.9999

D. PETROGRAPHIC ANALYSIS

Petrographic characteristics of the samples are given in Table D1 (Abbrevations: GP: Glazed pottery, UGP: Unglazed pottery, CW: Coarseware, TS: Tripod stit, BF: Biscuit-fired pottery, Equi: Equi-dimensional, Elon: Elongated, Spher: Spherical, Mod: Moderately, PMR: Polycrystalline metamorphic rock fragments, Ph/Sc: Phyllite/Schist fragments, Cal: Calcite, Qrt: Quartz, Plag: Plagioclase, Hrnb: Hornblende, Hem: Hematite).

Table D1. Petrographic Characteristics of Samples

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K101	GP	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low	●				●				●	A
K102	GP	Reddish	High	Spher.	Medium	Equi.	Small	Well	Low					●					A
K103	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Medium-Low			●		●		●		●	B
K104	GP	Reddish	High	Spher.	Medium	Equi.	Small	Well	Medium-Low									●	A
K105	GP	Reddish	High	Spher.	Small	Equi.	Small	Well	Low					●		●			B
K106	GP	Reddish	High	Spher.	Large	Equi.	Medium	Poorly	Medium-Low					●		●			B
K107	GP	Orange	Mod.	Spher.	Medium	Equi.	Medium	Mod.	Medium					●		●			A
K108	GP	Orange	High	Spher.	Small	Equi.	Small	Mod.	Low					●					A
K109	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low					●					B
K110	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low					●		●			B
K111	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low								●		B
K112	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low					●		●			B
K113	GP	Orange	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●		●			B
K114	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium-Low							●			B
K115	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●		●			B
K117	GP	Orange	High	Spher.	Small	Equi.	Medium	Poorly	Medium					●				●	A
K118	GP	Brown	High	Spher.	Small	Equi.	Medium	Poorly	Medium					●					B
K119	GP	Reddish	High	Spher.	Small	Equi.	Medium	Mod.	Medium -					●		●			B
K120	UGP	Brown	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●					B
K121	UGP	Orange	High	Spher.	Medium	Equi.	Medium	Mod.	Medium			●							B

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K122	GP	Reddish	High	Spher.	Small	Equi.	Medium	Mod.	Medium -			●		●				●	B
K123	GP	Orange	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●				●	B
K124	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●	●			●	B
K125	GP	Orange	High	Spher.	Medium	Equi.	Medium	Mod.	Medium									●	B
K127	UGP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium			●							A
K128	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium					●				●	B
K129	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium	●				●				●	B
K130	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium	●				●		●		●	B
K131	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium	●		●		●		●		●	B
K132	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Mod.	Medium			●		●				●	B
K133	UGP	Brown	High	Spher., Elon.	Medium	Equi.	Medium	Poorly	Medium -	●		●	●	●	●			●	C
K134	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●	●	●		●				●	C
K135	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●		●	●	●					C
K136	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●		●	●	●				●	C
K137	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●			●	●				●	C
K138	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●		●	●	●				●	C
K139	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●	●	●	●	●				●	C
K140	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●	●	●	●	●					C
K141	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●	●	●	●	●				●	C
K142	CW	Brown	Mod.	Spher., Elon.	Medium	Equi., Elon.	Large	Very Poorly	Medium -	●			●	●	●				C

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K143	GP	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Mod.	Medium-Low										A
K144	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium					●				●	B
K145	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●				●					A
K146	GP	Reddish	High	Spher., Elon.	Medium	Equi.	Medium	Poorly	Medium	●				●				●	A
K147	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●	●	●	●			●	A
K148	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium					●		●		●	B
K149	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium			●	●	●		●			B
K150	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium			●	●	●	●	●			B
K151	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●	●	●		●			B
K152	GP	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium			●	●	●					B
K153	GP	Reddish	High	Spher., Elon.	Medium	Equi.	Small	Poorly	Medium-Low					●					A
K154	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●				●	B
K155	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low	●			●	●					A
K156	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low	●				●				●	B
K158	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low	●	●	●		●	●	●			B
K159	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -	●		●	●	●					B
K160	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●	●	●					B
K161	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●	●	●					B
K162	TS	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium					●	●			●	B
K163	TS	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●	●	●		●	●				B

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K164	GP	Reddish	High	Spher.	Medium	Equi.	Small	Well	Low			●		●					A
K165	UGP	Green	High	Spher.	Medium	Equi.	Small	Poorly	Medium-Low					●				●	D
K166	GP	Green	High	Spher.	Large	Equi.	Small	Poorly	Low			●						●	D
K167	GP	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium			●		●	●			●	B
K168	GP	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Medium-Low		●			●					B
K169	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low	●		●		●					B
K170	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium			●		●					B
K171	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●	●				B
K172	GP	Brown	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●	●				B
K173	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●	●				B
K174	BF	Brown	High	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●	●				B
K175	TS	Reddish	High	Spher.	Small	Equi.	Small	Poorly	Medium-Low	●		●		●	●				B
K176	TS	Reddish	High	Spher.	Small	Equi.	Small	Mod.	Low	●				●				●	A
K177	TS	Reddish	High	Spher.	Small	Equi.	Small	Mod.	Medium-Low	●		●		●			●		B
K178	TS	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium	●	●	●		●					B
K179	TS	Brown	High	Spher.	Medium	Equi.	Medium	Poorly	Medium-Low		●			●					B
K180	TS	Reddish	High	Spher.	Small	Equi.	Small	Mod.	Low			●		●				●	B
K181	TS	Reddish	Mod.	Spher.	Small	Equi.	Medium	Poorly	Medium		●	●		●					B
K182	TS	Reddish	High	Spher.	Small	Equi.	Small	Mod.	Low					●				●	B
K183	TS	Reddish	High	Spher.	Small	Equi.	Small	Mod.	Low		●	●		●					B

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund.	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K184	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Medium -Low		●			●					B
K185	GP	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium	●		●		●					B
K186	BF	Reddish	High	Spher.	Medium	Equi.	Small	Well	Low										A
K187	BF	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low			●		●				●	B
K188	BF	Brown	High	Spher.	Medium	Equi.	Medium	Mod.	Medium -Low			●		●	●			●	B
K189	BF	Brown	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low			●		●					B
K190	BF	Reddish	High	Spher.	Medium	Equi.	Small	Well	Low			●		●					A
K191	BF	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low	●				●				●	B
K192	BF	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low	●		●		●				●	B
K193	BF	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Low					●				●	B
K194	BF	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low			●		●					A
K195	BF	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low					●					A
K196	BF	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low	●				●				●	A
K197	BF	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low			●		●	●			●	B
K198	BF	Reddish	High	Spher.	Medium	Equi.	Small	Well	Low					●					A
K199	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low	●		●		●				●	B
K200	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Low		●			●					A
K201	GP	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low	●		●		●					B
K202	CW	Brown	High	Spher., Elon.	Large	Equi., Elon.	Large	Poorly	High		●			●			●		E
K203	GP	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low	●		●		●					B

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K204	GP	Brown	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low	●		●		●	●				B
K205	BF	Reddish	Mod.	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low				●	●	●			●	B
K206	CW	Green	High	Spher.	Medium	Equi.	Medium	Very Poorly	Medium	●			●	●					D
K207	BF	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Medium -Low	●				●				●	B
K208	BF	Reddish	Slightly	Spher.	Medium	Equi.	Small	Poorly	Medium -Low			●		●				●	B
K209	CW	Brown	Slightly	Spher.	Medium	Equi., Elon.	Large	Very Poorly	High	●	●			●			●		C
K210	GP	Reddish	High	Spher.	Small	Equi.	Small	Poorly	Low									●	A
K211	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low			●		●					B
K212	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low			●		●					B
K213	GP	Reddish	High	Spher.	Medium	Equi.	Medium	Poorly	Medium -Low		●			●					B
K214	CW	Brown	Slightly	Spher.	Medium	Equi.	Large	Very Poorly	High		●			●			●	●	C
K215	GP	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low					●					A
K216	UGP	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low					●					B
K217	BF	Reddish	High	Spher.	Medium	Equi.	Small	Poorly	Low					●					A
K218	CW	Brown	Slightly	Spher.	Medium	Equi.	Large	Very Poorly	High	●	●	●		●			●		C
K219	CW	Black	High	Spher.	Medium	Equi., Elon.	Large	Very Poorly	High	●	●			●			●		E
K220	GP	Reddish	High	Spher.	Small	Equi.	Small	Well	Low					●					A
K221	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Medium -Low			●		●					B
K222	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Low					●					B
K223	GP	Reddish	High	Spher.	Medium	Equi.	Small	Mod.	Medium -Low					●					D

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
K224	CW	Brown	High	Spher.	Medium	Equi.	Large	Very Poorly	High	●	●			●		●			C
K225	GP	Grey	High	Spher.	Medium	Equi.	Medium	Well	Medium - High				●	●					D
K226	GP	Reddish	High	Spher.	Small	Equi.	Small	Well	Low					●					A
K227	UGP	Reddish	Mod.	Spher.	Small	Equi.	Medium	Mod.	Medium -Low	●	●			●					B
K228	GP	Green	High	Spher.	Medium	Equi.	Small	Well	Low			●		●					B
S01	Test t.									●				●				●	
S02	Test t.									●				●					
S03	Test t.									●				●					
S04	Test t.									●				●					
S05	Test t.									●				●					
S06	Test t.													●				●	
S07	Test t.									●				●				●	
S08	Test t.									●				●					
S09	Test t.									●	●			●					
S10	Test t.									●				●	●				
S11	Test t.									●				●	●				
S12	Test t.									●			●	●				●	
S13	Test t.									●				●					
S14	Test t.																		
S15	Test t.									●			●	●				●	

Table D1 Continued

Sample	Type	Matrix		Pores		Grains				Rock Fragments			Mineral Grain						Grouping
		Colour	Hmg	Shape	Size	Shape	Size	Sorting	Abund	PMR	Ph/Sc	Cal	Qrt	Feld	Plag	Hrnb	Mica	Hem	
S16	Test t.									●			●	●	●				
S17	Test t.									●			●	●				●	
S18	Test t.									●	●		●	●					
S19	Test t.									●			●					●	
S20	Test t.									●				●				●	
S21	Test t.									●				●					
S22	Test t.									●	●			●				●	
S23	Test t.									●			●	●					
S24	Test t.																		
S25	Test t.									●			●	●					
S26	Test t.									●	●		●	●					
S27	Test t.																		
S28	Test t.									●				●				●	
S29	Test t.									●				●					
S30	Test t.									●				●					

E. XRD ANALYSIS

Crystalline phases identified in samples are given in Table E1 (Q: Quartz; Fe: Feldspar minerals; Ca: Calcite; Do: Dolomite; Mi/Ill: Mica/Illite; Cl: Clay Minerals; He: Hematite; Py (Dio/Woll): Pyroxene (Diopside/Wollastonite); Ho: Hornblende). Question mark (?) used for indecisive situations.

Table E1. Crystalline Phases Identified in the Samples

Sample	Sample Type	Q	Fe	Ca	Do	Mi/Ill	Cl	He	Py (Dio/Woll)	Ho
K101	GP	+	+	+	-	-	-	+	+	-
K102	GP	+	+	-	-	-	-	+	+	+
K103	GP	+	+	?+	-	-	-	+	+	+
K104	GP	+	+	-	-	-	-	+	+	+
K105	GP	+	+					+	+	+
K106	GP	+	+	-	-	-	-	+	+	+
K107	GP	+	+	-	-	-	-	+	+	+
K108	GP	+	+	-	-	-	-	+	+	-
K109	GP	+	+	-	-	-		+	+	-
K110	GP	+	+	-	-	-		+	+	-
K111	GP	+	+	-	-	-		+	+	+
K112	GP	+	+	-	-	-	-	+	+	-
K113	GP	+	+	-	-	-	-	+	+	-
K114	GP	+	+	+	-	-	-	+	+	+
K115	GP	+	+	-	-	-		+	+	-
K117	GP	+	+	-	-	-		+	+	-
K118	GP									
K119	GP	+	+	-	-	-	-	+	+	-
K120	UGP	+	+	+	-	-	-	-	-	-
K121	UGP	+	+	+	-	+	-	+	-	-
K122	GP	+	+	?+	-	-		+	+	+
K123	GP	+	+	-	-	-	-	+	+	-
K124	GP	+	+	?+	-	-		+	+	+
K125	GP	+	+	-	-	-	-	+	+	-
K127	UGP	+	+	?+	-	-	-	+	+	-
K128	GP	+	+	-	-	-		+	+	-
K129	GP	+	+	-	-	-		+	+	-

Table E1 Continued

Sample	**Sample Type**	**Q**	**Fe**	**Ca**	**Do**	**Mi/Ill**	**Cl**	**He**	**Py (Dio/Woll)**	**Ho**
K130	GP	+	+	-	-	-	-	+	+	+
K131	GP	+	+	-	-	-	-	+	+	-
K132	GP	+	+	-	-	-	-	+	+	+
K133	UGP	+	+	+	-	-	-	+	+	+
K134	CW	+	+	+	+	+	+	-	-	+
K135	CW	+	+	-	-	+	-	-	-	-
K136	CW	+	+	-	-	+	+	-	-	-
K137	CW	+	+	-	-	-		-	+	+
K138	CW	+	+	+	-	-	-	-	+	-
K139	CW	+	+	-	-	-	-	+	+	-
K140	CW	+	+	+	-	+	-	+	-	-
K141	CW	+	+	+	-	+	+	-	-	-
K142	CW	+	+	-	-	-	-	+	+	+
K143	GP	+	+	-	-	-	-	+	+	-
K144	GP	+	+	-	-	-	-	+	+	-
K145	GP	+	+	-	-	-	-	+	+	-
K146	GP	+	+	-	-	-	?+	+	+	-
K147	GP	+	+	-	-	-	-	+	+	-
K148	GP	+	+	-	-	-	-	+	+	-
K149	GP	+	+	-	-	-	-	+	+	+
K150	GP	+	+	-	-	+	-	+	+	+
K151	GP	+	+	-	-	-	-	+	+	+
K152	GP	+	+	+	-	-	-	+	+	+
K153	GP	+	+	-	-	-	-	+	+	-
K154	GP	+	+	-	-	-	-	+	+	-
K155	GP	+	+	-	-	-	-	+	+	+
K156	GP	+	+	-	-	-	-	+	+	-
K158	GP	+	+	-	-	+	-	+	+	+
K159	GP	+	+	-	-	-	-	+	+	+
K160	GP	+	+	-	-	-	-	+	+	-
K161	GP	+	+	-	-	-	-	+	+	+
K162	TS	+	+	-	-	-	-	+	-	-
K163	TS	+	+	-	-	-	-	+	+	-
K164	GP	+	+	-	-	-	-	+	+	-
K165	UGP	+	+	-	-	-	-	+	+	-
K166	GP	+	+	-	-	-	-	+	-	-
K167	GP	+	+	?+	-	-	-	+	+	+
K168	GP	+	+	-	-	-	-	+	+	-
K169	GP	+	+	-	-	-	-	+	+	-
K170	GP	+	+	-	-	-	-	+	+	-

Table E1 Continued

Sample	Sample Type	Q	Fe	Ca	Do	Mi/Ill	Cl	He	Py (Dio/Woll)	Ho
K171	GP	+	+	-	-	-	-	+	+	-
K172	GP	+	+	-	-	-	-	+	+	-
K173	GP	+	+	-	-	-	-	+	+	+
K174	BF	+	+	+	-	+	-	+	-	+
K175	TS	+	+	-	-	-	-	+	+	-
K176	TS	+	+	-	-	-	-	+	+	-
K177	TS	+	+	-	-	-	-	+	+	-
K178	TS	+	+	-	-	-	-	+	+	-
K179	TS	+	+	-	-	-	-	+	+	-
K180	TS	+	+	-	-	-	-	+	+	-
K181	TS	+	+	-	?+	-	-	+	+	-
K182	TS	+	+	-	-	-	-	+	+	-
K183	TS	+	+	-	-	-	-	+	+	-
K184	GP	+	+	?+	-	-	-	+	+	+
K185	GP	+	+	-	-	-	?+	+	+	-
K186	BF	+	+	-	-	-	-	+	+	-
K187	BF	+	+	-	-	-	-	+	+	-
K188	BF	+	+	-	-	-	-	+	+	-
K189	BF	+	+	-	-	-	-	+	+	-
K190	BF	+	+	-	-	-	-	+	+	-
K191	BF	+	+	+	-	+	-	+	+	-
K192	BF	+	+	-	-	-	-	+	+	-
K193	BF	+	+	-	-	-	-	+	+	-
K194	BF	+	+	-	-	+	-	+	+	-
K195	BF	+	+	-	-	-	-	+	+	-
K196	BF	+	+	-	-	-	-	+	+	-
K197	BF	+	+	-	-	-	-	+	+	-
K198	BF	+	+	-	-	-	-	+	+	-
K199	GP	+	+	-	-	-	-	+	+	+
K200	GP	+	+	-	-	-	-	+	+	-
K201	GP	+	+	-	-	+		+	+	+
K202	CW	+	+	+	-	+	-	+	-	-
K203	GP	+	+	+	-	-	-	+	+	+
K204	GP	+	+	-	-	+	-	+	+	+
K205	BF	+	+	-	-	-	-	+	+	-
K206	CW	+	+	-	-	-	-	+	+	-
K207	BF	+	+	-	-	-	-	+	+	-
K208	BF	+	+	-	-	-	-	+	+	-
K209	CW	+	+	-	-	+	-	+	+	+
K210	GP	+	+	+	-	-	-	+	+	+

Table E1 Continued

Sample	**Sample Type**	**Q**	**Fe**	**Ca**	**Do**	**Mi/Ill**	**Cl**	**He**	**Py (Dio/Woll)**	**Ho**
K211	GP	+	+	-	-	-	-	+	+	-
K212	GP	+	+	-	-	-	-	+	+	+
K213	GP	+	+	-	-	-	-	+	+	-
K214	CW	+	+	-	-	+	-	-	-	-
K215	GP	+	+	-	-	-	-	+	+	+
K216	UGP	+	+	+	-	+	-	+	-	-
K217	BF	+	+	-	-	-	-	+	+	-
K218	CW	+	+	+	-	+	-	+	+	-
K219	CW	+	+	+	-	+	-	-	-	-
K220	GP	+	+	-	-	-	-	+	+	-
K221	GP	+	+	-	-	-	-	+	+	-
K222	GP	+	+	-	-	-	-	+	+	-
K223	GP	+	+	+	-	-	-	-	-	-
K224	CW	+	+	?+	-	+	+	-	-	-
K225	GP	+	+	+	-	-	-	-	-	-
K226	GP	+	+	-	-	-	-	+	+	-
K227	UGP	+	+	+	-	+	+	+	-	+
K228	GP	+	+	-	-	-	-	+	+	-

F. ELEMENTAL ANALYSIS

Concentrations of major, minor and trace elements are given in Tables F1-F4 (Concentration values without uncertainty values are LOD values).

Table F1. Concentration of major elements

Sample	% w/w						
	Na	**Mg**	**Al**	**K**	**Ti**	**Mn**	**Fe**
K101	1.15±0.05	2.36±0.13	15.06±0.09	1.60±0.02	1.57±0.04	0.08±0.01	5.03±0.36
K102	0.88±0.03	7.11±0.39	14.89±0.75	1.66±0.04	1.24±0.14	0.33±0.02	11.64±0.79
K103	1.42±0.06	5.14±0.30	15.17±3.15	1.37±0.07	2.63±0.28	0.41±0.11	20.95±5.58
K104	0.86±0.02	7.30±0.17	13.77±0.04	1.58±0.01	1.01±0.02	0.19±0.01	10.15±0.21
K105	0.80±0.01	4.56±0.20	12.48±0.41	0.91±0.06	1.40±0.07	0.20±0.02	10.33±0.15
K106	1.14±0.01	3.82±0.31	14.10±1.18	1.18±0.01	1.86±0.09	0.26±0.03	11.39±1.12
K107	1.29±0.02	4.91±0.30	22.06±0.56	2.62±0.01	1.46±0.03	0.09±0.01	5.91±0.18
K108	1.20±0.02	8.40±0.32	18.42±0.77	2.10±0.01	1.24±0.01	0.17±0.01	12.38±0.76
K109	0.81±0.01	3.55±0.15	14.93±4.31	0.85±0.03	1.39±0.24	0.20±0.01	11.54±0.22
K110	0.82±0.02	4.24±0.18	17.18±5.85	0.91±0.01	2.06±0.43	0.22±0.02	12.00±0.70
K111	1.42±0.05	5.58±0.29	27.81±1.27	2.12±0.08	2.31±0.21	0.17±0.01	19.68±2.50
K112	1.36±0.01	5.55±0.23	19.96±0.95	1.65±0.02	2.13±0.03	0.19±0.01	17.33±0.10
K113	1.52±0.01	5.36±0.14	24.18±0.29	2.09±0.03	2.10±0.02	0.21±0.02	16.00±0.25
K114	1.29±0.01	3.99±0.21	19.13±1.18	1.99±0.01	1.76±0.02	0.16±0.01	14.84±0.64
K115	1.10±0.04	4.18±0.17	15.33±0.73	1.60±0.01	2.09±0.03	0.23±0.02	12.38±1.34
K115	1.30±0.05	3.62±0.26	17.51±2.21	1.90±0.07	1.43±0.10	0.17±0.02	9.25±2.02
K117	0.73±0.01	7.57±0.01	15.32±2.78	1.02±0.04	1.44±0.25	0.22±0.02	14.95±0.03
K118	0.67±0.01	3.39±0.11	11.31±0.07	0.85±0.03	1.25±0.03	0.17±0.01	9.00±0.31
K119	1.38±0.09	4.52±0.28	22.80±1.39	1.59±0.09	3.05±0.23	0.20±0.02	26.24±2.88
K120	1.00±0.02	3.63±0.13	11.16±3.48	1.34±0.02	0.75±0.10	0.11±0.01	7.91±0.26
K121	0.93±0.02	3.06±0.17	17.99±1.13	2.63±0.03	1.91±0.05	0.16±0.01	8.19±0.04
K122	0.95±0.03	3.79±0.28	16.45±0.89	1.12±0.02	2.61±0.16	0.20±0.02	16.26±0.63
K123	1.31±0.02	4.76±0.19	15.76±0.29	1.39±0.01	2.36±0.05	0.19±0.01	15.63±0.22
K124	1.18±0.08	4.16±0.25	17.03±2.17	1.17±0.04	2.85±0.27	0.20±0.02	19.2±3.55
K125	0.92±0.03	4.82±0.37	18.80±0.80	1.21±0.02	2.16±0.15	0.17±0.03	15.97±0.18
K127	0.55±0.02	2.98±0.04	17.54±0.41	2.48±0.03	1.51±0.13	0.13±0.01	8.51±0.76
K128	1.01±0.03	4.85±0.09	15.64±0.43	1.41±0.05	2.27±0.13	0.26±0.02	12.74±0.62
K129	1.12±0.05	5.99±0.80	17.62±0.47	1.46±0.03	2.34±0.05	0.22±0.01	15.19±0.50
K130	1.21±0.01	3.47±0.18	12.41±0.18	1.44±0.02	2.22±0.15	0.25±0.03	10.91±0.10
K131	0.71±0.01	3.94±0.28	14.21±0.31	1.01±0.01	1.84±0.02	0.20±0.02	11.4±0.15
K132	0.99±0.01	3.27±0.02	10.96±0.09	1.22±0.01	1.44±0.03	0.16±0.01	7.55±0.11
K133	0.82±0.01	4.27±0.16	13.55±1.45	0.95±0.01	1.71±0.21	0.15±0.01	11.75±1.99
K134	0.92±0.01	0.33±0.01	7.56±0.26	0.80±0.01	1.22±0.02	0.02±0.01	0.55±0.03
K135	0.79±0.01	0.25±0.01	13.64±0.32	1.75±0.03	0.77±0.04	0.02±0.01	0.56±0.01
K136	0.71±0.02	0.23±0.01	13.86±0.51	2.28±0.04	0.74±0.04	0.02±0.01	0.52±0.07
K137	1.16±0.02	0.44±0.01	12.03±0.08	1.11±0.01	1.27±0.05	0.02±0.01	0.75±0.01
K138	0.79±0.02	6.41±0.22	15.26±1.48	1.03±0.01	1.27±0.03	0.21±0.02	10.16±0.67
K139	0.48±0.01	7.27±0.02	11.98±0.39	0.82±0.01	1.11±0.01	0.15±0.01	8.33±0.25
K140	0.54±0.01	3.50±0.04	14.88±0.33	1.32±0.01	1.23±0.03	0.20±0.01	8.28±0.39
K141	0.60±0.01	2.99±0.08	17.39±0.56	1.76±0.05	1.26±0.01	0.25±0.01	9.11±0.35
K142	0.75±0.03	5.19±0.20	16.03±0.03	0.48±0.02	0.82±0.03	0.15±0.01	9.20±0.19
K143	0.57±0.01	7.69±0.06	16.80±0.32	1.14±0.01	1.41±0.06	0.23±0.01	11.38±0.08
K144	0.96±0.04	4.28±0.18	13.42±0.19	1.33±0.03	2.49±0.25	0.25±0.04	12.82±0.05
K145	0.68±0.02	3.81±0.05	13.38±0.19	0.70±0.01	1.87±0.08	0.17±0.01	9.72±0.45
K146	0.88±0.02	4.22±0.03	11.32±0.19	1.20±0.02	1.77±0.01	0.21±0.01	12.62±0.55
K147	0.62±0.02	6.80±0.15	12.31±0.29	1.09±0.03	1.09±0.02	0.21±0.01	10.76±0.40
K148	1.17±0.08	5.54±0.71	14.68±0.65	1.36±0.06	1.97±0.16	0.20±0.01	11.73±2.88
K149	0.69±0.01	3.59±0.02	12.46±0.26	0.81±0.01	1.40±0.03	0.18±0.01	10.6±0.47
K150	0.83±0.03	4.51±0.21	11.36±0.58	0.66±0.01	1.63±0.08	0.20±0.01	11.56±0.04
K151	0.61±0.02	3.57±0.06	11.45±0.05	0.78±0.03	1.34±0.01	0.15±0.02	9.28±0.82
K152	0.77±0.04	4.72±0.17	13.17±0.16	0.81±0.02	1.42±0.01	0.20±0.01	9.82±0.53
K153	1.07±0.01	8.60±0.13	17.02±0.34	1.81±0.02	1.26±0.01	0.22±0.01	15.21±0.16
K154	0.73±0.01	3.92±0.09	13.32±0.16	0.87±0.02	1.60±0.10	0.18±0.01	11.42±0.47
K155	0.53±0.01	6.52±0.20	10.74±0.1	1.01±0.01	0.86±0.04	0.19±0.01	0.0024
K156	0.75±0.02	4.79±0.08	12.54±0.44	0.69±0.02	1.44±0.01	0.20±0.01	9.43±0.04
K158	0.91±0.01	4.48±0.05	12.46±0.33	0.70±0.02	1.82±0.07	0.17±0.01	11.87±0.61
K159	0.76±0.01	3.55±0.02	10.43±0.06	0.57±0.02	1.63±0.05	0.16±0.01	9.99±0.83
K160	0.84±0.04	3.49±0.08	14.34±0.02	1.29±0.19	1.47±0.08	0.18±0.02	0.0024

Table F1 Continued

Sample	**% w/w**						
	Na	**Mg**	**Al**	**K**	**Ti**	**Mn**	**Fe**
K161	1.45±0.02	3.81±0.27	18.62±1.17	1.95±0.04	2.76±0.11	0.37±0.04	17.31±1.91
K162	1.32±0.04	4.49±0.17	10.26±0.43	2.02±0.03	0.89±0.06	0.20±0.02	9.13±0.54
K163	1.39±0.04	4.10±0.26	9.61±0.37	2.15±0.02	0.73±0.01	0.17±0.03	6.51±0.21
K164	0.74±0.01	6.27±0.55	15.40±0.02	1.30±0.07	1.13±0.06	0.20±0.01	0.0024
K165	0.72±0.02	3.69±0.19	13.19±0.83	1.05±0.03	0.56±0.02	0.11±0.01	0.0024
K166	0.43±0.02	0.61±0.05	16.86±0.25	0.92±0.04	0.98±0.04	0.19±0.02	6.29±0.32
K167	0.82±0.03	4.37±0.26	14.08±0.60	0.88±0.03	1.56±0.01	0.21±0.02	0.0024
K168	0.59±0.01	6.31±0.73	12.60±1.51	0.95±0.01	0.98±0.06	0.19±0.01	8.80±1.09
K169	1.35±0.01	4.48±0.41	16.61±0.20	1.65±0.02	2.53±0.04	0.32±0.01	14.8±0.29
K170	0.79±0.01	4.19±0.20	13.46±1.70	0.76±0.07	1.36±0.01	0.16±0.03	0.0024
K171	0.68±0.05	3.71±0.40	12.60±1.05	0.84±0.06	1.24±0.09	0.19±0.02	0.0024
K172	0.59±0.01	3.87±0.10	15.00±1.24	0.81±0.08	1.31±0.01	0.16±0.01	0.0024
K173	0.61±0.01	4.08±0.20	12.37±0.74	0.78±0.02	1.10±0.05	0.17±0.01	0.0024
K174	1.10±0.04	3.61±0.06	17.01±3.40	1.96±0.03	1.25±0.05	0.17±0.01	8.15±0.26
K175	0.99±0.01	7.18±1.27	17.70±1.33	1.61±0.04	1.26±0.07	0.29±0.03	14.48±0.37
K176	1.08±0.01	6.39±0.17	18.89±0.15	2.00±0.05	1.31±0.02	0.25±0.01	17.54±0.31
K177	1.51±0.03	4.66±0.22	11.32±0.88	2.29±0.06	1.04±0.08	0.20±0.02	8.62±0.08
K178	1.24±0.04	3.91±0.33	9.47±0.73	1.91±0.01	0.75±0.02	0.18±0.01	6.91±0.83
K179	0.96±0.01	5.19±0.24	16.79±0.36	1.58±0.01	1.42±0.06	0.38±0.01	15.05±0.55
K180	1.29±0.01	4.27±0.03	10.14±0.15	2.37±0.01	0.85±0.02	0.18±0.01	8.81±0.22
K181	1.74±0.06	4.48±0.34	10.87±0.74	1.94±0.05	0.94±0.06	0.20±0.01	9.91±0.96
K182	1.10±0.01	4.62±0.01	17.73±0.31	1.90±0.03	1.03±0.02	0.17±0.01	9.37±0.23
K183	0.97±0.01	4.90±0.06	14.01±0.40	1.56±0.01	1.14±0.02	0.22±0.01	8.45±0.36
K184	0.64±0.02	3.48±0.05	12.28±0.14	0.67±0.02	1.22±0.01	0.14±0.01	0.0024
K185	0.80±0.02	3.93±0.02	11.64±0.55	0.83±0.01	1.95±0.04	0.18±0.01	10.35±1.12
K186	1.06±0.01	4.88±0.78	18.55±4.13	1.90±0.04	1.02±0.05	0.19±0.01	9.92±1.51
K187	1.38±0.02	5.16±0.15	14.94±0.99	1.88±0.04	1.02±0.04	0.21±0.01	8.80±0.77
K188	1.38±0.02	4.92±0.25	17.82±0.28	1.94±0.03	1.05±0.08	0.20±0.01	9.37±0.02
K189	1.75±0.01	4.50±0.21	16.28±1.19	2.61±0.03	0.97±0.02	0.17±0.02	6.94±0.54
K190	1.01±0.02	4.95±0.58	14.99±1.12	1.80±0.01	1.10±0.08	0.22±0.02	9.46±1.33
K191	1.13±0.01	5.38±0.15	15.59±0.88	1.91±0.02	1.03±0.03	0.22±0.01	9.82±0.17
K192	1.27±0.04	4.69±0.08	16.18±0.83	2.28±0.03	1.18±0.09	0.30±0.04	8.76±0.20
K193	1.42±0.01	4.78±0.15	11.82±0.54	2.81±0.06	1.02±0.07	0.19±0.01	9.50±0.38
K194	1.39±0.04	4.35±0.05	16.18±0.68	2.15±0.05	0.92±0.01	0.19±0.02	8.00±0.08
K195	1.13±0.01	5.95±0.02	18.54±0.19	2.10±0.01	1.32±0.01	0.27±0.01	17.00±0.79
K196	1.23±0.02	6.32±0.04	17.58±0.50	1.70±0.01	1.17±0.01	0.22±0.01	15.73±0.49
K197	1.58±0.02	5.21±0.03	15.58±0.75	1.80±0.03	1.07±0.01	0.19±0.01	9.06±0.30
K198	1.38±0.03	4.49±0.37	11.44±1.01	2.29±0.04	0.86±0.08	0.17±0.01	10.00±0.98
K199	0.82±0.01	4.47±0.28	12.67±0.19	1.06±0.05	1.35±0.02	0.21±0.01	11.00±0.10
K200	0.97±0.03	5.17±0.14	14.57±0.07	1.67±0.03	1.08±0.04	0.22±0.01	10.06±0.52
K201	0.61±0.01	3.81±0.17	12.20±0.05	0.82±0.02	1.66±0.02	0.17±0.01	9.72±0.28
K202	0.63±0.03	1.42±0.02	15.33±0.03	2.85±0.05	0.57±0.02	0.08±0.01	4.39±0.09
K203	0.70±0.01	3.98±0.01	12.61±0.06	0.90±0.03	1.85±0.21	0.18±0.01	11.52±0.31
K204	1.03±0.02	3.41±0.08	10.70±0.73	1.25±0.08	1.33±0.09	0.14±0.01	7.27±0.14
K205	1.38±0.04	4.56±0.54	10.41±1.07	2.23±0.07	0.86±0.08	0.17±0.01	8.88±2.20
K206	1.41±0.02	1.80±0.05	9.27±0.10	0.90±0.01	0.49±0.02	0.09±0.01	3.74±0.13
K207	0.81±0.01	5.31±0.10	15.27±0.19	1.40±0.02	1.13±0.03	0.30±0.01	11.35±0.02
K208	0.95±0.01	4.60±0.14	16.22±0.89	1.43±0.02	1.21±0.06	0.39±0.03	14.86±0.86
K209	0.86±0.04	3.96±0.20	12.11±0.48	0.97±0.02	1.08±0.02	0.18±0.01	8.56±0.59
K210	0.77±0.01	3.88±0.21	15.21±0.10	1.42±0.01	1.76±0.11	0.26±0.02	11.35±0.76
K211	1.05±0.04	5.61±0.19	17.51±0.23	1.36±0.07	2.04±0.15	0.21±0.04	14.67±0.33
K212	0.53±0.02	3.40±0.13	13.67±0.77	0.90±0.02	1.59±0.14	0.17±0.02	9.04±0.77
K213	0.66±0.02	4.07±0.12	13.09±0.70	0.68±0.05	2.03±0.14	0.20±0.02	11.61±0.13
K214	0.70±0.01	2.76±0.02	15.59±0.39	2.34±0.02	0.90±0.05	0.12±0.01	7.13±0.21
K215	1.08±0.01	4.17±0.10	15.12±0.63	2.10±0.01	1.26±0.02	0.10±0.01	5.13±0.04
K216	0.67±0.03	2.32±0.09	11.92±0.01	1.51±0.05	1.06±0.06	0.11±0.01	6.23±0.38
K217	0.82±0.01	5.85±0.12	17.85±3.13	1.51±0.01	1.34±0.21	0.21±0.01	17.67±4.40
K218	0.68±0.01	3.55±0.04	14.03±0.61	1.80±0.01	0.83±0.03	0.15±0.01	5.57±0.04
K219	0.35±0.01	1.34±0.02	12.80±0.25	2.60±0.02	0.55±0.02	0.06±0.01	4.20±0.03
K220	1.59±0.02	3.47±0.06	19.11±0.32	1.99±0.02	2.29±0.03	0.09±0.01	8.35±0.14
K221	1.00±0.04	4.91±0.09	19.28±3.09	1.07±0.07	2.92±0.59	0.23±0.01	21.11±5.61
K222	0.49±0.01	4.37±0.12	15.25±0.59	0.72±0.03	1.75±0.13	0.20±0.01	10.10±0.52
K223	0.37±0.01	0.53±0.02	5.61±0.10	0.40±0.01	0.11±0.01	0.05±0.01	1.08±0.03
K224	0.40±0.02	3.19±0.11	13.66±0.11	0.91±0.01	0.93±0.02	0.15±0.01	6.88±0.47
K225	1.93±0.03	0.81±0.03	11.05±0.53	0.78±0.02	0.09±0.01	0.03±0.01	0.49±0.04
K226	1.23±0.01	4.01±0.01	14.14±0.48	2.14±0.05	1.20±0.04	0.10±0.01	4.88±0.03
K227	1.20±0.03	4.79±0.19	14.30±0.29	1.57±0.01	0.0001	0.19±0.03	14.54±0.42
K228	0.49±0.02	3.87±0.16	11.36±0.25	0.47±0.03	1.69±0.07	0.18±0.01	9.85±0.08
S01	0.20±0.01	6.19±0.24	15.96±0.06	1.20±0.01	1.62±0.08	0.20±0.02	10.97±0.58
S02	0.21±0.01	4.86±0.18	15.77±0.33	0.0003	3.95±0.18	0.29±0.04	17.48±2.39
S03	0.33±0.03	5.00±0.14	13.59±0.72	1.41±0.10	0.84±0.14	0.22±0.03	8.97±0.21
S04	0.32±0.01	2.94±0.06	19.77±0.24	2.43±0.02	0.98±0.01	0.17±0.01	9.34±0.19
S05	1.86±0.04	1.59±0.12	11.38±0.70	0.18±0.01	1.02±0.02	0.16±0.02	7.71±0.35

Table F1 Continued

Sample	**% w/w**						
	Na	**Mg**	**Al**	**K**	**Ti**	**Mn**	**Fe**
S06	0.62±0.01	9.96±0.45	14.03±0.31	0.0003	2.36±0.01	0.23±0.01	17.60±0.41
S07	0.63±0.01	1.80±0.04	20.17±0.31	2.00±0.02	1.12±0.11	0.23±0.01	7.48±0.38
S08	0.17±0.02	3.11±0.15	22.35±0.75	2.01±0.02	1.18±0.05	0.13±0.01	9.64±0.14
S09	0.65±0.01	2.23±0.06	15.40±0.53	1.89±0.03	0.87±0.04	0.14±0.01	7.04±0.36
S10	1.15±0.04	3.10±0.20	10.71±0.80	0.54±0.02	1.92±0.06	0.19±0.01	10.17±0.36
S11	0.95±0.01	5.10±0.17	15.11±1.03	0.22±0.01	0.98±0.04	0.17±0.01	12.86±0.72
S12	1.52±0.08	4.17±0.66	15.91±1.52	0.0003	0.98±0.17	0.26±0.06	15.02±2.30
S13	0.10±0.01	8.11±0.04	4.77±0.01	0.28±0.01	0.34±0.01	0.09±0.01	4.71±0.06
S14	0.40±0.01	9.38±0.80	8.53±0.96	0.59±0.01	0.44±0.01	0.13±0.01	7.91±0.95
S15	1.29±0.34	4.87±0.10	11.40±0.03	0.43±0.01	2.86±0.14	0.21±0.01	0.0024
S16	0.81±0.02	2.79±0.06	17.62±4.98	2.06±0.01	0.94±0.11	0.19±0.01	9.70±0.32
S17	0.47±0.01	2.23±0.04	24.18±0.63	3.28±0.04	1.30±0.02	0.14±0.01	12.87±0.88
S18	0.97±0.03	3.90±0.17	15.02±4.63	1.31±0.02	0.99±0.09	0.20±0.01	9.09±1.08
S19	1.24±0.02	3.92±0.18	12.6±0.20	0.62±0.01	1.67±0.02	0.16±0.01	12.97±0.47
S20	0.62±0.01	1.81±0.08	9.27±3.59	0.44±0.01	0.56±0.01	0.14±0.01	7.42±0.19
S21	0.57±0.01	5.02±0.20	14.61±3.76	1.16±0.04	0.87±0.10	0.18±0.01	9.70±0.17
S22	0.71±0.02	5.37±0.36	15.72±0.15	1.46±0.02	1.12±0.01	0.31±0.03	9.44±0.31
S23	0.41±0.01	7.26±0.02	12.70±0.21	1.03±0.01	1.07±0.02	0.13±0.01	9.35±0.58
S24	0.73±0.01	3.12±0.01	16.28±5.11	1.40±0.03	1.05±0.13	0.19±0.01	8.15±0.06
S25	0.30±0.01	1.40±0.01	11.28±0.28	0.94±0.05	0.57±0.01	0.09±0.01	4.95±0.08
S26	0.85±0.03	2.75±0.32	15.15±1.01	2.86±0.08	0.02±0.01	0.13±0.03	7.78±0.41
S27	0.41±0.01	3.62±0.06	6.34±0.34	0.31±0.01	0.98±0.03	0.19±0.01	8.07±0.09
S28	3.08±0.01	2.75±0.04	11.26±0.75	0.0003	1.59±0.01	0.11±0.01	8.78±0.16
S29	1.80±0.02	2.03±0.07	14.05±0.09	0.32±0.01	0.84±0.01	0.12±0.01	7.75±0.29
S30	1.27±0.06	4.31±0.08	11.17±0.44	0.21±0.01	0.05±0.01	0.18±0.02	9.30±0.22

Table F2. Concentrations of minor elements

Sample	mg/kg						
	V	Cr	Co	Ni	Cu	Zn	Sr
K101	123.9 ± 8.4	1.56	30.3 ± 0.4	111.1 ± 3.8	1.95	118.0 ± 3.1	293.2 ± 0.4
K102	239.5 ± 26.0	494.7 ± 79.3	490.7 ± 49.8	386.3 ± 38.6	1.95	2.01	778.8 ± 33.2
K103	362.1 ± 26.4	715.2 ± 122.8	83.8 ± 5.7	295.7 ± 19.9	724.0 ± 338.3	2.01	356.9 ± 12.7
K104	272.1 ± 14.2	482.2 ± 10.5	64.4 ± 1.8	401.1 ± 18.7	307.7 ± 17.7	149.4 ± 2.0	285.1 ± 2.4
K105	265.5 ± 34.2	555.0 ± 47.1	64.7 ± 6.2	257.9 ± 16.1	1.95	76.0 ± 2.1	188.9 ± 6.2
K106	236.9 ± 11.6	428.6 ± 10.9	55.0 ± 2.2	242.1 ± 16.7	301.7 ± 8.3	2.01	277.0 ± 1.5
K107	116.0 ± 1.3	1.56	41.1 ± 1.7	195.0 ± 2.8	1.95	127.2 ± 0.1	447.2 ± 10.7
K108	214.4 ± 0.4	469.7 ± 21.8	120.0 ± 0.6	337.9 ± 2.8	169.5 ± 1.5	119.1 ± 2.1	348.3 ± 3.9
K109	329.1 ± 11.4	534.3 ± 3.5	59.5 ± 1.5	285.3 ± 27	325.1 ± 15.9	2.01	188.2 ± 0.8
K110	329.6 ± 3.2	613.9 ± 72.1	67.5 ± 4.8	370.8 ± 2.9	394.0 ± 13.4	2.01	179.5 ± 0.7
K111	271.4 ± 0.3	509.5 ± 7.0	84.5 ± 1.1	209.7 ± 9.2	403.3 ± 8.1	136.5 ± 2.6	384.0 ± 15.9
K112	266.0 ± 13.6	565.2 ± 15.7	76.4 ± 1.7	266.2 ± 6.8	260.8 ± 20.7	131.2 ± 2.4	343.1 ± 2.6
K113	296.2 ± 21.3	630.2 ± 71.3	58.3 ± 5.5	720.4 ± 62.0	278.6 ± 9.5	137.4 ± 9.6	351.1 ± 9.0
K114	233.4 ± 1.3	412.4 ± 1.6	41.7 ± 1.7	2431.9 ± 41.7	296.5 ± 6.7	111.5 ± 1.7	318.4 ± 4.8
K115	341.2 ± 12.0	583.7 ± 2.2	96.9 ± 6.1	316.1 ± 23.6	316.6 ± 14.6	142.4 ± 5.0	291.3 ± 19.0
K119	313.8 ± 21.8	485.3 ± 56.4	62.7 ± 6.1	267.3 ± 28.1	507.4 ± 261.5	119.5 ± 1.3	385.3 ± 1.2
K120	186.6 ± 15.1	869.6 ± 21.5	41.5 ± 1.6	302.7 ± 8.0	1.95	2.01	374.0 ± 0.7
K121	370.4 ± 2.9	391.2 ± 22.0	42.2 ± 0.8	236.2 ± 14.1	321.7 ± 7.8	2.01	291.9 ± 1.7
K122	349.4 ± 8.6	492.0 ± 16.2	93.9 ± 0.9	323.1 ± 1.6	602.4 ± 30.5	2.01	236.0 ± 10.3
K123	284.9 ± 15.7	554.2 ± 13.1	58.6 ± 0.9	279.6 ± 6.0	414.4 ± 12.2	131.4 ± 1.6	350.1 ± 1.5
K124	351.3 ± 32.4	634.9 ± 75.7	71.0 ± 6.7	304.4 ± 27.2	774.0 ± 77.8	86.6 ± 5.6	278.5 ± 11.2
K125	294.1 ± 28.0	530.7 ± 62.2	57.1 ± 7.8	274.6 ± 32.3	260.6 ± 26.0	78.8 ± 1.5	237.0 ± 1.1
K127	305.3 ± 3.6	200.3 ± 17.2	50.1 ± 1.5	135.9 ± 5.1	401.4 ± 5.5	2.01	228.2 ± 0.6
K128	413.7 ± 14.1	685.5 ± 42.0	111.9 ± 1.9	359.6 ± 21.0	368.6 ± 1.6	131.7 ± 3.5	298.0 ± 13.2
K130	407.9 ± 37.4	607.9 ± 39.7	77.2 ± 6.5	322.7 ± 28.6	571.2 ± 26.9	123.7 ± 2.1	286.7 ± 0.1
K131	325.5 ± 18.7	483.2 ± 44.6	61.3 ± 0.9	274.2 ± 0.5	521.3 ± 45.1	2.01	195.0 ± 3.9
K132	277.3 ± 2.6	907.4 ± 16.4	64.6 ± 0.5	168.2 ± 0.9	1.95	2.01	224.4 ± 1.7
K133	272.2 ± 14.0	423.3 ± 7.2	46.8 ± 3.0	217.3 ± 1.7	269.0 ± 7.6	2.01	173.3 ± 3.4
K134	19.8 ± 0.2	1.56	0.63	1.04	1.95	2.01	319.3 ± 9.1
K135	23.1 ± 1.6	1.56	0.63	1.04	1.95	2.01	86.8 ± 0.2
K136	23.2 ± 1.9	1.56	0.63	1.04	1.95	89589.7 ± 102.0	88.5 ± 3.2
K137	28.1 ± 0.4	1.56	0.63	1.04	1.95	88.9 ± 1.9	174.2 ± 0.6
K138	288.0 ± 9.6	980.3 ± 95.2	58.2 ± 0.8	1037.1 ± 8.2	1542.5 ± 78.3	2.01	147.3 ± 2.0
K139	236.8 ± 19.6	751.8 ± 16.7	58.8 ± 0.1	438.9 ± 47.6	264.6 ± 28.4	2.01	141.3 ± 2.3
K140	266.1 ± 3.4	586.4 ± 30.4	48.0 ± 3.8	296.5 ± 13.2	1.95	2.01	171.3 ± 28
K141	309.2 ± 25.2	441.3 ± 13.1	45.1 ± 1.4	192.5 ± 21.6	387.0 ± 44.2	2.01	77.1 ± 1.7
K142	327.3 ± 0.4	547.2 ± 52.7	56.9 ± 4.0	251.3 ± 27.8	300.9 ± 14.5	2.01	70.2 ± 1.5
K143	269.4 ± 4.7	468.1 ± 1.5	69.8 ± 3.9	368.9 ± 5.8	291.6 ± 10.7	2.01	173.4 ± 1.4
K144	381.1 ± 67.5	803.1 ± 166.7	132.3 ± 16.5	390.0 ± 45.1	375.2 ± 70.3	124.6 ± 4.4	267.1 ± 13.3
K145	250.0 ± 0.9	411.8 ± 28.4	48.4 ± 1.9	216.2 ± 7.6	867.2 ± 27.2	2.01	202.3 ± 3.7
K146	302.5 ± 0.5	547.5 ± 1.0	73.1 ± 0.6	334.9 ± 4.8	1.95	2.01	786.5 ± 13.1
K147	323.0 ± 6.5	621.4 ± 38.1	91.1 ± 0.4	592.3 ± 64.0	382.6 ± 7.3	2.01	236.8 ± 5.9
K148	326.1 ± 10.5	692.1 ± 20.1	70.8 ± 2.8	268.9 ± 8.4	288.1 ± 10.4	125.8 ± 2.3	285.4 ± 5.3
K149	252.1 ± 7.3	1.56	62.2 ± 1.9	331.0 ± 2.8	1.95	2.01	185.3 ± 2.0
K150	363.4 ± 18.1	576.9 ± 29.8	75.1 ± 0.6	433.1 ± 22.5	1.95	2.01	209.7 ± 1.1
K151	240.3 ± 3.2	1.56	0.63	1.04	1.95	2.01	179.1 ± 1.3
K152	301.0 ± 15	1.56	61.3 ± 6.3	1.04	1.95	2.01	180.5 ± 12.6
K153	320.7 ± 1.1	543.2 ± 3.2	73.1 ± 2.1	438.5 ± 12	349.2 ± 6.2	152.9 ± 2.0	346.0 ± 0.5
K154	248.7 ± 1.3	380.2 ± 5.2	55.7 ± 1.2	225.0 ± 22.8	249.0 ± 13.4	59.2 ± 4.5	164.1 ± 5.1
K155	268.1 ± 13.2	1.56	55.8 ± 3.1	388.5 ± 1.9	1.95	2.01	166.9 ± 4.0
K156	329.2 ± 6.4	1.56	66.0 ± 3.9	1.04	1.95	2.01	184.9 ± 10.1
K158	260.4 ± 3.7	428.7 ± 27.2	46.9 ± 3.0	185.8 ± 4.4	188.6 ± 7.6	46.9 ± 1.3	152.9 ± 2.4
K159	265.0 ± 6.4	397.7 ± 16.4	47.1 ± 0.8	195.5 ± 2.9	342.5 ± 1.9	39.7 ± 1.7	133.2 ± 0.3
K160	274.2 ± 3.4	1.56	0.63	1.04	1.95	2.01	590.8 ± 10.8
K162	310.5 ± 12.2	479.5 ± 6.0	74.2 ± 2.2	224.0 ± 15.1	177 .0± 1.4	193.7 ± 4.2	179.8 ± 1.4
K163	252.5 ± 7.7	391.3 ± 47.4	54.2 ± 3.2	202.4 ± 13.5	1.95	205.6 ± 6.6	221.7 ± 5.1
K164	247.9 ± 19.4	1.56	68.0 ± 6.3	466.8 ± 22.4	1.95	2.01	0.24
K165	148.9 ± 12.4	1.56	0.63	1.04	1.95	2.01	337.9 ± 17.2
K166	294.4 ± 29.7	672.3 ± 66.9	57.2 ± 6.8	116.3 ± 12.8	1.95	156.1 ± 9.9	246.9 ± 3.7
K167	306.1 ± 15.3	1.56	64.3 ± 4.3	366.9 ± 43.1	1.95	2.01	234.7 ± 11.5
K168	225.5 ± 10.6	436.9 ± 2.4	72.4 ± 3.5	338.0 ± 12.6	1.95	53.7 ± 1.5	161.6 ± 7.5
K169	350.6 ± 16.1	570.7 ± 62.8	79.5 ± 2.1	277.5 ± 11.9	558.0 ± 5.7	142.1 ± 5.9	368.4 ± 0.9
K170	212.5 ± 37.2	1.56	0.63	1.04	1.95	2.01	210.3 ± 1.1
K171	256.4 ± 30.3	1.56	0.63	1.04	1.95	2.01	0.24
K172	216.3 ± 10.7	1.56	0.63	1.04	1.95	2.01	0.24
K173	241.2 ± 6.2	1.56	0.63	1.04	1.95	2.01	0.24
K174	258.6 ± 1.4	343.6 ± 16.0	46.4 ± 1.5	198.3 ± 8.6	1.95	184.0 ± 0.9	235.2 ± 0.5
K175	428.7 ± 28.2	611.7 ± 13.5	98.8 ± 11.1	324.6 ± 16.8	325.1 ± 8.9	187.6 ± 2.1	172.3 ± 1.0
K176	352.9 ± 4.8	497.1 ± 11.4	78.3 ± 1.9	284.1 ± 3.6	298.7 ± 15.9	183.7 ± 4.4	178.5 ± 2.2
K177	282.1 ± 23.7	497.5 ± 58.9	61.7 ± 4.8	292.7 ± 23.6	173.3 ± 11.2	228.8 ± 4.5	242.7 ± 4.8
K178	258.8 ± 7.8	545.4 ± 25.6	64.6 ± 0.6	525.5 ± 20.0	182.2 ± 12.4	165.8 ± 1.9	160.7 ± 2.5

Table F2 Continued

Sample	mg/kg						
	V	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**Sr**
K179	416.2 ± 10.6	786.9 ± 22.9	93.2 ± 0.2	278.3 ± 19.9	247.0 ± 1.3	2.01	193.2 ± 1.1
K180	273.3 ± 2.7	424.2 ± 13.0	80.5 ± 3.4	217.6 ± 6.5	162.8 ± 4.3	183.0 ± 5.9	179.0 ± 6.3
K181	283.1 ± 5.4	699.4 ± 15.7	59.9 ± 3.1	257.7 ± 7.9	237.8 ± 5.6	151.6 ± 1.3	198.7 ± 4.5
K182	259.0 ± 9.0	395.2 ± 4.8	79.3 ± 2.5	205.0 ± 1.4	1.95	169.8 ± 0.3	156.2 ± 0.7
K183	323.8 ± 20.9	414.9 ± 4.5	84.8 ± 0.3	207.2 ± 2.1	1.95	115.2 ± 2.8	136.0 ± 0.5
K184	183.6 ± 5.4	1.56	0.63	1.04	1.95	2.01	0.24
K185	271.4 ± 0.7	423.7 ± 15.1	47.7 ± 3.9	207.9 ± 11.6	1.95	69.1 ± 1.3	201.8 ± 1.2
K186	281.2 ± 4.0	384.5 ± 5.1	54.9 ± 3.4	228.7 ± 4.6	1.95	160.0 ± 4.9	132.9 ± 6.0
K187	292.2 ± 10.4	445.6 ± 16.2	61.8 ± 3.9	262.4 ± 0.7	1.95	168.3 ± 4.3	236.8 ± 5.0
K188	316.0 ± 7.7	441.4 ± 33.5	58.6 ± 1.1	251.0 ± 11.6	1.95	148.1 ± 0.6	225.5 ± 3.0
K189	258.7 ± 16.1	448.5 ± 38.0	48.8 ± 4.2	333.7 ± 29.6	1.95	163.5 ± 2.3	253.0 ± 3.2
K190	329.0 ± 22.9	419.6 ± 0.2	66.9 ± 1.3	256.0 ± 3.7	1.95	163.9 ± 5.2	144.9 ± 2.3
K191	312.7 ± 1.0	406.2 ± 5.8	60.4 ± 0.7	227.1 ± 2.9	1.95	154.7 ± 0.4	165.5 ± 3.1
K192	475.3 ± 42.2	632.1 ± 46.6	92.3 ± 9.8	427.4 ± 50.7	216.3 ± 29.8	189.2 ± 1.0	165.8 ± 6.7
K193	323.5 ± 0.6	400.5 ± 8.6	71.5 ± 1.3	217.7 ± 0.9	151.4 ± 4.5	203.7 ± 4.5	194.5 ± 8.8
K194	300.7 ± 18.0	415.7 ± 40.3	51.7 ± 4.0	240.6 ± 20.3	1.95	172.6 ± 1.1	161.8 ± 0.2
K195	394.2 ± 7.7	553.8 ± 15.6	75.7 ± 1.2	293.6 ± 0.7	1.95	181.8 ± 7.4	165.7 ± 1.4
K196	280.8 ± 1.3	470.5 ± 9.1	58.5 ± 0.6	244.9 ± 8.7	1.95	125.0 ± 2.8	200.7 ± 0.1
K197	279.7 ± 2.6	455.2 ± 9.9	52.6 ± 1.5	252.6 ± 4.0	1.95	1395.7 ± 21.3	249.8 ± 4.0
K198	259.2 ± 3.6	341.5 ± 13.7	54.2 ± 1.4	205.3 ± 4.4	144.7 ± 9.4	243.3 ± 1.1	170.9 ± 0.2
K199	299.5 ± 1.1	520.3 ± 53.6	57.0 ± 2.6	252.2 ± 18	320.0 ± 15.4	2.01	237.3 ± 2.3
K200	327.0 ± 14.2	420.2 ± 3.2	76.8 ± 1.8	229.7 ± 3.6	326.4 ± 5.4	156.9 ± 3.5	150.2 ± 3.0
K201	273.3 ± 13.0	401.1 ± 15.2	47.6 ± 2.3	629.4 ± 24.1	747.9 ± 30.5	2.01	167.2 ± 1.7
K202	115.7 ± 1.0	1.56	22.7 ± 0.9	80.6 ± 2.7	1.95	2.01	120.0 ± 1.2
K203	250.2 ± 40.1	425.3 ± 54.7	44.8 ± 6.2	192.4 ± 31.2	1.95	2.01	170.2 ± 3.3
K204	227.3 ± 14.0	383.2 ± 45.9	43.8 ± 6.8	176.8 ± 16.7	1.95	128.2 ± 2.5	261.0 ± 6.2
K205	261.9 ± 2.0	412.9 ± 26.0	56.8 ± 2.0	229.1 ± 5.2	152.0 ± 0.4	217.7 ± 3.4	221.9 ± 13.1
K206	132.4 ± 3.1	1054.8 ± 1.0	24.2 ± 0.9	106.9 ± 1.3	1.95	2.01	226.1 ± 1.5
K207	341.1 ± 12.7	459.1 ± 11.3	76.8 ± 0.9	235.6 ± 4.2	216.7 ± 5	2.01	151.7 ± 4.8
K208	340.0 ± 8.8	507.0 ± 8.9	84.8 ± 0.6	260.7 ± 1.2	231.9 ± 14.1	2.01	154.9 ± 1.2
K209	246.2 ± 13.3	544.3 ± 26.8	44.8 ± 2.7	243.7 ± 15.7	1.95	2.01	132.3 ± 1.1
K210	276.6 ± 16.9	500.7 ± 70.1	69.4 ± 1.0	235.9 ± 14.1	328.9 ± 5.4	2.01	226.9 ± 4.5
K211	358.7 ± 64.0	1001.4 ± 15.5	76.2 ± 15.3	288.6 ± 69.7	261.5 ± 43	2.01	294.7 ± 2.3
K212	198.0 ± 14.3	297.0 ± 26.6	37.3 ± 1.1	158.8 ± 9.7	1.95	2.01	133.6 ± 3.0
K213	267.5 ± 30.6	458.0 ± 44.2	58.8 ± 1.2	248.3 ± 22.4	278.4 ± 18.8	2.01	168.4 ± 5.0
K214	300.6 ± 7.6	260.4 ± 32.7	31.3 ± 1.8	115.3 ± 2.7	1.95	2.01	1200 ± 0.5
K215	109.0 ± 1.8	1.56	35.5 ± 0.2	167.4 ± 3.2	1.95	117.2 ± 2.9	364.1 ± 7.6
K216	206.6 ± 9.0	119.8 ± 6.3	32.9 ± 0.5	95.8 ± 1.5	1.95	2.01	198 ± 10.5
K217	323.4 ± 2.0	414.1 ± 8.7	57.1 ± 3.5	228.7 ± 8.3	197.8 ± 4.7	213.9 ± 2.6	139.1 ± 5.8
K218	246.9 ± 9.0	295.8 ± 6.5	35.2 ± 0.2	140.7 ± 7.3	1.95	2.01	189.2 ± 0.9
K219	128.7 ± 1.4	478.9 ± 22.5	21.8 ± 1.1	1.04	1.95	93.4 ± 5.8	83.0 ± 0.2
K220	139.7 ± 0.3	1.56	36.8 ± 1.6	156.4 ± 2.4	1.95	149.4 ± 1.2	373.4 ± 0.6
K221	395.7 ± 17.8	889.7 ± 286.4	79.9 ± 5.3	480.2 ± 197.6	248.7 ± 14.0	2.01	283.1 ± 8.7
K222	284.5 ± 2.0	516.7 ± 18.0	64.7 ± 4.6	268.9 ± 18.9	311.3 ± 14.4	2.01	128.0 ± 0.7
K223	13.6 ± 0.5	133.8 ± 6.2	0.63	1.04	265.9 ± 8.6	2.01	93.7 ± 2.4
K224	221.4 ± 16.6	387.6 ± 21.6	35.4 ± 1.9	192.2 ± 16	1.95	2.01	36.9 ± 1.4
K225	7.9 ± 0.1	1.56	0.63	1.04	1.95	110.2 ± 3.2	282.8 ± 3.9
K226	120.4 ± 3.7	1.56	41.9 ± 0.5	166.4 ± 0.6	1.95	120.7 ± 4.3	401.8 ± 5.2
K227	315.9 ± 41.9	454.8 ± 54.6	61.1 ± 8.3	256.9 ± 33.9	1.95	111.3 ± 2.4	272.1 ± 15.5
K228	234.4 ± 21.7	437.9 ± 24.4	44.8 ± 2.9	403.8 ± 1.6	246.7 ± 5.8	2.01	116.0 ± 1.5
S01	405.0 ± 38.8	1510.7 ± 81.5	91.3 ± 8.6	756.6 ± 67.4	255.8 ± 20.3	2.01	127.5 ± 5.8
S02	559.9 ± 50.2	3788.6 ± 75.9	221.3 ± 30.4	1066.7 ± 78.9	483.5 ± 30.3	2.01	94.6 ± 0.5
S03	265.5 ± 70.4	655.2 ± 188.0	52.2 ± 12.5	143.9 ± 36.9	1.95	2.01	41.7 ± 0.1
S04	329.0 ± 2.3	283.0 ± 29.3	44.2 ± 5.4	156.4 ± 2.7	1.95	2.01	39.8 ± 0.6
S05	478.7 ± 58.8	1.56	43.3 ± 4.0	1.04	378.3 ± 54.9	2.01	39 .0± 0.1
S06	499.5 ± 47.7	680.5 ± 62.1	87.6 ± 11.6	346.6 ± 70.8	344.5 ± 20.6	2.01	195.7 ± 2.3
S07	303.0 ± 26.7	297.5 ± 13.4	38.2 ± 1.2	128.4 ± 4.1	1.95	2.01	150.3 ± 6.5
S08	265.7 ± 5.9	445.7 ± 54.1	27.8 ± 4.0	754.5 ± 38.9	1.95	2.01	117.3 ± 4.6
S09	216.5 ± 11.9	197.6 ± 19.5	23.6 ± 1.9	102.2 ± 10.8	1.95	2.01	47.1 ± 0.7
S10	274.8 ± 10.2	307.3 ± 4.6	41.9 ± 0.6	140.8 ± 6.5	1.95	67.5 ± 0.4	182.3 ± 4.7
S11	327.5 ± 0.4	387.0 ± 18.7	45.4 ± 1.8	198 ± 15.1	1.95	2.01	223.2 ± 5.3
S12	468.1 ± 103.3	174.6 ± 11.1	48.2 ± 13.8	1.04	1.95	2.01	98.8 ± 5.6
S13	122.0 ± 6.4	186.4 ± 36.8	26.5 ± 1.5	174.9 ± 4.4	1.95	2.01	383.9 ± 5.6
S14	146.4 ± 4.1	1.56	15.0 ± 1.7	1.04	1.95	2.01	470.7 ± 1.4
S15	423.7 ± 12.9	275.7 ± 3.8	62.9 ± 0.3	148.4 ± 0.5	305.7 ± 0.3	111.7 ± 0.2	155.7 ± 79.5
S16	307.2 ± 16.3	319.7 ± 4.2	40.6 ± 0.6	186.7 ± 9.5	1.95	2.01	79.3 ± 1.2
S17	319.5 ± 7.7	228.6 ± 3.9	28.0 ± 1.5	123.3 ± 1.0	1.95	72.6 ± 1.7	59.7 ± 1.1
S18	298.0 ± 4.1	518.4 ± 35.3	54.2 ± 7.8	274.2 ± 30.7	1.95	2.01	130.7 ± 3.2
S19	275.8 ± 5.4	608.6 ± 2.6	43.4 ± 0.9	207.5 ± 14.5	1.95	52.3 ± 0.6	298.8 ± 6.3
S20	237.5 ± 13.1	447.5 ± 11.4	36.8 ± 1.8	205.5 ± 1.2	1.95	2.01	200.9 ± 1.0
S21	332.2 ± 9.0	721.0 ± 36	71.3 ± 5.4	349.8 ± 13.4	1.95	2.01	93.6 ± 1.1
S22	300.6 ± 15.7	539.9 ± 7.8	48.1 ± 3.6	278.8 ± 2.9	1.95	55.5 ± 0.8	46.0 ± 1.0
S23	228.0 ± 5.7	633.8 ± 30.3	41.7 ± 0.3	379.2 ± 5.6	1.95	38.3 ± 0.5	26.9 ± 1.2

Table F2 Continued

Sample	mg/kg						
	V	Cr	Co	Ni	Cu	Zn	Sr
S24	302.6 ± 8.2	415.7 ± 48.1	43.1 ± 1.8	194.4 ± 0.9	1.95	2.01	65.1 ± 2.7
S25	146.5 ± 0.9	1.56	15.6 ± 0.4	1.04	1.95	2.01	21.2 ± 0.9
S26	343.2 ± 61.9	350.1 ± 51.9	43.7 ± 8.3	184.4 ± 30.1	1.95	84.9 ± 6	56.0 ± 3.7
S27	176.1 ± 1.1	462.6 ± 8.9	37.2 ± 0.8	303.1 ± 0.2	1.95	2.01	102.2 ± 2.2
S28	280.4 ± 14.2	473.7 ± 35.2	37.6 ± 3.2	87.6 ± 7.5	1.95	2.01	88.7 ± 0.8
S29	307.1 ± 1.6	164.0 ± 9.8	34.6 ± 0.5	1.04	1.95	2.01	32.7 ± 0.7
S30	376.6 ± 16.8	184.2 ± 7.0	51.8 ± 4.5	99.6 ± 0.5	1.95	61.7 ± 1.1	77.0 ± 2.0

Table F3. Concentration of trace elements (Y – Eu)

Samples	mg/kg								
	Y	Zr	Ba	La	Ce	Pr	Nd	Sm	Eu
K101	22.2 ± 0.3	104.9 ± 4.9	456.3 ± 9.1	20.6 ± 0.6	81.3 ± 3.0	5.7 ± 0.2	21.7 ± 0.6	4.8 ± 0.3	1.9 ± 0.2
K102	17.2 ± 1.0	49.1 ± 5.1	377.8 ± 21.1	16.1 ± 0.5	122.5 ± 7.4	4.7 ± 0.6	18.3 ± 2.6	4.2 ± 0.3	1.7 ± 0.1
K103	21.4 ± 0.7	63.2 ± 3.6	447.8 ± 22.7	19.0 ± 0.1	154.4 ± 17.2	5.4 ± 0.3	21.0 ± 0.9	4.4 ± 0.2	1.9 ± 0.1
K104	19.4 ± 0.2	54.8 ± 1.1	289.5 ± 5.8	18.0 ± 0.1	65.6 ± 1.4	4.8 ± 0.1	18.0 ± 0.2	3.9 ± 0.2	1.5 ± 0.1
K105	0.12	225.8 ± 15.6	284.2 ± 2.3	16.3 ± 0.1	79.2 ± 4.0	4.0 ± 0.2	16.5 ± 0.5	3.4 ± 0.1	1.1 ± 0.1
K106	18.8 ± 1.5	44.9 ± 0.9	341.6 ± 18.4	17.9 ± 1.1	94.6 ± 1.3	4.9 ± 0.4	21.5 ± 1.0	4.3 ± 0.4	1.9 ± 0.1
K107	28.6 ± 0.5	68.7 ± 0.3	474.6 ± 12.7	20.2 ± 0.9	90.3 ± 1.0	5.2 ± 0.3	20.6 ± 0.5	4.5 ± 0.5	1.6 ± 0.2
K108	229.6 ± 207	0.05	397.4 ± 16.5	20.3 ± 0.2	48.7 ± 1.8	5.6 ± 0.2	22.2 ± 0.3	4.8 ± 0.2	2.0 ± 0.1
K109	0.12	220.9 ± 1.3	248.0 ± 1.0	15.3 ± 0.2	70.0 ± 5.8	4.5 ± 0.2	16.7 ± 0.2	3.9 ± 0.1	1.6 ± 0.1
K110	0.12	279.7 ± 33.0	275.1 ± 2.2	16.8 ± 0.5	92.1 ± 9.5	5.1 ± 0.3	17.5 ± 0.1	3.8 ± 0.2	1.6 ± 0.1
K111	48.5 ± 1.5	31.7 ± 0.5	512.4 ± 36.4	20.0 ± 1.3	75.0 ± 9.6	6.0 ± 0.4	23.4 ± 2.2	4.9 ± 0.1	2.1 ± 0.2
K112	38.7 ± 6.8	0.05	535 ± 13.4	23.3 ± 0.8	74.0 ± 0.3	6.7 ± 0.2	27.4 ± 0.3	5.8 ± 0.5	2.5 ± 0.1
K113	45.7 ± 0.7	46.0 ± 3.9	539.3 ± 5.0	24.2 ± 0.7	75.0 ± 1.0	7.2 ± 0.2	28.7 ± 0.1	6.3 ± 0.1	2.5 ± 0.1
K114	43.4 ± 6.7	58.4 ± 1.6	517.6 ± 13.6	21.1 ± 0.7	72.1 ± 3.4	6.4 ± 0.4	24.8 ± 0.5	5.4 ± 0.3	2.2 ± 0.2
K115	39.9 ± 8.0	39.8 ± 2.8	421.9 ± 9.3	24.9 ± 0.2	100.1 ± 1.6	6.3 ± 0.3	24.6 ± 1.2	4.8 ± 0.1	1.8 ± 0.2
K117	0.12	205.5 ± 1.5	286.3 ± 5.1	14.5 ± 0.1	82.4 ± 16.6	3.9 ± 0.1	14.4 ± 0.8	3.1 ± 0.1	1.4 ± 0.2
K118	0.12	199.6 ± 7.3	226.8 ± 0.1	15.1 ± 0.3	70.7 ± 2.1	3.7 ± 0.1	15.5 ± 0.2	3.3 ± 0.4	0.9 ± 0.1
K119	25.2 ± 0.6	76.9 ± 6.6	475.1 ± 21.6	28.4 ± 2.3	136.9 ± 6.5	6.1 ± 0.1	25.2 ± 0.3	12.3 ± 0.1	1.9 ± 0.2
K120	0.12	148.8 ± 6.2	391.8 ± 8.8	13.9 ± 0.7	62.0 ± 5.2	3.3 ± 0.1	12.0 ± 0.6	2.5 ± 0.1	1.3 ± 0.1
K121	301.7 ± 247.2	408.7 ± 1.9	648.5 ± 19.9	109.1 ± 0.1	139.2 ± 6.2	6.8 ± 0.1	24.5 ± 0.8	3.9 ± 0.4	1.9 ± 0.3
K122	0.12	263.1 ± 0.3	295.0 ± 13	18.2 ± 1.0	87.9 ± 0.8	4.2 ± 0.1	16.1 ± 0.5	3.5 ± 0.3	1.4 ± 0.1
K123	25.0 ± 3.1	55.1 ± 0.3	425.0 ± 7.5	26.6 ± 0.9	104.0 ± 0.5	6.1 ± 0.1	24.4 ± 0.6	5.2 ± 0.3	1.8 ± 0.1
K124	0.12	274.6 ± 42.4	362.9 ± 27.7	32.7 ± 1.5	99.2 ± 13.2	4.3 ± 0.1	16.3 ± 0.8	3.5 ± 0.6	1.8 ± 0.1
K125	0.12	233.2 ± 37.2	371.4 ± 4.4	24.5 ± 1.6	75.5 ± 0.8	3.7 ± 0.2	15.5 ± 1.0	3.0 ± 0.3	1.4 ± 0.2
K127	0.12	54.5 ± 4.2	514.1 ± 16.1	25.7 ± 1.6	112.2 ± 8.5	5.1 ± 0.1	18.8 ± 0.6	3.2 ± 0.5	1.5 ± 0.2
K128	19.8 ± 1.8	35.2 ± 1.3	405.3 ± 11.0	23.8 ± 0.1	102.0 ± 7.1	6.0 ± 0.1	23.1 ± 0.4	4.8 ± 0.5	1.8 ± 0.1
K129	22.6 ± 0.8	264.1 ± 4.8	419.4 ± 19.7	24.3 ± 1.2	97.8 ± 0.1	6.2 ± 0.1	23.8 ± 1.0	5.3 ± 0.2	1.8 ± 0.2
K130	21.3 ± 1.3	258.6 ± 14	407.4 ± 2.0	26.3 ± 0.2	99.7 ± 1.1	6.6 ± 0.2	24.9 ± 0.1	5.5 ± 0.2	1.9 ± 0.2
K131	0.12	187.4 ± 20.1	279.0 ± 8.2	53.4 ± 1.9	84.1 ± 7.0	3.7 ± 0.1	15.2 ± 0.6	3.1 ± 0.4	1.3 ± 0.1
K132	16.0 ± 0.1	78.5 ± 0.4	306.8 ± 2.7	20.1 ± 0.5	70.0 ± 0.9	4.8 ± 0.1	19.8 ± 0.1	4.1 ± 0.3	1.5 ± 0.1
K133	0.12	72.1 ± 1.0	219.1 ± 4.4	62.0 ± 3.5	65.7 ± 5.4	3.2 ± 0.2	13.8 ± 0.5	2.8 ± 0.1	1.2 ± 0.1
K134	12.9 ± 0.2	7.8 ± 0.5	225.0 ± 6.2	14.8 ± 0.3	51.9 ± 0.5	3.8 ± 0.2	15.8 ± 0.1	3.6 ± 0.2	1.2 ± 0.1
K135	17.8 ± 0.3	5.2 ± 0.8	322.3 ± 3.4	26.3 ± 0.3	97.1 ± 0.1	6.3 ± 0.2	22.7 ± 1.5	4.8 ± 0.2	1.4 ± 0.2
K136	18.3 ± 0.5	4.4 ± 0.8	352.0 ± 12.7	25.6 ± 0.9	90.7 ± 7.0	5.7 ± 0.1	23.0 ± 0.1	4.4 ± 0.3	1.4 ± 0.1
K137	18.3 ± 0.6	0.05	265.6 ± 10.8	21.8 ± 0.2	77.0 ± 1.9	5.2 ± 0.1	20.4 ± 1.3	4.2 ± 0.4	1.6 ± 0.1
K138	0.12	49.7 ± 0.3	215.8 ± 0.7	15.5 ± 1.0	81.6 ± 0.5	3.8 ± 0.1	15.7 ± 0.7	2.9 ± 0.4	1.2 ± 0.1
K139	0.12	53.8 ± 4.4	233.6 ± 1.4	83.7 ± 1.2	66.2 ± 2.8	3.2 ± 0.1	13.3 ± 1.1	2.6 ± 0.2	3.8 ± 0.1
K140	455.1 ± 105.2	236.6 ± 20.2	232.5 ± 5.9	135.5 ± 5.4	103.5 ± 11.2	4.4 ± 0.1	17.4 ± 0.4	3.5 ± 0.2	1.0 ± 0.1
K141	34.8 ± 1.3	288.6 ± 11.2	286.4 ± 8.0	22.8 ± 0.3	139.9 ± 4.9	5.4 ± 0.1	21.0 ± 1.0	4.1 ± 0.2	1.4 ± 0.1
K142	0.12	111.7 ± 3.5	96.8 ± 6.6	10.5 ± 0.8	25.8 ± 1.4	1.7 ± 0.1	6.2 ± 0.5	1.5 ± 0.2	0.6 ± 0.1
K143	0.12	211.8 ± 1.1	238.6 ± 1.3	13.6 ± 0.5	70.7 ± 3.4	3.1 ± 0.2	12.2 ± 0.4	2.6 ± 0.2	1.0 ± 0.1
K144	17.0 ± 1.0	54.2 ± 5.6	357.5 ± 12.2	24.3 ± 0.6	112.8 ± 14.6	6.3 ± 0.3	24.8 ± 0.8	4.7 ± 0.6	2.0 ± 0.1
K145	0.12	61.7 ± 1.4	198.9 ± 0.4	12.2 ± 0.5	74.7 ± 4.9	3.3 ± 0.3	13.3 ± 0.9	2.6 ± 0.3	1.2 ± 0.1
K146	2000.1 ± 30.3	184.4 ± 2.8	300.9 ± 2.2	22.7 ± 1.1	56.2 ± 3.1	5.1 ± 0.2	19.0 ± 0.8	4.4 ± 0.1	1.9 ± 0.2
K147	0.12	167.5 ± 4.4	222.1 ± 6.4	13.1 ± 0.8	42.4 ± 1.6	3.4 ± 0.2	12.9 ± 0.1	2.9 ± 0.3	1.5 ± 0.1
K148	20.7 ± 4.4	240.8 ± 8.0	352.1 ± 8.1	24.6 ± 0.8	89.1 ± 4.8	6.2 ± 0.5	23.4 ± 0.6	4.8 ± 0.2	1.9 ± 0.1
K149	0.12	170.3 ± 7.2	232.2 ± 4.5	17.0 ± 0.4	48.9 ± 3.1	3.7 ± 0.1	13.9 ± 0.5	3.0 ± 0.1	1.5 ± 0.1
K150	0.12	212.3 ± 4.3	216.5 ± 7.6	15.6 ± 0.3	51.6 ± 0.5	4.1 ± 0.1	15.7 ± 0.4	3.3 ± 0.4	1.6 ± 0.1
K151	0.12	135.0 ± 8.7	218.2 ± 2.8	15.3 ± 1.0	48.5 ± 3.5	3.7 ± 0.2	14.1 ± 0.2	3.3 ± 0.3	1.5 ± 0.1
K152	0.12	180.4 ± 10	235.5 ± 4.9	20.3 ± 0.7	48.4 ± 1.9	4.0 ± 0.4	15.4 ± 0.9	3.4 ± 0.2	1.7 ± 0.2
K153	22.1 ± 0.4	136.8 ± 3.0	376.5 ± 5.5	19.7 ± 0.7	83.5 ± 2.1	5.0 ± 0.1	20.3 ± 0.2	4.2 ± 0.2	1.7 ± 0.1
K154	0.12	51.6 ± 3.3	265.2 ± 4.8	16.4 ± 0.1	88.0 ± 6.7	3.9 ± 0.1	16.3 ± 0.3	3.1 ± 0.2	1.1 ± 0.1
K155	0.12	161.8 ± 9.1	217.6 ± 4.4	11.9 ± 0.1	45.2 ± 5.4	3.3 ± 0.3	12.9 ± 0.7	2.9 ± 0.2	1.3 ± 0.1
K156	0.12	208.5 ± 2.3	204.2 ± 5.7	12.9 ± 0.7	56.0 ± 1.2	4.2 ± 0.2	15.7 ± 0.2	3.4 ± 0.3	1.6 ± 0.1
K158	0.12	216.2 ± 1.3	213.0 ± 6.8	47.8 ± 1.0	98.4 ± 2.9	3.7 ± 0.1	15.0 ± 0.4	3.1 ± 0.1	2.2 ± 0.1
K159	0.12	189.1 ± 19.6	185.1 ± 3.1	14.3 ± 0.6	67.6 ± 0.3	3.4 ± 0.1	12.9 ± 0.1	2.7 ± 0.1	1.1 ± 0.1
K160	1364.2 ± 40.7	182.7 ± 7.6	310.6 ± 11.6	20.6 ± 0.7	74.7 ± 1.8	5.3 ± 0.3	20.1 ± 0.7	4.5 ± 0.1	1.9 ± 0.1
K161	52.9 ± 21.2	196.0 ± 24.9	478.6 ± 16.8	39.5 ± 0.4	117.6 ± 0.1	6.7 ± 0.1	25.3 ± 1.6	5.5 ± 0.4	2.1 ± 0.1
K162	26.2 ± 0.2	44.4 ± 1.1	352.5 ± 0.8	19.1 ± 0.5	65.4 ± 2.6	4.9 ± 0.2	20.9 ± 1.3	4.5 ± 0.2	1.2 ± 0.1
K163	25.6 ± 1.3	40.6 ± 0.2	376.2 ± 1.4	21.1 ± 0.2	56.4 ± 0.4	5.1 ± 0.2	21.5 ± 0.3	4.7 ± 0.3	1.2 ± 0.1
K164	0.12	178.0 ± 10.6	281.4 ± 13.4	17.0 ± 0.7	70.5 ± 4.9	4.7 ± 0.4	18.9 ± 1.0	4.3 ± 0.1	1.8 ± 0.1
K165	0.12	149.2 ± 9.2	285.6 ± 3.1	16.7 ± 0.5	68.3 ± 0.8	4.2 ± 0.1	16.2 ± 0.2	3.6 ± 0.3	1.5 ± 0.1
K166	53.9 ± 2.2	68.3 ± 5.0	197.5 ± 7.0	67.5 ± 0.8	127.2 ± 5.1	12.2 ± 0.2	46.6 ± 1.1	8.9 ± 0.1	1.7 ± 0.1
K167	0.12	247.1 ± 9.5	269.7 ± 7.6	15.6 ± 0.5	78.3 ± 1.3	4.5 ± 0.2	18.6 ± 1.5	3.8 ± 0.1	1.9 ± 0.1
K168	0.12	193.5 ± 15	235.5 ± 14.7	13.7 ± 0.7	67.1 ± 7.3	3.3 ± 0.1	13.1 ± 0.8	2.7 ± 0.2	0.8 ± 0.1
K169	27.5 ± 3.6	129.9 ± 7.6	430.7 ± 11.0	22.1 ± 0.8	106.6 ± 5.1	6.3 ± 0.2	25.5 ± 0.5	5.3 ± 0.2	2.2 ± 0.2
K170	0.12	175.8 ± 18.6	241.3 ± 0.1	16.2 ± 1.0	72.0 ± 1.5	4.3 ± 0.1	17.6 ± 1.2	3.8 ± 0.5	1.7 ± 0.1
K171	0.12	216.6 ± 19.7	233.6 ± 16.9	17.3 ± 0.9	83.7 ± 8.6	5.1 ± 0.5	19.3 ± 1.3	4.3 ± 0.3	1.7 ± 0.1
K172	0.12	182.9 ± 1.5	269.9 ± 11.8	13.6 ± 0.5	74.1 ± 2.0	4.1 ± 0.6	15.5 ± 1.1	3.5 ± 0.5	1.6 ± 0.2
K173	0.12	46.5 ± 1.4	237.9 ± 14.1	25.3 ± 0.3	69.2 ± 4.2	3.8 ± 0.2	16.2 ± 1.4	3.6 ± 0.3	1.5 ± 0.1
K174	22.8 ± 0.6	68.0 ± 71.7	380.4 ± 16.6	25.1 ± 0.2	77.3 ± 5.1	6.3 ± 0.2	26.8 ± 0.3	5.3 ± 0.3	1.7 ± 0.1

Table F3 Continued

Samples	mg/kg								
	Y	**Zr**	**Ba**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**
K175	15.5 ± 2.6	202.8 ± 14.6	346.0 ± 11.1	17.2 ± 0.2	73.1 ± 7.2	4.6 ± 0.1	17.6 ± 0.2	4.1 ± 0.1	1.4 ± 0.3
K176	25.1 ± 1.4	0.05	362.5 ± 6.4	15.1 ± 0.1	69.2 ± 3.7	3.9 ± 0.1	16.2 ± 1.0	3.5 ± 0.5	1.5 ± 0.1
K177	27.7 ± 1.0	64.7 ± 5.6	410.9 ± 20.4	27.9 ± 1.7	99.5 ± 10.5	6.4 ± 0.3	28.2 ± 1.4	5.7 ± 0.7	1.5 ± 0.2
K178	22.8 ± 1.2	52.2 ± 0.7	290.0 ± 0.8	17.7 ± 0.6	55.7 ± 0.8	4.3 ± 0.1	18.4 ± 0.4	3.8 ± 0.2	1.0 ± 0.2
K179	17.9 ± 1.1	184.5 ± 7.6	366.9 ± 4.2	13.2 ± 0.1	80.3 ± 2.2	4.0 ± 0.1	15.7 ± 0.5	3.5 ± 0.3	1.5 ± 0.1
K180	29.8 ± 0.2	22.9 ± 0.7	369.1 ± 0.8	21.1 ± 0.4	63.7 ± 0.7	5.0 ± 0.2	21.6 ± 0.2	4.4 ± 0.7	1.2 ± 0.1
K181	23.6 ± 0.7	76.3 ± 3.8	300.2 ± 11.9	16.1 ± 0.2	67.3 ± 1.3	4.3 ± 0.2	18.6 ± 0.3	3.7 ± 0.3	1.1 ± 0.1
K182	25.4 ± 0.4	45.0 ± 43.7	332.7 ± 5.9	17.9 ± 0.8	53.0 ± 2.0	4.6 ± 0.2	18.3 ± 0.9	4.3 ± 0.2	1.3 ± 0.1
K183	18.7 ± 1.1	23.6 ± 0.7	299.5 ± 2.0	16.1 ± 0.4	62.6 ± 2.1	4.5 ± 0.2	17.8 ± 0.5	4.1 ± 0.1	1.4 ± 0.1
K184	0.12	159.1 ± 0.6	219.7 ± 22.1	14.3 ± 0.9	66.3 ± 4.6	4.0 ± 0.3	16.6 ± 0.8	4.5 ± 0.3	1.6 ± 0.1
K185	16.1 ± 0.1	139.1 ± 5.8	285.9 ± 3.6	29.3 ± 0.2	82.5 ± 0.3	4.6 ± 0.1	19.6 ± 0.2	3.9 ± 0.1	1.7 ± 0.1
K186	24.4 ± 0.6	59.9 ± 1.6	327.0 ± 9.1	17.4 ± 0.4	53.8 ± 4.8	4.7 ± 0.1	17.4 ± 0.2	3.9 ± 0.1	1.4 ± 0.1
K187	24.7 ± 1.6	49.9 ± 2.2	382.8 ± 9.7	21.2 ± 0.7	65.8 ± 2.9	5.7 ± 0.2	23.3 ± 0.9	4.9 ± 0.5	1.8 ± 0.1
K188	26.1 ± 0.8	73.2 ± 3.0	375.4 ± 3.7	19.0 ± 0.2	57.7 ± 5.0	5.0 ± 0.2	19.3 ± 0.5	4.5 ± 0.1	1.6 ± 0.2
K189	27.2 ± 0.3	35.4 ± 1.8	454.9 ± 7.3	30.0 ± 0.8	71.3 ± 0.9	7.2 ± 0.4	27.2 ± 1.1	5.6 ± 0.4	1.8 ± 0.1
K190	21.8 ± 0.3	65.5 ± 0.1	311.7 ± 7.7	18.3 ± 1.0	61.3 ± 3.8	4.6 ± 0.2	20.2 ± 1.0	4.2 ± 0.6	1.6 ± 0.1
K191	22.7 ± 0.9	80.3 ± 2.2	372.1 ± 2.6	17.8 ± 1.7	56.4 ± 2.5	4.6 ± 0.5	19.5 ± 1.4	4.4 ± 0.7	1.7 ± 0.2
K192	28.2 ± 0.6	33.5 ± 4.6	391.8 ± 11.7	23.0 ± 1.1	63.5 ± 4.5	5.8 ± 0.3	22.8 ± 1.5	5.2 ± 0.4	1.8 ± 0.2
K193	34.6 ± 0.4	77.2 ± 3.2	490.4 ± 11.6	24.7 ± 1.2	75.6 ± 5.3	6.2 ± 0.4	25.2 ± 0.2	5.7 ± 0.4	1.6 ± 0.1
K194	25.9 ± 0.6	73.2 ± 5.4	385.5 ± 1.4	20.1 ± 0.3	49.6 ± 1.9	4.9 ± 0.1	19.6 ± 0.1	4.6 ± 0.1	1.4 ± 0.1
K195	38.9 ± 10.1	31.9 ± 1.0	404.0 ± 4.4	16.2 ± 0.1	67.9 ± 1.2	4.5 ± 0.1	17.8 ± 0.3	3.8 ± 0.3	1.7 ± 0.1
K196	24.7 ± 1.0	34.5 ± 1.4	377.5 ± 4.8	15.7 ± 0.8	68.8 ± 1.7	4.3 ± 0.1	17.4 ± 0.8	3.9 ± 0.7	1.6 ± 0.1
K197	23.9 ± 0.4	69.5 ± 0.6	386.9 ± 5.5	21.7 ± 1.0	67.6 ± 2.1	5.5 ± 0.6	23.3 ± 1.4	4.4 ± 0.3	1.8 ± 0.1
K198	28.2 ± 2.2	27.0± 2.2	362.7 ± 11.6	19.8 ± 0.1	66.2 ± 6.0	4.9 ± 0.1	20.3 ± 0.2	4.6 ± 0.2	1.1 ± 0.1
K199	19.3 ± 1.8	211.1 ± 5.3	360.9 ± 1.8	20.4 ± 0.1	82.7 ± 4.4	4.8 ± 0.1	18.3 ± 1.1	4.4 ± 0.6	1.8 ± 0.2
K200	22.2 ± 0.7	25.9 ± 1.0	278.2 ± 16.7	16.1 ± 0.2	57.8 ± 4.7	4.2 ± 0.2	17.8 ± 0.2	3.9 ± 0.1	1.4 ± 0.1
K201	14.9 ± 0.2	136.1 ± 6.6	264.4 ± 4.3	19.7 ± 1.0	78.9 ± 2.7	4.3 ± 0.1	17.6 ± 0.4	3.4 ± 0.2	1.5 ± 0.1
K202	19.3 ± 0.3	13.3 ± 0.2	599.9 ± 5.5	39.1 ± 0.4	118.7 ± 0.8	9.3 ± 0.5	35.2 ± 1.2	6.2 ± 0.1	1.8 ± 0.1
K203	14.5 ± 1.3	137.7 ± 22.9	314.3 ± 7.6	17.6 ± 0.7	86.8 ± 5.4	4.3 ± 0.1	17.6 ± 1.0	3.5 ± 0.1	1.6 ± 0.1
K204	19.2 ± 0.3	72.8 ± 19	300.1 ± 1.4	19.5 ± 0.5	65.8 ± 4.0	5.1 ± 0.1	21.9 ± 0.8	4.3 ± 0.5	1.6 ± 0.1
K205	28.6 ± 0.4	44.1 ± 2.4	412.3 ± 29.8	21.7 ± 0.2	70.7 ± 7.4	5.4 ± 0.1	23.2 ± 1.0	4.5 ± 0.5	1.2 ± 0.1
K206	11.7 ± 0.8	69.8 ± 2.8	249.3 ± 2.9	13.0 ± 0.5	44.1 ± 1.4	3.3 ± 0.1	12.6 ± 0.1	2.6 ± 0.2	0.9 ± 0.1
K207	15.7 ± 0.2	45.5 ± 0.3	346.5 ± 7.1	64.2 ± 4.2	74.5 ± 3.6	3.7 ± 0.2	14.6 ± 0.2	3.6 ± 0.2	1.6 ± 0.2
K208	17.8 ± 0.6	57.1 ± 4.0	298.4 ± 1.8	12.2 ± 1.0	71.5 ± 2.3	3.6 ± 0.1	14.3 ± 0.6	3.9 ± 0.2	1.4 ± 0.1
K209	14.4 ± 0.7	113.4 ± 4.8	240.8 ± 1.2	26.8 ± 0.1	75.3 ± 0.4	3.8 ± 0.1	15.8 ± 0.3	3.7 ± 0.1	1.4 ± 0.1
K210	17.5 ± 0.5	225.2 ± 23.5	397.6 ± 2.1	17.5 ± 0.9	98.0 ± 4.6	5.4 ± 0.1	21.2 ± 1.2	4.7 ± 0.3	1.7 ± 0.1
K211	18.7 ± 0.3	248.9 ± 47.2	461.5 ± 4.8	18.7 ± 1.3	103.9 ± 10.9	5.5 ± 0.2	21.0 ± 1.1	4.6 ± 0.4	1.9 ± 0.2
K212	14.6 ± 0.1	118.0 ± 6.6	406.2 ± 7.6	24.3 ± 1.0	86.3 ± 5.3	4.4 ± 0.3	24.1 ± 1.1	3.5 ± 0.2	1.6 ± 0.1
K213	0.12	262.1 ± 33.6	224.1 ± 2.8	17.7 ± 2.3	77.0 ± 11.8	3.6 ± 0.1	13.8 ± 0.7	3.1 ± 0.1	1.4 ± 0.2
K214	22.2 ± 0.3	184.4 ± 2.1	499.1 ± 10.4	35.8 ± 0.7	140.8 ± 0.9	8.2 ± 0.4	30.6 ± 0.5	6.0 ± 0.2	1.7 ± 0.1
K215	26.4 ± 0.4	55.2 ± 0.4	516.9 ± 14.2	20.1 ± 0.5	76.0 ± 0.3	5.1 ± 0.1	20.8 ± 0.1	4.1 ± 0.1	1.6 ± 0.1
K216	0.12	269.6 ± 4.2	417.4 ± 9.7	23.6 ± 0.4	114.2 ± 3.8	4.7 ± 0.1	17.2 ± 0.7	2.9 ± 0.2	1.0 ± 0.1
K217	15.3 ± 3.1	140.1 ± 3.2	356.4 ± 27.5	18.3 ± 1.2	84.4 ± 10.6	4.2 ± 0.1	16.9 ± 0.5	3.2 ± 0.1	1.3 ± 0.1
K218	18.0 ± 0.1	187.9 ± 5.1	340.9 ± 10.1	26.6 ± 0.7	100.5 ± 0.2	6.4 ± 0.1	23.5 ± 0.4	4.7 ± 0.1	1.3 ± 0.1
K219	17.0 ± 0.5	121.2 ± 3.8	476.8 ± 2.2	33.2 ± 0.2	109.2 ± 2.7	7.9 ± 0.1	28.5 ± 0.7	5.4 ± 0.4	1.4 ± 0.1
K220	33.4 ± 0.7	114.8 ± 1.8	503.2 ± 14.4	25.4 ± 0.1	103.5 ± 0.6	6.8 ± 0.2	27.3 ± 0.1	5.5 ± 0.1	2.2 ± 0.2
K221	19.7 ± 2.4	260.0 ± 9.8	423.2 ± 18.9	175.3 ± 7.6	136.4 ± 23.3	5.8 ± 0.3	47.7 ± 0.3	4.9 ± 0.2	2.0 ± 0.1
K222	0.12	292.6 ± 16.8	185.7 ± 8.0	15.9 ± 0.7	76.5 ± 3.8	3.2 ± 0.1	13.0 ± 0.5	3.1 ± 0.2	1.1 ± 0.1
K223	0.12	61.7 ± 4.9	71.1 ± 4.1	25.4 ± 1.2	17.1 ± 2.7	0.9 ± 0.1	3.8 ± 0.7	1.0 ± 0.3	0.4 ± 0.1
K224	0.12	229.1 ± 10.7	161.7 ± 1.6	19.6 ± 0.4	81.6 ± 1.2	2.9 ± 0.1	16.2 ± 0.3	2.3 ± 0.2	0.8 ± 0.1
K225	6.6 ± 0.1	4.7 ± 0.2	164.8 ± 1.3	9.1 ± 0.3	25.1 ± 1.3	2.0 ± 0.1	6.2 ± 0.1	1.3 ± 0.2	0.5 ± 0.1
K226	30.1 ± 0.7	86.5 ± 1.0	458.7 ± 4.3	21.8 ± 0.5	72.2 ± 2.9	5.5 ± 0.2	21.8 ± 1.2	4.7 ± 0.1	1.7 ± 0.1
K227	100.7 ± 20.6	132.4 ± 14	394.3 ± 22.6	185.6 ± 21.0	100.7 ± 12.8	5.2 ± 0.6	21.9 ± 1.8	4.7 ± 0.6	1.5 ± 0.1
K228	0.12	196.8 ± 0.1	203.8 ± 8.4	9.5 ± 0.2	67.2 ± 2.6	2.7 ± 0.2	11.2 ± 0.1	2.2 ± 0.2	1.0 ± 0.1
S01	53.5 ± 8.6	197.8 ± 22.4	224.7 ± 0.3	23.6 ± 1.0	108.6 ± 3.7	5.7 ± 0.1	19.9 ± 0.3	4.3 ± 0.4	1.2 ± 0.1
S02	0.12	181.1 ± 19.6	227.8 ± 4.1	15.1 ± 1.8	109.3 ± 4.2	5.0 ± 0.3	20.7 ± 1.1	4.4 ± 0.1	1.6 ± 0.1
S03	10.6 ± 1.4	50.2 ± 14.3	113.5 ± 4.1	1.7 ± 0.1	19.6 ± 1.0	0.3 ± 0.1	2.8 ± 0.2	0.7 ± 0.1	0.7 ± 0.1
S04	0.12	141.3 ± 2.6	233.6 ± 2.8	26.0 ± 0.3	126.3 ± 2.5	6.2 ± 0.3	22.8 ± 0.2	4.3 ± 0.1	1.1 ± 0.1
S05	16.4 ± 0.6	74.9 ± 3.9	24.2 ± 5.9	2.4 ± 0.1	21.6 ± 0.1	0.7 ± 0.1	4.9 ± 0.1	1.4 ± 0.1	0.8 ± 0.1
S06	0.12	149.0 ± 10.6	31.7 ± 2.4	9.4 ± 0.5	54.9 ± 2.0	2.9 ± 0.1	12.0 ± 0.7	3.1 ± 0.1	1.1 ± 0.1
S07	0.12	125.6 ± 1.4	449.3 ± 20.5	18.1 ± 0.8	122.7 ± 6.7	4.9 ± 0.2	17.1 ± 0.6	3.8 ± 0.2	1.1 ± 0.1
S08	0.12	237.2 ± 1.5	336.5 ± 2.0	21.5 ± 2.2	146.0 ± 8.6	5.5 ± 0.1	19.2 ± 0.6	3.7 ± 0.3	1.2 ± 0.2
S09	17.7 ± 0.2	95.4 ± 6.8	349.9 ± 6.0	26.6 ± 1.6	112.1 ± 5.4	6.1 ± 0.2	23.0 ± 1.1	4.4 ± 0.1	1.5 ± 0.1
S10	17.4 ± 0.8	105.7 ± 4.2	223.7 ± 2.8	17.8 ± 0.2	81.5 ± 1.3	4.5 ± 0.2	19.4 ± 0.5	3.8 ± 0.2	1.6 ± 0.1
S11	0.12	134.8 ± 2.1	156.4 ± 1.0	6.2 ± 0.1	40.0 ± 4.2	2.3 ± 0.2	8.8 ± 0.3	2.1 ± 0.4	0.9 ± 0.1
S12	0.12	86.0 ± 15.0	33.1 ± 0.2	2.9 ± 0.3	20.0 ± 3.0	1.5 ± 0.3	5.2 ± 0.1	1.3 ± 0.1	0.7 ± 0.1
S13	0.12	85.8 ± 13.9	80.9 ± 0.9	4.9 ± 0.3	21.8 ± 0.3	1.5 ± 0.2	4.5 ± 0.3	1.0 ± 0.1	0.4 ± 0.1
S14	0.12	86.3 ± 0.1	150.0 ± 6.7	7.1 ± 0.1	42.7 ± 3.7	2.2 ± 0.1	7.7 ± 0.5	1.8 ± 0.1	0.5 ± 0.1
S15	30.1 ± 16.1	169.6 ± 2.9	145.5 ± 2.0	19.4 ± 0.5	90.9 ± 13.4	4.9 ± 0.1	20.4 ± 0.3	4.4 ± 0.2	1.6 ± 0.1
S16	59.0 ± 10.2	259.2 ± 17	298.2 ± 1.2	20.6 ± 0.9	87.9 ± 6.0	5.2 ± 0.2	18.9 ± 0.1	3.7 ± 0.3	1.6 ± 0.1
S17	29.8 ± 2.6	168.6 ± 1.7	394.1 ± 0.4	35.2 ± 2.8	171.6 ± 2.1	8.1 ± 0.1	30.1 ± 0.4	5.0 ± 0.2	1.5 ± 0.1
S18	0.12	231.9 ± 18.4	259.6 ± 5.4	22.6 ± 0.4	99.3 ± 16.5	5.8 ± 0.5	22.3 ± 0.2	4.4 ± 0.3	1.7 ± 0.1
S19	14.0 ± 0.5	140.9 ± 5.9	237.0 ± 4.4	18.5 ± 0.1	84.3 ± 1.6	4.4 ± 0.1	17.0 ± 0.4	3.5 ± 0.1	1.2 ± 0.1

Table F3 Continued

Samples	**mg/kg**								
	Y	**Zr**	**Ba**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**
S20	0.12	97.5 ± 1.1	64.1 ± 5.7	7.0 ± 0.4	32.1 ± 2.5	2.1 ± 0.1	7.6 ± 0.7	1.9 ± 0.1	1.0 ± 0.1
S21	0.12	205.4 ± 0.4	262.2 ± 0.7	12.4 ± 0.1	67.2 ± 0.1	3.7 ± 0.1	13.8 ± 0.4	2.7 ± 0.1	1.4 ± 0.1
S22	14.1 ± 0.2	166.3 ± 1.6	254.7 ± 3.4	20.5 ± 1.2	101.5 ± 0.6	5.1 ± 0.1	19.3 ± 0.5	3.7 ± 0.1	1.1 ± 0.1
S23	0.12	127.6 ± 0.3	170.9 ± 5.1	19.3 ± 0.9	94.7 ± 1.2	4.3 ± 0.1	16.7 ± 0.1	3.1 ± 0.2	1.0 ± 0.1
S24	0.12	248.4 ± 4.2	245.8 ± 4.7	28.9 ± 2.9	137.9 ± 18.8	7.2 ± 0.1	26.6 ± 0.1	4.9 ± 0.1	1.8 ± 0.1
S25	0.12	34.4 ± 1.9	176.9 ± 1.0	20.4 ± 1.2	106.4 ± 2.0	4.6 ± 0.2	17.8 ± 0.4	3.1 ± 0.2	1.0 ± 0.1
S26	0.12	138.7 ± 26.5	426.4 ± 23.1	30.5 ± 3.5	121.6 ± 12.1	7.2 ± 0.7	27.1 ± 2.3	5.1 ± 0.5	1.3 ± 0.3
S27	0.12	119.6 ± 0.8	55.8 ± 0.9	8.9 ± 0.1	47.8 ± 0.5	2.2 ± 0.1	8.7 ± 0.2	2.0 ± 0.1	0.7 ± 0.1
S28	0.12	37.4 ± 2.0	43.0 ± 2.8	2.9 ± 0.1	14.5 ± 0.9	0.6 ± 0.1	3.7 ± 0.1	0.9 ± 0.1	0.4 ± 0.1
S29	0.12	89.1 ± 2.5	58.0 ± 1.0	6.5 ± 0.1	35.1 ± 1.8	1.5 ± 0.1	6.2 ± 0.1	1.6 ± 0.1	0.6 ± 0.1
S30	0.12	34.8 ± 0.7	32.8 ± 1.3	0.9 ± 0.1	7.3 ± 0.3	0.3 ± 0.1	2.8 ± 0.2	1.0 ± 0.2	0.3 ± 0.1

Table F4. Concentration of trace elements (Tb – U)

Samples	mg/kg								
	Tb	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Th**	**U**
K101	0.8 ± 0.1	3.9 ± 0.3	0.8 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	2.6 ± 0.2	0.3 ± 0.1	6.8 ± 0.2	2.8 ± 0.1
K102	1.0 ± 0.1	4.1 ± 0.3	0.8 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	2.3 ± 0.1	0.4 ± 0.1	6.4 ± 0.5	3.7 ± 0.5
K103	0.9 ± 0.1	4.2 ± 0.1	0.8 ± 0.1	2.4 ± 0.2	0.3 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	5.2 ± 0.2	3.5 ± 0.3
K104	0.7 ± 0.1	3.6 ± 0.2	0.8 ± 0.1	2.5 ± 0.1	0.4 ± 0.1	2.3 ± 0.2	0.3 ± 0.1	6.8 ± 0.5	3.2 ± 0.1
K105	0.4 ± 0.1	3.0 ± 0.2	0.7 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	1.7 ± 0.1	0.4 ± 0.1	4.2 ± 0.1	3.2 ± 0.4
K106	1.0 ± 0.1	3.8 ± 0.3	0.8 ± 0.1	2.5 ± 0.1	0.3 ± 0.1	2.1 ± 0.3	0.4 ± 0.1	5.2 ± 0.5	3.3 ± 0.3
K107	0.8 ± 0.1	3.8 ± 0.4	0.8 ± 0.1	2.5 ± 0.1	0.3 ± 0.1	2.5 ± 0.1	0.3 ± 0.1	8.1 ± 0.1	2.9 ± 0.1
K108	0.9 ± 0.1	4.4 ± 0.1	0.9 ± 0.1	2.9 ± 0.2	0.5 ± 0.1	2.9 ± 0.1	0.5 ± 0.1	7.2 ± 0.1	2.6 ± 0.1
K109	0.7 ± 0.1	3.0 ± 0.2	0.7 ± 0.1	1.8 ± 0.2	0.3 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	5.9 ± 0.1	3.0 ± 0.7
K110	0.7 ± 0.1	3.2 ± 0.2	0.8 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	2.0 ± 0.1	0.5 ± 0.1	6.0 ± 0.6	2.9 ± 0.8
K111	0.9 ± 0.2	4.4 ± 0.3	0.9 ± 0.1	2.9 ± 0.3	0.5 ± 0.1	2.7 ± 0.3	0.5 ± 0.1	6.5 ± 0.6	2.4 ± 0.3
K112	1.1 ± 0.2	5.0 ± 0.2	1.0 ± 0.1	3.1 ± 0.2	0.5 ± 0.1	3.0 ± 0.2	0.5 ± 0.1	5.6 ± 0.2	2.4 ± 0.1
K113	1.1 ± 0.1	5.9 ± 0.3	1.1 ± 0.1	3.4 ± 0.1	0.6 ± 0.1	3.3 ± 0.3	0.6 ± 0.1	6.7 ± 0.1	2.8 ± 0.1
K114	1.0 ± 0.1	5.0 ± 0.2	1.0 ± 0.1	3.0 ± 0.2	0.5 ± 0.1	3.0 ± 0.2	0.5 ± 0.1	7.0 ± 0.1	2.7 ± 0.2
K115	0.9 ± 0.1	4.3 ± 0.1	0.9 ± 0.1	2.5 ± 0.3	0.5 ± 0.1	2.3 ± 0.3	0.4 ± 0.1	6.8 ± 0.1	2.7 ± 0.2
K117	0.6 ± 0.1	2.7 ± 0.3	0.6 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	5.7 ± 0.2	3.2 ± 0.8
K118	0.3 ± 0.1	2.8 ± 0.1	0.7 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	1.7 ± 0.2	0.4 ± 0.1	4.5 ± 0.2	3.0 ± 0.1
K119	2.0 ± 0.2	4.8 ± 0.3	1.0 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	6.9 ± 0.4	2.3 ± 0.1
K120	0.5 ± 0.1	2.1 ± 0.1	0.5 ± 0.1	1.4 ± 0.1	0.3 ± 0.1	1.6 ± 0.1	0.3 ± 0.1	6.1 ± 0.3	4.0 ± 1.2
K121	9.9 ± 0.3	3.7 ± 0.1	0.7 ± 0.1	2.4 ± 0.1	0.4 ± 0.1	2.1 ± 0.1	0.6 ± 0.1	11.7 ± 0.1	7.5 ± 0.7
K122	0.9 ± 0.2	3.3 ± 0.1	0.7 ± 0.1	2.0 ± 0.3	0.3 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	4.2 ± 0.1	2.3 ± 0.1
K123	1.2 ± 0.1	4.7 ± 0.3	1.0 ± 0.1	2.6 ± 0.3	0.5 ± 0.1	2.3 ± 0.2	0.4 ± 0.1	7.1 ± 0.2	2.5 ± 0.1
K124	1.9 ± 0.2	3.2 ± 0.1	0.7 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	4.1 ± 0.2	2.0 ± 0.1
K125	1.6 ± 0.1	2.9 ± 0.4	0.6 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	1.9 ± 0.3	0.3 ± 0.1	3.8 ± 0.1	1.6 ± 0.2
K127	0.9 ± 0.1	2.9 ± 0.3	0.6 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	10.2 ± 0.8	7.5 ± 0.3
K128	1.0 ± 0.1	4.5 ± 0.6	0.9 ± 0.1	2.6 ± 0.2	0.5 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	6.7 ± 0.2	3.7 ± 0.8
K129	0.9 ± 0.1	4.4 ± 0.1	1.0 ± 0.1	2.5 ± 0.4	0.5 ± 0.1	2.0 ± 0.3	0.4 ± 0.1	7.4 ± 0.8	2.6 ± 0.2
K130	1.0 ± 0.1	4.8 ± 0.3	1.0 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	2.4 ± 0.3	0.4 ± 0.1	7.5 ± 0.2	3.0 ± 0.2
K131	5.5 ± 0.3	3.1 ± 0.1	0.6 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	1.7 ± 0.4	0.4 ± 0.1	4.4 ± 0.2	2.6 ± 0.2
K132	0.9 ± 0.1	3.9 ± 0.2	0.8 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	5.7 ± 0.1	2.8 ± 0.1
K133	5.0 ± 0.1	2.8 ± 0.2	0.6 ± 0.1	1.8 ± 0.1	0.2 ± 0.1	1.3 ± 0.1	0.4 ± 0.1	3.2 ± 0.3	1.3 ± 0.1
K134	0.9 ± 0.1	3.2 ± 0.1	0.7 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	1.7 ± 0.1	0.3 ± 0.1	3.9 ± 0.1	2.2 ± 0.1
K135	1.0 ± 0.1	4.5 ± 0.2	1.0 ± 0.1	2.9 ± 0.1	0.5 ± 0.1	2.6 ± 0.2	0.5 ± 0.1	12.7 ± 0.1	4.7 ± 0.3
K136	1.0 ± 0.1	4.4 ± 0.1	1.0 ± 0.1	3.1 ± 0.1	0.5 ± 0.1	2.7 ± 0.2	0.5 ± 0.1	13.1 ± 0.7	4.6 ± 0.1
K137	1.0 ± 0.1	4.3 ± 0.1	1.0 ± 0.1	2.6 ± 0.1	0.5 ± 0.1	2.4 ± 0.1	0.4 ± 0.1	7.0 ± 0.1	3.1 ± 0.1
K138	0.7 ± 0.1	4.1 ± 0.2	0.6 ± 0.1	1.9 ± 0.1	0.3 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	6.0 ± 0.3	3.0 ± 0.6
K139	0.7 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	1.7 ± 0.2	0.3 ± 0.1	1.5 ± 0.2	0.3 ± 0.1	5.1 ± 0.2	2.5 ± 0.1
K140	16.1 ± 0.1	2.9 ± 0.4	0.5 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	1.2 ± 0.2	0.5 ± 0.1	7.0 ± 0.2	1.8 ± 0.2
K141	0.9 ± 0.1	3.4 ± 0.1	0.6 ± 0.1	2.1 ± 0.2	0.3 ± 0.1	1.8 ± 0.2	0.3 ± 0.1	8.7 ± 0.8	4.0 ± 0.2
K142	0.8 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	0.9 ± 0.1	0.1 ± 0.1	2.5 ± 0.2	0.4 ± 0.2
K143	0.9 ± 0.1	2.6 ± 0.1	0.5 ± 0.1	1.8 ± 0.1	0.2 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	5.3 ± 0.1	3.1 ± 0.1
K144	0.9 ± 0.1	4.6 ± 0.3	1.0 ± 0.2	2.4 ± 0.2	0.4 ± 0.1	2.3 ± 0.2	0.4 ± 0.1	6.7 ± 0.6	4.0 ± 1.2
K145	0.6 ± 0.1	2.6 ± 0.3	0.5 ± 0.1	1.4 ± 0.3	0.3 ± 0.1	1.2 ± 0.2	0.2 ± 0.1	3.6 ± 0.3	2.9 ± 0.3
K146	1.2 ± 0.1	3.6 ± 0.1	0.8 ± 0.1	2.3 ± 0.1	0.5 ± 0.1	2.1 ± 0.2	0.5 ± 0.1	4.3 ± 0.3	2.6 ± 0.2
K147	0.01	2.6 ± 0.3	0.7 ± 0.1	1.9 ± 0.2	0.4 ± 0.1	1.7 ± 0.1	0.4 ± 0.1	3.3 ± 0.1	2.6 ± 0.3
K148	0.9 ± 0.1	4.4 ± 0.1	1.0 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	2.4 ± 0.3	0.4 ± 0.1	6.9 ± 0.2	2.4 ± 0.1
K149	1.3 ± 0.2	2.5 ± 0.1	0.7 ± 0.1	1.9 ± 0.3	0.4 ± 0.1	1.9 ± 0.1	0.5 ± 0.1	4.3 ± 0.4	2.3 ± 0.2
K150	1.6 ± 0.1	2.8 ± 0.2	0.6 ± 0.1	1.8 ± 0.2	0.4 ± 0.1	2.1 ± 0.1	0.5 ± 0.1	3.5 ± 0.1	2.3 ± 0.3
K151	2.8 ± 0.1	2.9 ± 0.1	0.7 ± 0.1	2.0 ± 0.3	0.4 ± 0.1	2.8 ± 0.3	0.6 ± 0.1	4.1 ± 0.3	2.6 ± 0.3
K152	0.01	2.8 ± 0.3	0.7 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	1.9 ± 0.3	0.4 ± 0.1	4.2 ± 0.4	3.0 ± 0.2
K153	0.8 ± 0.1	3.9 ± 0.2	0.8 ± 0.1	2.6 ± 0.1	0.3 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	7.6 ± 0.2	3.4 ± 0.3
K154	0.4 ± 0.1	2.9 ± 0.3	0.7 ± 0.1	1.7 ± 0.1	0.4 ± 0.1	1.7 ± 0.2	0.4 ± 0.1	4.3 ± 0.2	3.2 ± 0.3
K155	0.01	2.6 ± 0.1	0.7 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	1.8 ± 0.3	0.4 ± 0.1	4.2 ± 0.2	3.7 ± 0.2
K156	0.9 ± 0.1	3.1 ± 0.2	0.8 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	4.1 ± 0.2	3.2 ± 0.1
K158	0.8 ± 0.1	2.2 ± 0.1	0.5 ± 0.1	1.5 ± 0.1	0.2 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	3.3 ± 0.1	2.1 ± 0.1
K159	0.6 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	1.4 ± 0.1	0.2 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	3.3 ± 0.1	2.0 ± 0.1
K160	0.01	3.7 ± 0.1	1.2 ± 0.1	2.3 ± 0.3	0.3 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	4.8 ± 0.4	3.1 ± 0.2
K161	2.1 ± 0.1	4.7 ± 0.1	0.9 ± 0.1	3.0 ± 0.1	0.3 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	6.3 ± 0.2	3.4 ± 0.2
K162	0.8 ± 0.1	4.4 ± 0.3	0.9 ± 0.1	2.7 ± 0.3	0.4 ± 0.1	2.6 ± 0.2	0.5 ± 0.1	6.6 ± 0.7	1.7 ± 0.3
K163	0.8 ± 0.1	4.6 ± 0.2	0.9 ± 0.1	2.7 ± 0.1	0.4 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	7.3 ± 0.8	1.5 ± 0.1
K164	0.01	3.6 ± 0.5	1.2 ± 0.1	2.2 ± 0.2	0.4 ± 0.1	2.6 ± 0.2	0.4 ± 0.1	6.3 ± 0.2	3.5 ± 0.2
K165	0.01	2.9 ± 0.1	1.1 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	5.1 ± 0.3	4.2 ± 0.5
K166	1.3 ± 0.1	7.0 ± 0.4	1.5 ± 0.1	4.8 ± 0.2	0.7 ± 0.1	4.5 ± 0.2	0.8 ± 0.1	21.3 ± 1.1	4.7 ± 0.7
K167	0.0041	3.4 ± 0.2	1.2 ± 0.1	2.1 ± 0.1	0.3 ± 0.1	2.1 ± 0.3	0.4 ± 0.1	4.0 ± 0.3	3.1 ± 0.1
K168	0.3 ± 0.1	2.5 ± 0.1	0.6 ± 0.1	1.6 ± 0.1	0.4 ± 0.1	1.6 ± 0.1	0.3 ± 0.1	4.7 ± 0.1	3.6 ± 0.5
K169	1.1 ± 0.1	4.7 ± 0.2	0.8 ± 0.1	3.0 ± 0.1	0.3 ± 0.1	2.5 ± 0.1	0.4 ± 0.1	6.4 ± 0.2	3.6 ± 0.1
K170	0.01	3.2 ± 0.3	1.1 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	2.2 ± 0.1	0.3 ± 0.1	3.9 ± 0.4	3.3 ± 0.4
K171	0.01	3.5 ± 0.5	1.1 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	2.2 ± 0.2	0.3 ± 0.1	4.6 ± 0.3	3.7 ± 0.6
K172	0.01	3.0 ± 0.1	1.1 ± 0.1	1.9 ± 0.1	0.3 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	4.7 ± 0.1	3.5 ± 0.2
K173	0.01	3.0 ± 0.3	1.0 ± 0.1	1.9 ± 0.1	0.3 ± 0.1	2.2 ± 0.3	0.4 ± 0.1	4.1 ± 0.3	3.5 ± 0.1
K174	1.2 ± 0.1	4.7 ± 0.7	1.1 ± 0.1	2.8 ± 0.2	0.4 ± 0.1	2.9 ± 0.3	0.4 ± 0.1	8.9 ± 0.2	3.4 ± 0.3

Table F4 Continued

Samples	mg/kg								
	Tb	Dy	Ho	Er	Tm	Yb	Lu	Th	U
K175	0.8 ± 0.1	3.8 ± 0.2	0.8 ± 0.1	2.3 ± 0.2	0.4 ± 0.1	2.2 ± 0.1	0.3 ± 0.1	6.2 ± 0.2	1.7 ± 0.2
K176	0.7 ± 0.1	3.7 ± 0.2	0.7 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	2.5 ± 0.1	0.4 ± 0.1	5.4 ± 0.1	2.2 ± 0.1
K177	0.9 ± 0.1	4.8 ± 0.4	0.9 ± 0.1	2.8 ± 0.1	0.4 ± 0.1	2.7 ± 0.2	0.4 ± 0.1	8.3 ± 0.3	2.9 ± 0.5
K178	0.7 ± 0.1	3.8 ± 0.4	0.8 ± 0.1	2.5 ± 0.2	0.3 ± 0.1	2.3 ± 0.1	0.4 ± 0.1	6.0 ± 0.2	1.4 ± 0.3
K179	0.9 ± 0.1	3.6 ± 0.2	0.8 ± 0.1	2.2 ± 0.1	0.3 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	5.6 ± 0.1	3.5 ± 0.4
K180	0.8 ± 0.1	4.6 ± 0.4	0.9 ± 0.1	2.8 ± 0.1	0.4 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	7.0 ± 0.2	1.3 ± 0.1
K181	0.7 ± 0.1	4.1 ± 0.2	0.7 ± 0.1	2.6 ± 0.1	0.3 ± 0.1	2.2 ± 0.2	0.4 ± 0.1	5.3 ± 0.1	1.5 ± 0.1
K182	1.0 ± 0.1	4.5 ± 0.1	1.1 ± 0.1	2.8 ± 0.3	0.6 ± 0.1	2.6 ± 0.4	0.3 ± 0.1	6.2 ± 0.1	2.0 ± 0.2
K183	1.0 ± 0.1	4.5 ± 0.1	1.0 ± 0.1	2.8 ± 0.1	0.5 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	7.3 ± 0.2	3.0 ± 0.1
K184	0.01	3.3 ± 0.1	1.1 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	2.1 ± 0.1	0.3 ± 0.1	3.9 ± 0.1	2.9 ± 0.3
K185	1.2 ± 0.1	4.0 ± 0.1	0.8 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	3.3 ± 0.1	2.3 ± 0.2
K186	1.0 ± 0.1	4.4 ± 0.1	1.1 ± 0.1	2.7 ± 0.2	0.6 ± 0.1	2.5 ± 0.1	0.4 ± 0.1	5.9 ± 0.3	1.8 ± 0.1
K187	1.2 ± 0.1	5.3 ± 0.3	1.2 ± 0.1	3.2 ± 0.3	0.4 ± 0.1	2.9 ± 0.1	0.4 ± 0.1	7.7 ± 0.3	2.9 ± 0.1
K188	1.0 ± 0.2	4.5 ± 0.3	1.1 ± 0.1	2.8 ± 0.1	0.6 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	6.3 ± 0.3	2.2 ± 0.1
K189	1.1 ± 0.1	5.3 ± 0.4	1.2 ± 0.1	3.4 ± 0.1	0.6 ± 0.1	2.9 ± 0.1	0.4 ± 0.1	9.2 ± 0.2	2.6 ± 0.1
K190	1.1 ± 0.1	4.6 ± 0.4	1.1 ± 0.1	2.9 ± 0.4	0.4 ± 0.1	3.0± 0.1	0.5 ± 0.1	7.2 ± 0.7	2.4 ± 0.2
K191	1.1 ± 0.1	4.5 ± 0.4	10.0 ± 0.1	2.7 ± 0.3	0.4 ± 0.1	2.5 ± 0.3	0.4 ± 0.1	6.5 ± 0.6	2.0 ± 0.2
K192	1.2 ± 0.1	5.3 ± 0.3	1.3 ± 0.1	3.3 ± 0.2	0.7 ± 0.1	2.9 ± 0.1	0.5 ± 0.1	7.4 ± 0.6	2.7 ± 0.4
K193	1.0 ± 0.1	5.7 ± 0.2	1.1 ± 0.1	3.5 ± 0.1	0.4 ± 0.1	3.0 ± 0.2	0.5 ± 0.1	8.4 ± 0.2	1.9 ± 0.2
K194	1.0 ± 0.1	4.4 ± 0.2	1.1 ± 0.1	2.9 ± 0.2	0.6 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	6.8 ± 0.1	1.9 ± 0.1
K195	0.7 ± 0.1	3.9 ± 0.2	0.9 ± 0.1	2.8 ± 0.1	0.3 ± 0.1	2.4 ± 0.2	0.4 ± 0.1	5.9 ± 0.2	2.2 ± 0.1
K196	0.7 ± 0.1	4.0 ± 0.1	0.8 ± 0.1	2.6 ± 0.4	0.4 ± 0.1	2.4 ± 0.1	0.4 ± 0.1	5.7 ± 0.2	2.4 ± 0.1
K197	1.2 ± 0.1	5.3 ± 0.2	1.1 ± 0.1	2.8 ± 0.5	0.4 ± 0.1	2.8 ± 0.2	0.4 ± 0.1	7.1 ± 0.7	2.5 ± 0.2
K198	0.7 ± 0.1	4.3 ± 0.1	0.9 ± 0.1	2.6 ± 0.2	0.4 ± 0.1	2.5 ± 0.1	0.4 ± 0.1	6.6 ± 0.5	1.2 ± 0.1
K199	1.0 ± 0.2	4.3 ± 0.4	0.7 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	5.2 ± 0.1	3.1 ± 0.1
K200	1.1 ± 0.1	4.3 ± 0.5	0.9 ± 0.1	2.7 ± 0.3	0.4 ± 0.1	2.6 ± 0.1	0.3 ± 0.1	5.8 ± 0.2	2.4 ± 0.2
K201	0.8 ± 0.1	3.4 ± 0.1	0.8 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	4.7 ± 0.3	2.5 ± 0.2
K202	1.2 ± 0.1	4.6 ± 0.4	1.0 ± 0.1	2.6 ± 0.1	0.3 ± 0.1	2.3 ± 0.1	0.3 ± 0.1	16.6 ± 0.2	5.0 ± 0.3
K203	0.7 ± 0.1	3.2 ± 0.2	0.8 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	4.4 ± 0.1	3.3 ± 0.6
K204	1.1 ± 0.1	4.2 ± 0.1	0.9 ± 0.1	2.3 ± 0.1	0.3 ± 0.1	2.3 ± 0.3	0.3 ± 0.1	5.4 ± 0.4	2.4 ± 0.1
K205	0.8 ± 0.1	4.4 ± 0.1	0.9 ± 0.1	2.8 ± 0.2	0.4 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	6.9 ± 0.2	1.6 ± 0.2
K206	0.7 ± 0.1	2.9 ± 0.1	0.7 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	7.1 ± 0.2	3.1 ± 0.2
K207	6.1 ± 0.2	3.8 ± 0.1	0.7 ± 0.1	2.5 ± 0.1	0.3 ± 0.1	2.2 ± 0.2	0.5 ± 0.1	4.8 ± 0.3	2.8 ± 0.1
K208	0.9 ± 0.1	3.8 ± 0.4	0.7 ± 0.1	2.5 ± 0.1	0.3 ± 0.1	2.1 ± 0.1	0.3 ± 0.1	4.5 ± 0.2	2.3 ± 0.2
K209	0.8 ± 0.1	4.3 ± 0.1	0.8 ± 0.1	2.1 ± 0.1	0.4 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	4.7 ± 0.1	2.5 ± 0.1
K210	1.0 ± 0.1	3.9 ± 0.3	0.9 ± 0.1	2.6 ± 0.3	0.3 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	7.0 ± 0.1	4.3 ± 0.2
K211	0.9 ± 0.1	4.1 ± 0.1	0.8 ± 0.1	2.6 ± 0.1	0.3 ± 0.1	2.1 ± 0.2	0.4 ± 0.1	5.5 ± 0.4	3.7 ± 0.7
K212	0.9 ± 0.1	7.2 ± 0.5	0.8 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	5.2 ± 0.1	3.8 ± 0.8
K213	0.6 ± 0.1	2.7 ± 0.1	0.5 ± 0.1	1.6 ± 0.1	0.3 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	3.3 ± 0.3	2.4 ± 0.4
K214	1.2 ± 0.1	5.2 ± 0.1	1.2 ± 0.1	3.2 ± 0.1	0.5 ± 0.1	3.1 ± 0.2	0.5 ± 0.1	17.0 ± 0.3	5.9 ± 0.1
K215	0.8 ± 0.1	3.8 ± 0.1	0.8 ± 0.1	2.7 ± 0.2	0.4 ± 0.1	2.5 ± 0.3	0.4 ± 0.1	7.6 ± 0.3	2.8 ± 0.1
K216	0.3 ± 0.1	2.2 ± 0.2	0.6 ± 0.1	1.6 ± 0.1	0.4 ± 0.1	1.6 ± 0.1	0.4 ± 0.1	7.9 ± 0.2	6.9 ± 0.6
K217	0.7 ± 0.1	3.6 ± 0.2	0.8 ± 0.1	2.2 ± 0.3	0.4 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	6.4 ± 0.2	1.3 ± 0.1
K218	1.0 ± 0.1	4.2 ± 0.1	1.0 ± 0.1	2.9 ± 0.1	0.5 ± 0.1	2.5 ± 0.1	0.5 ± 0.1	12.8 ± 0.6	5.5 ± 0.2
K219	1.1 ± 0.1	4.3 ± 0.5	1.0 ± 0.1	2.9 ± 0.3	0.5 ± 0.1	2.5 ± 0.1	0.5 ± 0.1	17.8 ± 0.6	6.7 ± 0.1
K220	0.9 ± 0.1	4.6 ± 0.2	1.0 ± 0.1	2.9 ± 0.2	0.4 ± 0.1	2.5 ± 0.2	0.4 ± 0.1	7.3 ± 0.2	2.5 ± 0.1
K221	17.4 ± 0.6	5.6 ± 0.1	0.9 ± 0.1	2.9 ± 0.1	0.3 ± 0.1	2.2 ± 0.2	0.8 ± 0.2	5.1 ± 0.3	4.7 ± 0.7
K222	0.6 ± 0.1	2.8 ± 0.2	0.5 ± 0.1	1.6 ± 0.1	0.3 ± 0.1	1.2 ± 0.1	0.2 ± 0.1	3.8 ± 0.1	3.0 ± 0.2
K223	0.2 ± 0.1	3.6 ± 0.1	0.2 ± 0.1	0.8 ± 0.2	0.2 ± 0.1	0.7 ± 0.1	0.1 ± 0.1	0.6 ± 0.1	0.2 ± 0.1
K224	0.5 ± 0.1	2.0 ± 0.2	0.3 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	1.1 ± 0.2	0.2 ± 0.1	4.5 ± 0.1	2.9 ± 0.4
K225	0.4 ± 0.1	1.3 ± 0.1	0.4 ± 0.1	0.7 ± 0.1	0.3 ± 0.1	0.8 ± 0.1	0.1 ± 0.1	2.8 ± 0.1	2.4 ± 0.2
K226	0.8 ± 0.1	4.1 ± 0.5	0.8 ± 0.1	2.6 ± 0.1	0.4 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	7.8 ± 0.1	2.7 ± 0.3
K227	0.7 ± 0.1	25.1 ± 0.5	0.8 ± 0.1	2.1 ± 0.2	0.4 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	4.4 ± 0.3	2.6 ± 0.4
K228	0.5 ± 0.1	2.4 ± 0.1	0.4 ± 0.1	1.3 ± 0.2	0.2 ± 0.1	1.1 ± 0.1	0.1 ± 0.1	2.8 ± 0.5	1.8 ± 0.3
S01	0.6 ± 0.1	3.5 ± 0.1	0.7 ± 0.1	2.2 ± 0.2	0.3 ± 0.1	2.2 ± 0.3	0.3 ± 0.1	9.5 ± 0.1	5.0 ± 0.4
S02	0.6 ± 0.1	3.2 ± 0.5	0.7 ± 0.1	1.7 ± 0.2	0.2 ± 0.1	1.4 ± 0.1	0.02	3.4 ± 0.4	1.2 ± 0.4
S03	0.4 ± 0.1	1.7 ± 0.2	0.5 ± 0.1	1.2 ± 0.1	0.3 ± 0.1	1.1 ± 0.1	0.3 ± 0.1	0.6 ± 0.1	0.02
S04	0.6 ± 0.1	3.5 ± 0.3	0.8 ± 0.1	2.4 ± 0.1	0.3 ± 0.1	2.3 ± 0.2	0.3 ± 0.1	12.5 ± 0.1	5.5 ± 0.2
S05	0.6 ± 0.1	2.9 ± 0.1	0.8 ± 0.1	2.0 ± 0.1	0.4 ± 0.1	2.0 ± 0.2	0.4 ± 0.1	0.6 ± 0.1	0.02
S06	0.5 ± 0.1	2.8 ± 0.2	0.7 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	1.6 ± 0.1	0.2 ± 0.1	1.4 ± 0.1	0.02
S07	0.5 ± 0.1	2.7 ± 0.1	0.6 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	2.1 ± 0.1	0.3 ± 0.1	10.5 ± 0.9	6.5 ± 0.4
S08	0.4 ± 0.1	2.9 ± 0.3	0.6 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	10.0 ± 0.7	6.5 ± 0.4
S09	0.9 ± 0.1	3.4 ± 0.1	0.9 ± 0.1	2.2 ± 0.1	0.4 ± 0.1	2.1 ± 0.1	0.5 ± 0.1	6.1 ± 0.1	4.5 ± 0.4
S10	0.8 ± 0.1	3.6 ± 0.1	0.8 ± 0.1	2.1 ± 0.2	0.4 ± 0.1	1.9 ± 0.1	0.4 ± 0.1	4.4 ± 0.2	1.5 ± 0.2
S11	0.01	1.9 ± 0.1	0.5 ± 0.1	1.4 ± 0.2	0.2 ± 0.1	1.5 ± 0.1	0.2 ± 0.1	2.5 ± 0.2	0.7 ± 0.2
S12	0.01	2.3 ± 0.1	0.6 ± 0.1	1.6 ± 0.3	0.2 ± 0.1	1.9 ± 0.1	0.2 ± 0.1	1.0 ± 0.2	0.02
S13	0.01	0.6 ± 0.1	0.2 ± 0.1	0.7 ± 0.2	0.1 ± 0.1	0.8 ± 0.2	0.02	2.0 ± 0.1	0.9 ± 0.1
S14	0.01	1.3 ± 0.2	0.3 ± 0.1	0.9 ± 0.1	0.2 ± 0.1	1.2 ± 0.1	0.02	3.5 ± 0.4	4.1 ± 0.4
S15	0.8 ± 0.1	3.5 ± 0.1	0.8 ± 0.1	2.2 ± 0.1	0.2 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	2.1 ± 0.1	1.5 ± 0.1
S16	0.8 ± 0.1	3.5 ± 0.3	0.8 ± 0.1	2.3 ± 0.1	0.4 ± 0.1	2.4 ± 0.2	0.5 ± 0.1	11.2 ± 1.6	4.3 ± 0.6
S17	0.9 ± 0.1	4.1 ± 0.1	0.9 ± 0.1	2.9 ± 0.1	0.3 ± 0.1	2.8 ± 0.2	0.4 ± 0.1	11.1 ± 0.3	5.5 ± 0.3
S18	0.8 ± 0.1	3.1 ± 0.4	0.7 ± 0.1	2.0 ± 0.1	0.3 ± 0.1	2.0 ± 0.1	0.5 ± 0.1	7.7 ± 0.9	3.6 ± 0.5
S19	0.7 ± 0.1	3.0 ± 0.2	0.6 ± 0.1	1.9 ± 0.1	0.2 ± 0.1	1.7 ± 0.1	0.3 ± 0.1	4.0 ± 0.1	2.2 ± 0.1

Table F4 Continued

Samples	mg/kg								
	Tb	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Th**	**U**
S20	0.01	1.8 ± 0.4	0.5 ± 0.1	1.2 ± 0.2	0.2 ± 0.1	1.4 ± 0.2	0.3 ± 0.1	2.4 ± 0.3	1.4 ± 0.2
S21	0.6 ± 0.1	2.6 ± 0.3	0.6 ± 0.1	1.7 ± 0.1	0.3 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	6.6 ± 0.2	3.5 ± 0.9
S22	0.7 ± 0.1	2.9 ± 0.2	0.6 ± 0.1	2.1 ± 0.1	0.3 ± 0.1	1.9 ± 0.1	0.3 ± 0.1	6.4 ± 0.2	4.4 ± 0.1
S23	0.6 ± 0.1	2.1 ± 0.1	0.5 ± 0.1	1.5 ± 0.1	0.2 ± 0.1	1.4 ± 0.1	0.2 ± 0.1	5.6 ± 0.5	2.8 ± 0.2
S24	0.8 ± 0.1	3.8 ± 0.4	0.8 ± 0.1	2.4 ± 0.1	0.4 ± 0.1	2.2 ± 0.2	0.5 ± 0.1	11.6 ± 0.1	5.2 ± 1.2
S25	0.6 ± 0.1	2.3 ± 0.2	0.4 ± 0.1	1.5 ± 0.1	0.2 ± 0.1	1.3 ± 0.1	0.2 ± 0.1	7.7 ± 0.3	4.7 ± 0.3
S26	0.6 ± 0.1	3.8 ± 0.4	0.9 ± 0.1	2.5 ± 0.3	0.5 ± 0.1	2.6 ± 0.2	0.5 ± 0.1	11.6 ± 0.5	5.5 ± 0.8
S27	0.4 ± 0.1	1.6 ± 0.3	0.4 ± 0.1	1.1 ± 0.1	0.1 ± 0.1	1.0 ± 0.1	0.1 ± 0.1	2.2 ± 0.2	1.3 ± 0.2
S28	0.01	1.8 ± 0.1	0.5 ± 0.1	1.2 ± 0.1	0.3 ± 0.1	1.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.6 ± 0.1
S29	0.4 ± 0.1	1.8 ± 0.1	0.4 ± 0.1	1.4 ± 0.1	0.2 ± 0.1	1.4 ± 0.1	0.2 ± 0.1	2.4 ± 0.2	1.4 ± 0.1
S30	0.01	2.0 ± 0.1	0.6 ± 0.1	1.5 ± 0.1	0.4 ± 0.1	1.6 ± 0.1	0.4 ± 0.1	0.01	0.5 ± 0.1

G. THE RESULTS OF STATISTICAL TESTS

The results of Shaphiro – Wilk test for normality, two sample t-test and Mann-Whitney u-test are given in Tables G1-3.

Table G1. Summary table for Shaphiro – Wilk Test for Normality ((Test group “1” represents biscuit-fired samples and “2” represents tripod-stilts samples. Significance levels below 0.05 were marked with bold text) is given in Table G1.)

		Shapiro-Wilk					**Shapiro-Wilk**		
Element	**Test group**	**Statistic**	**df**	**Sig.**	**Element**	**Test group**	**Statistic**	**df**	**Sig.**
Na	1	0.96	18.00	0.69	**Zr**	1	0.86	18.00	**0.01**
	2	0.93	11.00	0.37		2	0.74	10.00	**0.00**
Mg	1	0.97	18.00	0.73	**La**	1	0.97	17.00	0.90
	2	0.82	11.00	**0.02**		2	0.90	11.00	0.17
Al	1	0.88	18.00	**0.03**	**Ce**	1	0.99	18.00	0.99
	2	0.84	11.00	**0.03**		2	0.88	11.00	0.12
K	1	0.96	18.00	0.67	**Pr**	1	0.97	18.00	0.79
	2	0.93	11.00	0.41		2	0.86	11.00	0.05
Ti	1	0.97	18.00	0.75	**Nd**	1	0.96	18.00	0.60
	2	0.96	11.00	0.72		2	0.85	11.00	**0.04**
Mn	1	0.81	18.00	**0.00**	**Sm**	1	0.98	18.00	0.89
	2	0.78	11.00	**0.01**		2	0.91	11.00	0.24
Fe	1	0.80	18.00	**0.00**	**Eu**	1	0.93	18.00	0.22
	2	0.85	11.00	**0.04**		2	0.92	11.00	0.34
V	1	0.84	18.00	**0.01**	**Tb**	1	0.89	17.00	0.05
	2	0.85	11.00	**0.04**		2	0.87	11.00	0.08
Cr	1	0.90	18.00	0.07	**Dy**	1	0.94	18.00	0.31
	2	0.89	11.00	0.13		2	0.89	11.00	0.13
Co	1	0.91	18.00	0.08	**Ho**	1	0.90	18.00	0.06
	2	0.96	11.00	0.81		2	0.92	11.00	0.29
Ni	1	0.90	17.00	0.08	**Er**	1	0.95	18.00	0.36
	2	0.74	11.00	**0.00**		2	0.88	11.00	0.11
Cu	1	0.85	7.00	0.12	**Tm**	1	0.88	18.00	**0.03**
	2	0.88	8.00	0.18		2	0.89	11.00	0.16
Zn	1	0.97	15.00	0.92	**Yb**	1	0.93	18.00	0.23
	2	0.97	10.00	0.86		2	0.87	11.00	0.09
Sr	1	0.90	18.00	0.07	**Lu**	1	0.97	18.00	0.81
	2	0.96	11.00	0.83		2	0.97	11.00	0.87
Ba	1	0.94	18.00	0.34	**Th**	1	0.97	18.00	0.84
	2	0.94	11.00	0.54		2	0.95	11.00	0.68
Pb	1	0.79	18.00	**0.00**	**U**	1	0.99	18.00	0.99
	2	0.87	11.00	**0.08**		2	0.88	11.00	0.09
Y	1	0.94	18.00	0.34					
	2	0.94	11.00	0.47					

Table G2. The result of Independent Two Sample t-test (Significance levels below 0.05 were marked with bold text)

		Levene's Test for Equality of Variances		**t-test for Equality of Means**			
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**
Na	Equal variances assumed	0.03	0.86	-0.04	27.00	0.97	-38.47
	Equal variances not assumed			-0.04	21.62	0.97	-38.47
K	Equal variances assumed	1.03	0.32	0.33	27.00	0.75	429.25
	Equal variances not assumed			0.35	26.01	0.73	429.25
Ti	Equal variances assumed	3.38	0.08	0.76	27.00	0.45	524.18
	Equal variances not assumed			0.68	14.71	0.51	524.18
Cr	Equal variances assumed	5.25	**0.03**	-2.18	27.00	0.04	-80.33
	Equal variances not assumed			-1.90	13.63	0.08	-80.33
Co	Equal variances assumed	0.18	0.68	-2.49	27.00	0.02	-12.65
	Equal variances not assumed			-2.43	19.54	0.02	-12.65
Cu	Equal variances assumed	2.89	0.11	-1.43	13.00	0.18	-38.24
	Equal variances not assumed			-1.47	11.61	0.17	-38.24
Zn	Equal variances assumed	0.04	0.85	0.07	23.00	0.95	0.83
	Equal variances not assumed			0.07	19.28	0.95	0.83
Ba	Equal variances assumed	0.03	0.88	1.99	27.00	0.06	32.64
	Equal variances not assumed			2.09	24.61	0.05	32.64
Y	Equal variances assumed	0.22	0.64	0.79	27.00	0.44	1.61
	Equal variances not assumed			0.84	25.59	0.41	1.61
La	Equal variances assumed	0.07	0.80	1.09	26.00	0.29	1.71
	Equal variances not assumed			1.10	22.22	0.28	1.71
Ce	Equal variances assumed	0.87	0.36	-0.24	27.00	0.81	-0.97
	Equal variances not assumed			-0.22	15.53	0.83	-0.97
Pr	Equal variances assumed	1.79	0.19	1.14	27.00	0.26	0.37
	Equal variances not assumed			1.23	26.12	0.23	0.37
Sm	Equal variances assumed	0.18	0.68	0.87	27.00	0.39	0.23
	Equal variances not assumed			0.89	22.71	0.38	0.23
Eu	Equal variances assumed	0.03	0.86	3.13	27.00	**0.00**	0.24
	Equal variances not assumed			3.23	23.53	0.00	0.24
Tb	Equal variances assumed	9.64	**0.00**	2.71	26.00	0.01	0.17
	Equal variances not assumed			3.11	24.57	**0.00**	0.17
Dy	Equal variances assumed	0.79	0.38	1.46	27.00	0.15	0.31
	Equal variances not assumed			1.59	26.37	0.12	0.31
Ho	Equal variances assumed	5.28	**0.03**	2.31	27.00	0.03	0.14
	Equal variances not assumed			2.54	26.67	**0.02**	0.14
Er	Equal variances assumed	0.65	0.43	2.02	27.00	0.05	0.23
	Equal variances not assumed			2.21	26.62	0.04	0.23
Yb	Equal variances assumed	1.37	0.25	1.14	27.00	0.26	0.12
	Equal variances not assumed			1.26	26.74	0.22	0.12
Lu	Equal variances assumed	0.00	0.95	0.38	27.00	0.70	0.01
	Equal variances not assumed			0.38	20.85	0.71	0.01
Th	Equal variances assumed	0.53	0.47	0.72	27.00	0.48	0.32
	Equal variances not assumed			0.77	25.87	0.45	0.32
U	Equal variances assumed	1.30	0.26	0.68	27.00	0.50	0.16
	Equal variances not assumed			0.63	17.08	0.54	0.16

Table G 3. Tables for Mann-Whitney u-test

Descriptive Statistics

	Test_groups	N	Mean Rank	Sum of Ranks
Mg	1	18	16.22	292.00
	2	11	13.00	143.00
Al	1	18	17.00	306.00
	2	11	11.73	129.00
Mn	1	18	14.83	267.00
	2	11	15.27	168.00
Fe	1	18	15.89	286.00
	2	11	13.55	149.00
V	1	18	15.28	275.00
	2	11	14.55	160.00
Ni	1	18	14.89	268.00
	2	11	15.18	167.00
Sr	1	18	14.94	269.00
	2	11	15.09	166.00
Zr	1	18	14.72	265.00
	2	10	14.10	141.00
Nd	1	18	15.83	285.00
	2	11	13.64	150.00
Tm	1	18	15.83	285.00
	2	11	13.64	150.00

Test Statistics

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
Mg	77.000	143.000	-.989	.323	.340[b]
Al	63.000	129.000	-1.618	.106	.112[b]
Mn	96.000	267.000	-.135	.893	.912[b]
Fe	83.000	149.000	-.719	.472	.492[b]
V	94.000	160.000	-.225	.822	.842[b]
Ni	97.000	268.000	-.090	.928	.947[b]
Sr	98.000	269.000	-.045	.964	.982[b]
Zr	86.000	141.000	-.192	.848	.869[b]
Nd	84.000	150.000	-.674	.500	.521[b]
Tm	84.000	150.000	-.676	.499	.521[b]

H. STATISTICS FOR ELEMENTS

Statistical measures used to expore element concentrations are given in Table H1.

Table H1. Statistics for sample groups

Element	Samples	n	Mean	Median	SD	Min	Max	Percentile		$\%C_{Var}$
								5th	95th	
Na	Biscuit-fired	18	1.23	1.24	0.25	0.80	1.74	0.81	1.60	21
	Tripod Stilt	11	1.23	1.24	0.25	0.96	1.74	0.96	1.62	20
	Glazed and Unglazed Pottery	82	0.90	0.77	0.42	0.36	1.92	0.53	1.42	47
	Coarseware	17	0.72	0.69	0.27	0.34	1.41	0.38	1.21	37
	Soil	31	0.80	0.63	0.63	0.10	3.08	0.18	1.83	79
	All Samples	**159**	**0.98**	**0.91**	**0.36**	**0.51**	**1.98**	**0.57**	**1.53**	**41**
Mg	Biscuit-fired	18	4.97	4.90	0.64	3.61	6.31	4.24	6.00	13
	Tripod Stilt	11	4.92	4.61	1.00	3.91	7.17	4.00	6.78	20
	Glazed and Unglazed Pottery	82	3.61	3.87	1.32	0.53	5.61	2.64	7.29	37
	Coarseware	17	2.87	2.98	2.14	1.34	7.26	0.24	6.58	74
	Soil	31	4.17	3.90	2.19	1.39	9.95	1.69	8.74	53
	All Samples	**159**	**4.11**	**4.05**	**1.46**	**2.15**	**7.26**	**2.56**	**7.08**	**39**
Al	Biscuit-fired	18	15.68	16.17	2.35	10.41	18.55	11.28	18.54	15
	Tripod Stilt	11	13.34	11.32	3.75	9.47	18.89	9.54	18.31	28
	Glazed and Unglazed Pottery	82	13.65	13.66	3.32	5.61	19.27	10.96	19.92	24
	Coarseware	17	13.33	13.65	2.49	9.26	17.38	8.92	16.30	19
	Soil	31	13.69	14.05	4.68	2.57	24.18	5.55	21.25	34
	All Samples	**159**	**13.94**	**13.77**	**3.32**	**7.46**	**19.65**	**9.25**	**18.86**	**24**
K	Biscuit-fired	18	1.98	1.92	0.38	1.39	2.80	1.42	2.64	19
	Tripod Stilt	11	1.94	1.93	0.27	1.56	2.37	1.57	2.33	14
	Glazed and Unglazed Pottery	82	1.18	1.06	0.55	0.40	2.14	0.66	2.14	47
	Coarseware	17	1.43	1.11	0.73	0.47	2.84	0.63	2.65	51
	Soil	27	1.14	1.02	0.87	0.17	3.28	0.21	2.72	76
	All Samples	**155**	**1.53**	**1.41**	**0.56**	**0.80**	**2.69**	**0.90**	**2.49**	**41**
Ti	Biscuit-fired	18	1.08	1.05	0.14	0.85	1.33	0.86	1.32	13
	Tripod Stilt	11	1.03	1.02	0.23	0.72	1.41	0.73	1.36	22
	Glazed and Unglazed Pottery	82	1.55	1.69	0.70	0.08	2.92	0.75	2.62	45
	Coarseware	17	0.96	0.93	0.28	0.48	1.29	0.53	1.27	29
	Soil	28	0.94	0.97	0.38	0.22	1.92	0.37	1.65	40
	All Samples	**156**	**1.11**	**1.13**	**0.35**	**0.47**	**1.78**	**0.65**	**1.64**	**30**
V	Biscuit-fired	18	312.63	306.66	54.28	258.52	475.23	258.60	406.30	17
	Tripod Stilt	11	312.76	283.06	62.22	252.42	428.66	255.58	422.42	20
	Glazed and Unglazed Pottery	82	216.38	234.39	108.88	7.83	395.62	120.50	370.06	50
	Coarseware	17	186.55	236.78	111.31	115.63	327.23	22.36	312.76	60
	Soil	31	302.01	302.54	112.92	47.53	559.84	134.15	489.08	37
	All Samples	**159**	**266.06**	**272.69**	**89.92**	**136.39**	**437.32**	**158.24**	**400.12**	**37**
Cr	Biscuit-fired	18	441.72	430.45	69.92	341.50	632.02	343.21	565.53	16
	Tripod Stilt	11	522.05	497.04	129.40	391.21	786.81	393.19	743.08	25
	Glazed and Unglazed Pottery	61	462.99	437.84	248.71	119.79	1001.3	200.24	869.54	54
	Coarseware	11	575.31	544.28	258.21	260.37	1054.7	278.06	1017.52	45
	Soil	26	441.06	401.31	276.31	163.98	1510.6	176.93	710.85	63
	All Samples	**127**	**488.63**	**462.18**	**196.51**	**255.37**	**997.12**	**278.33**	**781.30**	**40**

Table H1 Continued

Mn	Biscuit-fired	18	0.22	0.20	0.06	0.16	0.38	0.16	0.31	27
	Tripod Stilt	11	0.22	0.19	0.06	0.17	0.38	0.17	0.33	29
	Glazed and Unglazed Pottery	82	0.15	0.16	0.06	0.03	0.26	0.09	0.26	43
	Coarseware	17	0.11	0.14	0.07	0.05	0.25	0.01	0.21	65
	Soil	31	0.17	0.16	0.06	0.04	0.30	0.09	0.27	35
	All Samples	**159**	**0.17**	**0.17**	**0.06**	**0.09**	**0.31**	**0.10**	**0.28**	**40**
Fe	Biscuit-fired	18	10.73	9.47	3.25	6.93	17.66	7.84	17.09	30
	Tripod Stilt	11	10.43	9.12	3.59	6.50	17.54	6.70	16.29	34
	Glazed and Unglazed Pottery	71	9.23	9.72	5.05	0.49	21.10	5.07	19.44	55
	Coarseware	17	5.71	6.87	3.48	3.73	10.16	0.54	9.48	61
	Soil	30	9.57	9.19	3.17	4.71	17.60	4.99	16.37	33
	All Samples	**147**	**9.13**	**8.88**	**3.71**	**4.47**	**16.81**	**5.03**	**15.73**	**43**
Co	Biscuit-fired	18	62.71	58.48	12.72	46.35	92.28	48.40	85.90	20
	Tripod Stilt	11	75.37	78.26	14.13	54.18	98.76	57.01	95.94	19
	Glazed and Unglazed Pottery	70	51.65	44.79	15.43	32.84	79.86	36.06	105.09	30
	Coarseware	12	40.14	40.00	13.77	21.73	58.73	22.21	58.43	34
	Soil	30	43.07	42.44	17.95	14.96	91.22	16.48	80.22	42
	All Samples	**141**	**54.59**	**52.79**	**14.80**	**34.01**	**84.17**	**36.03**	**85.12**	**29**
Ni	Biscuit-fired	17	245.01	240.58	32.31	198.22	333.66	203.88	301.57	13
	Tripod Stilt	11	274.42	257.70	93.05	202.39	525.47	203.65	425.02	34
	Glazed and Unglazed Pottery	68	261.69	235.86	142.43	95.77	629.38	143.01	475.50	54
	Coarseware	10	205.80	192.30	107.65	80.60	438.82	92.41	374.75	52
	Soil	25	240.49	186.68	175.90	87.54	756.51	90.74	679.36	73
	All Samples	**131**	**245.48**	**222.62**	**110.27**	**132.90**	**536.77**	**146.74**	**451.24**	**45**
Cu	Biscuit-fired	7	187.21	197.70	36.87	144.68	231.86	146.69	227.31	20
	Tripod Stilt	8	225.45	209.94	61.86	162.76	325.09	166.44	315.83	27
	Glazed and Unglazed Pottery	46	336.12	272.11	168.90	246.66	747.84	247.15	741.86	50
	Coarseware	4	623.72	343.93	614.62	300.86	1542.43	270.03	1369.11	99
	Soil	5	353.50	344.41	85.79	255.74	483.46	265.71	462.42	24
	All Samples	**70**	**345.20**	**273.62**	**193.61**	**222.14**	**666.14**	**219.20**	**623.31**	**44**
Zn	Biscuit-fired	15	179.27	172.59	30.52	124.99	243.27	141.12	225.30	17
	Tripod Stilt	10	178.44	183.27	30.89	115.19	228.79	131.56	218.32	17
	Glazed and Unglazed Pottery	35	122.79	118.90	14.59	110.19	149.40	51.63	151.75	12
	Coarseware	3	29923.91	93.33	51672.01	93.33	89589.61	89.26	80639.98	173
	Soil	8	68.02	64.58	22.49	38.30	111.69	43.18	102.28	33
	All Samples	**71**	**6094.49**	**126.53**	**10354.10**	**96.40**	**18064.55**	**91.35**	**16267.53**	**50**
Sr	Biscuit-fired	18	187.20	168.29	40.28	132.81	252.96	138.09	250.25	22
	Tripod Stilt	11	183.47	178.96	30.00	135.94	242.63	146.04	232.16	16
	Glazed and Unglazed Pottery	77	231.42	226.89	94.92	93.63	401.74	133.50	410.82	41
	Coarseware	17	136.93	132.22	67.59	36.89	319.24	63.51	244.72	49
	Soil	31	139.53	94.59	132.58	21.13	580.51	29.76	427.28	95
	All Samples	**154**	**175.71**	**160.19**	**73.07**	**84.08**	**359.42**	**102.18**	**313.05**	**45**
Y	Biscuit-fired	18	25.05	24.67	5.83	15.27	38.83	15.59	35.17	23
	Tripod Stilt	11	23.43	25.08	4.41	15.42	29.74	16.65	28.72	19
	Glazed and Unglazed Pottery	36	19.57	18.69	7.69	6.60	33.32	14.57	46.33	39
	Coarseware	11	18.57	17.94	6.15	11.70	34.79	12.27	28.47	33
	Soil	10	26.20	17.51	17.10	10.56	58.92	12.11	56.45	65
	All Samples	**86**	**22.56**	**20.78**	**8.24**	**11.91**	**39.12**	**14.24**	**39.03**	**36**

Table H1 Continued

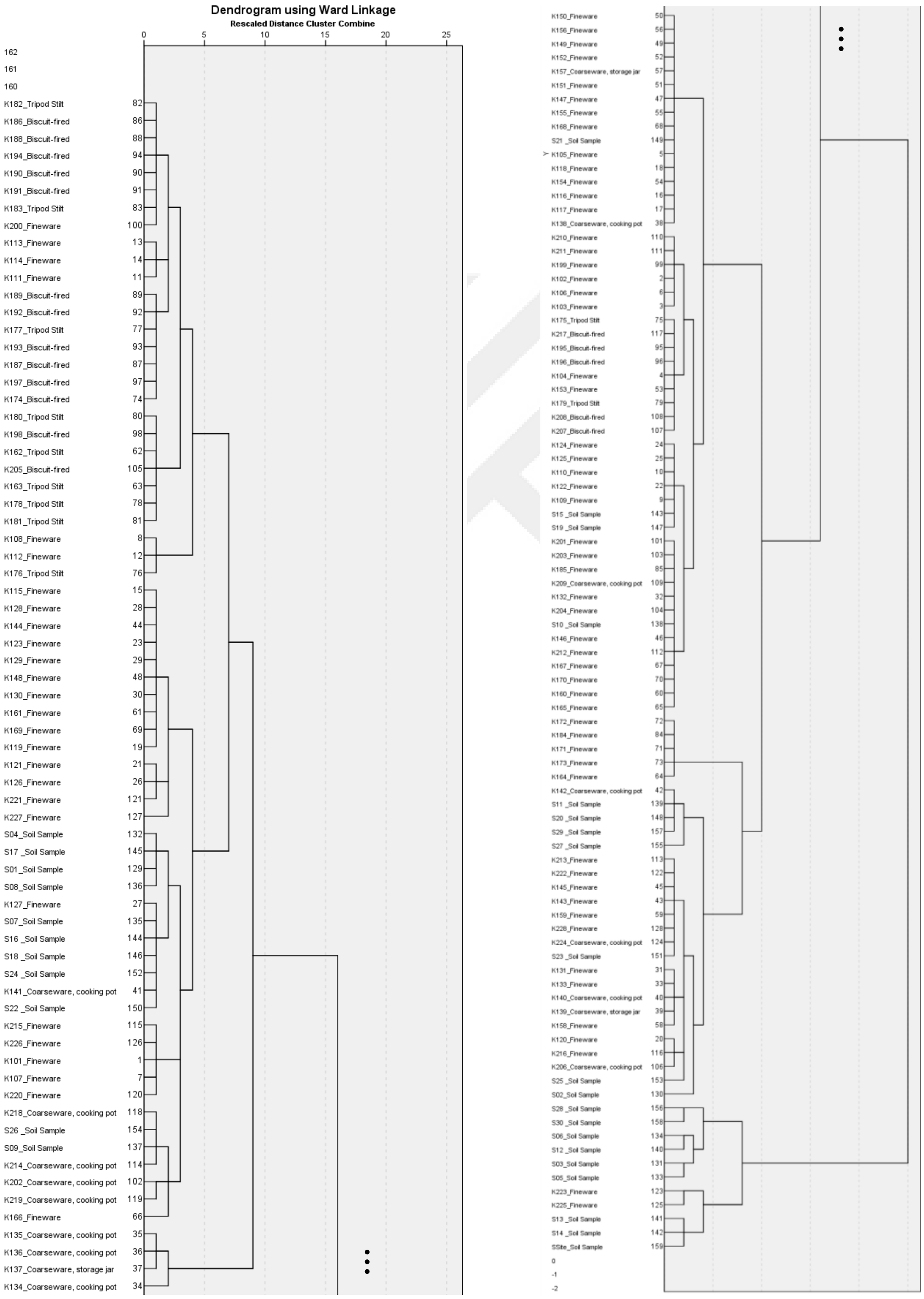
Zr	Biscuit-fired	18	59.16	58.40	26.64	26.94	140.08	31.07	89.25	45
	Tripod Stilt	8	46.15	44.66	18.40	22.88	76.21	23.11	72.15	40
	Glazed and Unglazed Pottery	80	157.31	136.07	89.03	4.68	292.54	39.54	274.79	57
	Coarseware	16	116.84	112.52	93.23	13.26	288.53	4.91	249.58	80
	Soil	31	130.37	127.58	65.51	22.48	259.20	34.57	242.75	50
	All Samples	**153**	**101.97**	**95.85**	**58.56**	**18.05**	**211.31**	**26.64**	**185.70**	**54**
Ba	Biscuit-fired	18	378.65	378.92	45.89	298.34	490.30	309.66	460.16	12
	Tripod Stilt	11	346.01	352.41	37.40	289.96	410.89	294.71	393.54	11
	Glazed and Unglazed Pottery	82	335.67	394.26	131.52	71.09	516.86	199.10	517.56	39
	Coarseware	17	302.20	265.54	126.68	96.77	599.87	148.67	519.25	42
	Soil	31	189.91	176.89	122.52	24.17	449.23	32.17	410.24	65
	All Samples	**159**	**310.49**	**313.61**	**92.80**	**156.07**	**493.43**	**196.86**	**460.15**	**34**
La	Biscuit-fired	17	20.08	19.73	4.15	12.15	29.97	14.96	26.04	21
	Tripod Stilt	11	18.36	17.68	3.97	13.12	27.88	14.10	24.49	22
	Glazed and Unglazed Pottery	79	19.01	19.49	4.98	9.00	25.39	12.80	39.79	26
	Coarseware	16	26.87	24.16	17.23	10.43	83.62	12.32	50.16	64
	Soil	31	14.82	17.75	9.75	0.86	35.18	1.99	29.66	66
	All Samples	**154**	**19.83**	**19.76**	**8.01**	**9.11**	**40.41**	**11.24**	**34.03**	**40**
Ce	Biscuit-fired	18	66.83	67.65	8.80	49.54	84.32	53.13	78.27	13
	Tripod Stilt	11	67.79	65.35	13.16	52.98	99.41	54.34	89.82	19
	Glazed and Unglazed Pottery	82	81.46	78.86	29.28	17.03	136.35	48.31	129.36	36
	Coarseware	17	85.83	81.58	31.84	25.76	140.72	40.43	139.99	37
	Soil	31	75.51	84.27	45.75	7.29	171.58	14.80	141.89	61
	All Samples	**159**	**75.49**	**75.54**	**25.76**	**30.52**	**126.48**	**42.20**	**115.87**	**33**
Pr	Biscuit-fired	18	5.01	4.88	0.95	3.54	7.19	3.59	6.41	19
	Tripod Stilt	11	4.64	4.51	0.68	3.87	6.35	3.89	5.68	15
	Glazed and Unglazed Pottery	82	4.33	4.67	1.49	0.89	6.70	3.17	6.63	34
	Coarseware	17	4.97	4.34	2.08	1.63	9.26	2.63	8.41	42
	Soil	31	3.74	4.34	2.27	0.22	8.01	0.42	7.18	61
	All Samples	**159**	**4.54**	**4.55**	**1.49**	**2.03**	**7.50**	**2.74**	**6.86**	**34**
Nd	Biscuit-fired	18	20.46	19.89	3.83	14.21	27.11	14.53	26.77	19
	Tripod Stilt	11	19.48	18.34	3.49	15.64	28.17	15.91	24.88	18
	Glazed and Unglazed Pottery	82	19.25	20.76	9.62	3.76	47.63	12.16	25.46	50
	Coarseware	17	19.56	17.37	7.21	6.11	35.14	11.23	31.51	37
	Soil	31	14.47	16.98	8.16	2.71	30.00	3.00	26.81	56
	All Samples	**159**	**18.64**	**18.67**	**6.46**	**8.49**	**33.61**	**11.37**	**27.09**	**36**
Sm	Biscuit-fired	18	4.40	4.40	0.70	3.12	5.69	3.44	5.55	16
	Tripod Stilt	11	4.17	4.07	0.64	3.44	5.67	3.46	5.17	15
	Glazed and Unglazed Pottery	81	3.58	3.46	1.26	0.95	5.44	2.51	5.40	35
	Coarseware	17	3.82	3.62	1.31	1.47	6.17	2.06	6.03	34
	Soil	31	2.90	3.09	1.44	0.59	5.06	0.74	4.88	49
	All Samples	**158**	**3.77**	**3.73**	**1.07**	**1.91**	**5.61**	**2.44**	**5.40**	**30**
Eu	Biscuit-fired	18	1.50	1.52	0.21	1.05	1.79	1.09	1.75	14
	Tripod Stilt	11	1.25	1.29	0.19	0.94	1.47	0.98	1.47	15
	Glazed and Unglazed Pottery	82	1.38	1.53	0.49	0.38	2.20	0.91	2.17	35
	Coarseware	17	1.39	1.32	0.68	0.60	3.74	0.69	2.14	49
	Soil	31	1.01	1.06	0.44	0.14	1.71	0.29	1.61	44
	All Samples	**159**	**1.31**	**1.34**	**0.40**	**0.62**	**2.18**	**0.80**	**1.83**	**31**
Tb	Biscuit-fired	17	0.93	0.98	0.19	0.66	1.19	0.67	1.16	20
	Tripod Stilt	11	0.77	0.72	0.09	0.66	0.92	0.67	0.92	12
	Glazed and Unglazed Pottery	65	0.66	0.71	0.24	0.19	1.03	0.30	1.84	37
	Coarseware	15	0.84	0.81	0.21	0.43	1.16	0.55	1.12	24
	Soil	23	0.57	0.54	0.16	0.33	0.83	0.34	0.81	28
	All Samples	**131**	**0.75**	**0.75**	**0.18**	**0.46**	**1.03**	**0.51**	**1.17**	**24**

Table H1 Continued

Dy	Biscuit-fired	18	4.48	4.40	0.62	3.53	5.63	3.68	5.34	14
	Tripod Stilt	11	4.17	4.35	0.43	3.59	4.77	3.63	4.68	10
	Glazed and Unglazed Pottery	81	3.64	3.68	1.41	1.20	7.16	2.15	4.91	39
	Coarseware	17	3.59	4.03	0.94	1.94	5.16	1.95	4.66	26
	Soil	31	2.55	2.75	0.93	0.53	4.01	0.89	3.75	37
	All Samples	**158**	**3.69**	**3.84**	**0.86**	**2.16**	**5.34**	**2.46**	**4.67**	**25**
Ho	Biscuit-fired	18	0.96	1.05	0.17	0.66	1.23	0.69	1.16	18
	Tripod Stilt	11	0.83	0.80	0.12	0.69	1.04	0.69	1.02	14
	Glazed and Unglazed Pottery	82	0.64	0.73	0.21	0.19	0.91	0.42	1.06	32
	Coarseware	17	0.71	0.70	0.26	0.29	1.12	0.29	1.01	36
	Soil	31	0.55	0.55	0.18	0.20	0.87	0.24	0.82	33
	All Samples	**159**	**0.74**	**0.77**	**0.19**	**0.40**	**1.03**	**0.47**	**1.01**	**27**
Er	Biscuit-fired	18	2.79	2.75	0.33	2.18	3.44	2.41	3.33	12
	Tripod Stilt	11	2.56	2.65	0.22	2.15	2.79	2.22	2.78	9
	Glazed and Unglazed Pottery	82	1.97	2.00	0.68	0.62	2.89	1.37	2.93	35
	Coarseware	17	2.20	2.01	0.60	1.29	3.16	1.29	3.07	27
	Soil	31	1.69	1.75	0.55	0.50	2.80	0.76	2.43	33
	All Samples	**159**	**2.24**	**2.23**	**0.48**	**1.35**	**3.02**	**1.61**	**2.91**	**23**
Tm	Biscuit-fired	18	0.39	0.34	0.13	0.21	0.63	0.22	0.60	32
	Tripod Stilt	11	0.35	0.34	0.09	0.25	0.54	0.26	0.50	24
	Glazed and Unglazed Pottery	82	0.28	0.28	0.07	0.13	0.36	0.19	0.48	26
	Coarseware	17	0.34	0.34	0.10	0.17	0.48	0.18	0.46	29
	Soil	31	0.23	0.23	0.10	0.06	0.47	0.09	0.37	42
	All Samples	**159**	**0.32**	**0.31**	**0.10**	**0.17**	**0.50**	**0.19**	**0.48**	**31**
Yb	Biscuit-fired	18	2.55	2.53	0.31	1.91	2.95	2.06	2.93	12
	Tripod Stilt	11	2.43	2.55	0.20	2.10	2.66	2.14	2.64	8
	Glazed and Unglazed Pottery	82	1.75	1.87	0.57	0.69	2.46	1.17	2.78	33
	Coarseware	17	1.95	1.86	0.61	0.85	3.03	1.03	2.76	31
	Soil	31	1.66	1.70	0.52	0.51	2.71	0.88	2.45	31
	All Samples	**159**	**2.07**	**2.10**	**0.44**	**1.21**	**2.76**	**1.46**	**2.71**	**23**
Lu	Biscuit-fired	18	0.36	0.36	0.05	0.28	0.46	0.29	0.45	14
	Tripod Stilt	11	0.36	0.36	0.05	0.28	0.45	0.28	0.43	14
	Glazed and Unglazed Pottery	82	0.29	0.32	0.17	0.04	0.75	0.11	0.49	61
	Coarseware	17	0.33	0.38	0.13	0.06	0.49	0.11	0.49	38
	Soil	27	0.28	0.26	0.11	0.07	0.48	0.15	0.46	40
	All Samples	**155**	**0.32**	**0.33**	**0.10**	**0.15**	**0.52**	**0.19**	**0.46**	**33**
Pb	Biscuit-fired	18	491.80	230.37	470.55	92.04	1736.15	121.47	1248.50	96
	Tripod Stilt	11	1167.01	789.95	1027.25	45.97	2964.31	162.81	2877.91	88
	Glazed and Unglazed Pottery	80	6933.05	3355.60	10964.22	61.14	46790.20	265.21	46738.07	158
	Coarseware	10	2635.25	71.14	5539.13	50.10	15596.87	48.63	13128.73	210
	Soil	9	44.49	35.92	21.28	22.27	86.74	25.18	80.41	48
	All Samples	**128**	**2254.32**	**896.59**	**3604.49**	**54.30**	**13434.86**	**124.66**	**12814.72**	**120**
Th	Biscuit-fired	18	6.74	6.66	1.26	4.43	9.15	4.69	8.94	19
	Tripod Stilt	11	6.42	6.17	0.93	5.23	8.24	5.30	7.76	15
	Glazed and Unglazed Pottery	82	4.98	5.09	2.04	0.54	7.82	3.20	7.82	41
	Coarseware	17	8.81	7.00	5.08	2.47	17.79	3.53	17.13	58
	Soil	30	5.32	4.12	4.05	0.02	12.47	0.48	11.55	76
	All Samples	**158**	**6.46**	**5.81**	**2.67**	**2.54**	**11.09**	**3.44**	**10.64**	**42**
U	Biscuit-fired	18	2.18	2.19	0.56	1.17	3.36	1.23	2.90	26
	Tripod Stilt	11	2.02	1.70	0.74	1.24	3.44	1.30	3.21	37
	Glazed and Unglazed Pottery	82	3.00	2.67	1.41	0.17	6.81	1.91	4.64	47
	Coarseware	17	3.56	3.08	1.62	0.33	6.67	1.49	6.01	46
	Soil	27	3.13	3.45	1.99	0.46	6.50	0.57	6.13	64
	All Samples	**155**	**2.78**	**2.62**	**1.26**	**0.67**	**5.35**	**1.30**	**4.58**	**44**

I. CLUSTER ANALYSIS

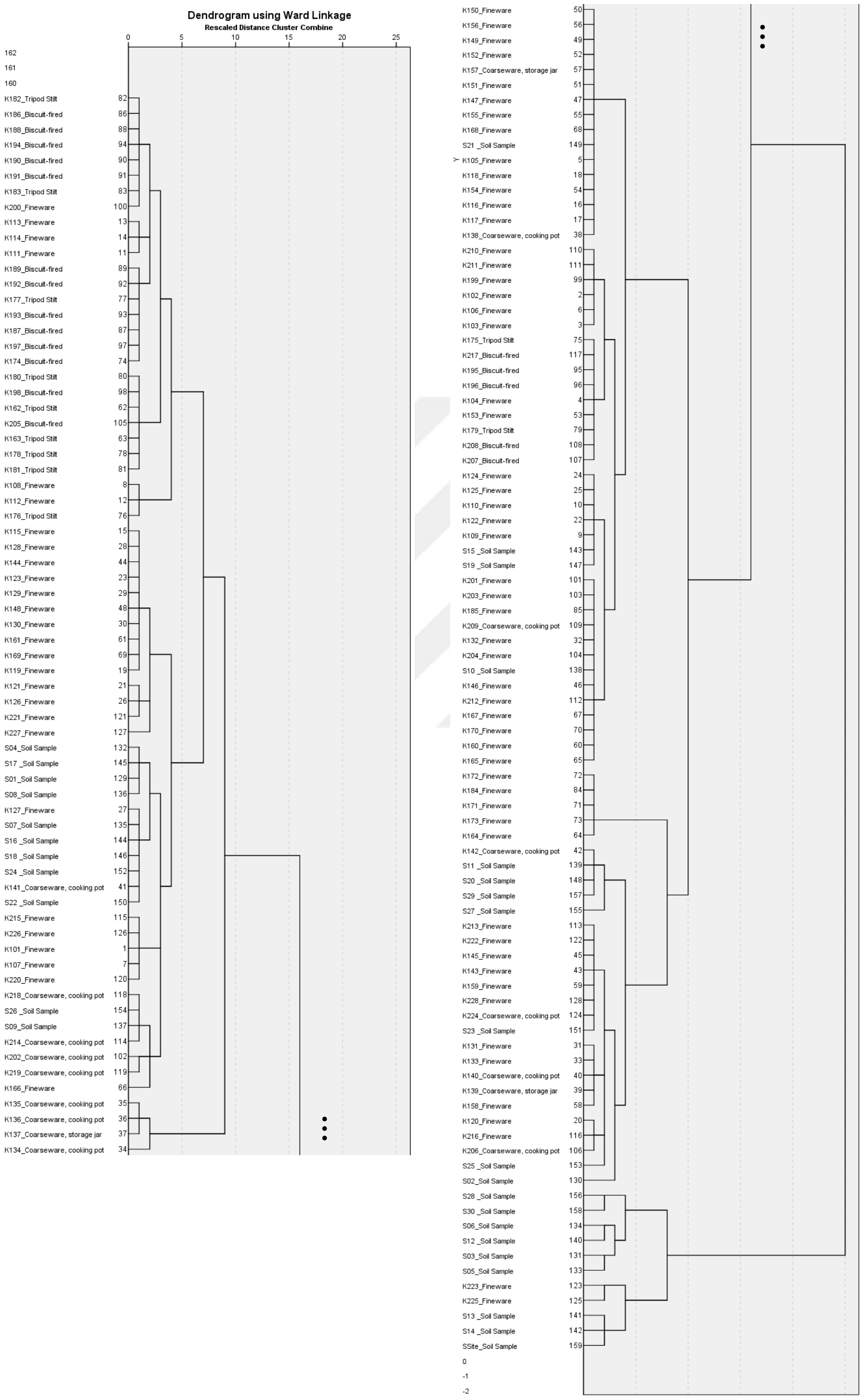
I1. Dendrogram produced by using log transformed data



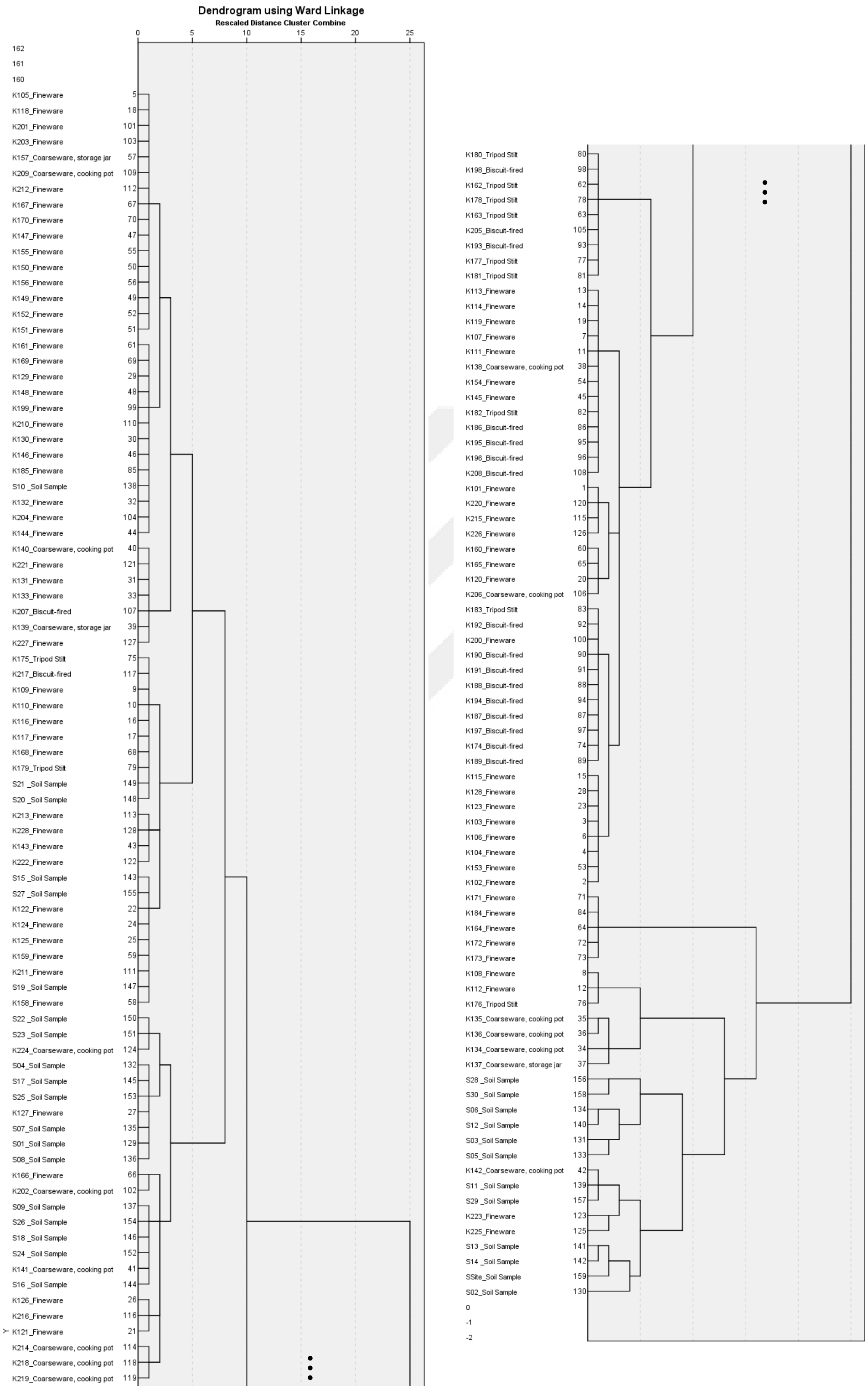
Dendrogram using Ward Linkage

Rescaled Distance Cluster Combine

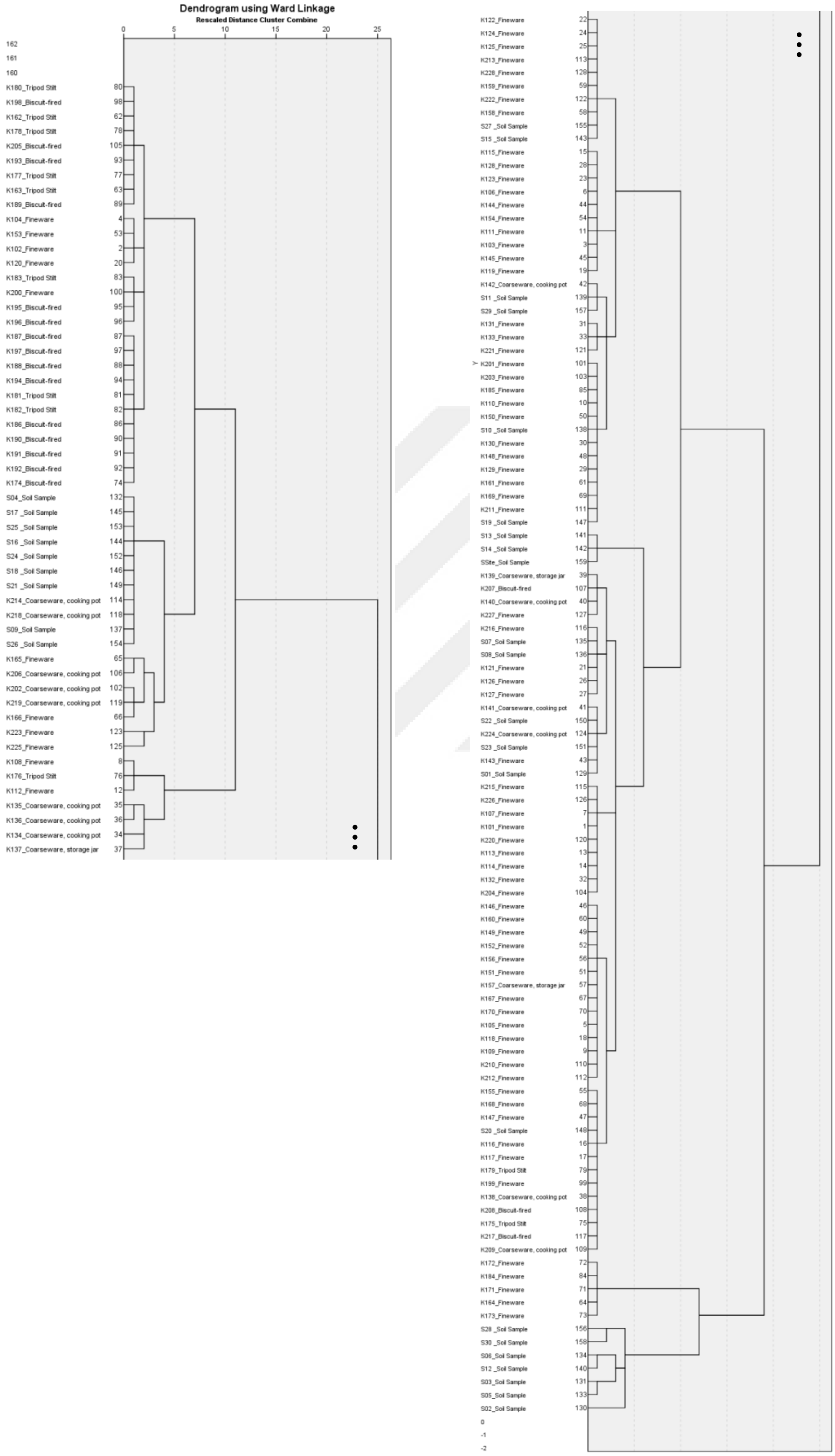
I2. Dendrogram produced by using z-score standardized data



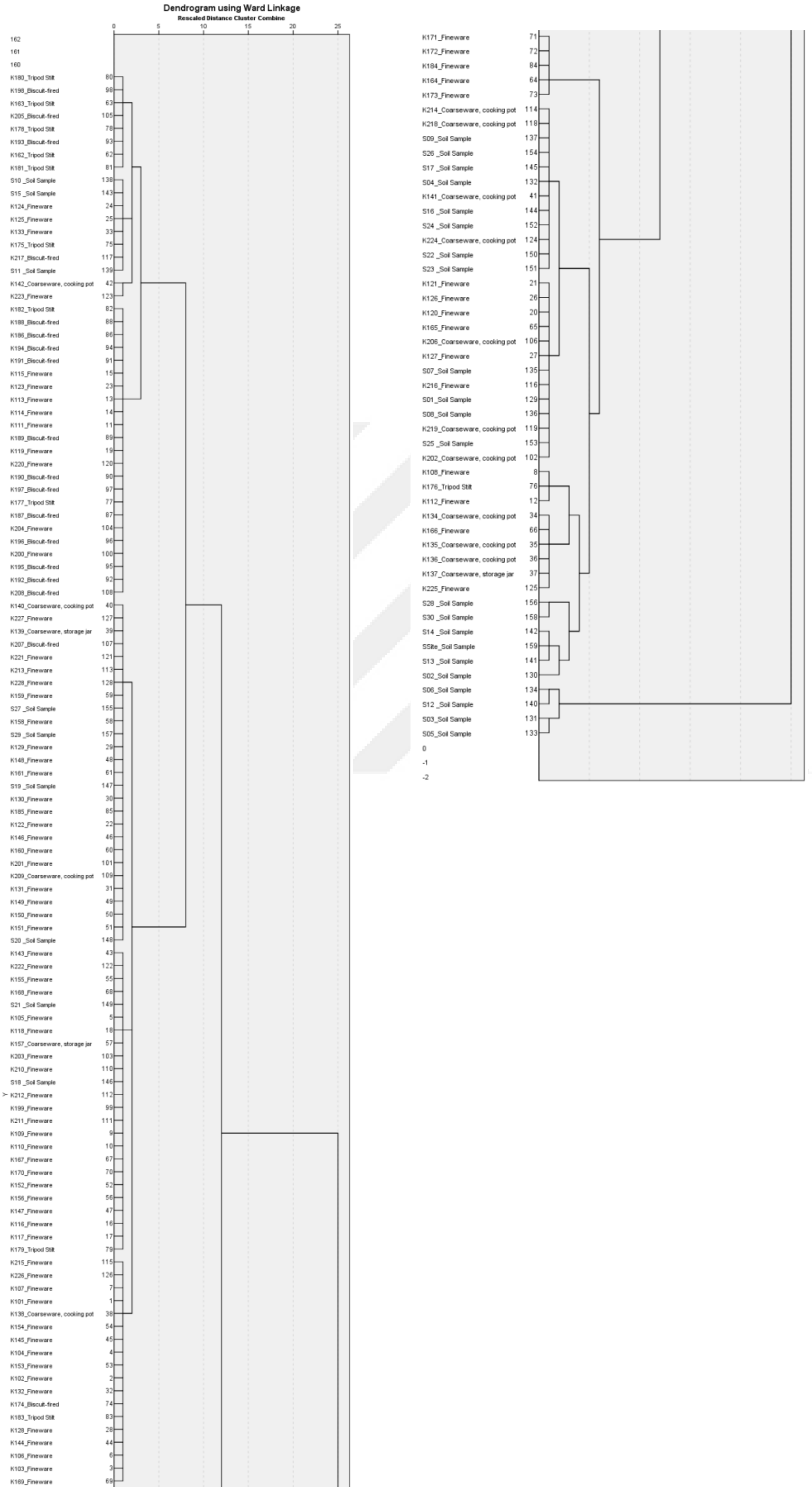
I3. Dendrogram produced by using logratio (Al) transformed data



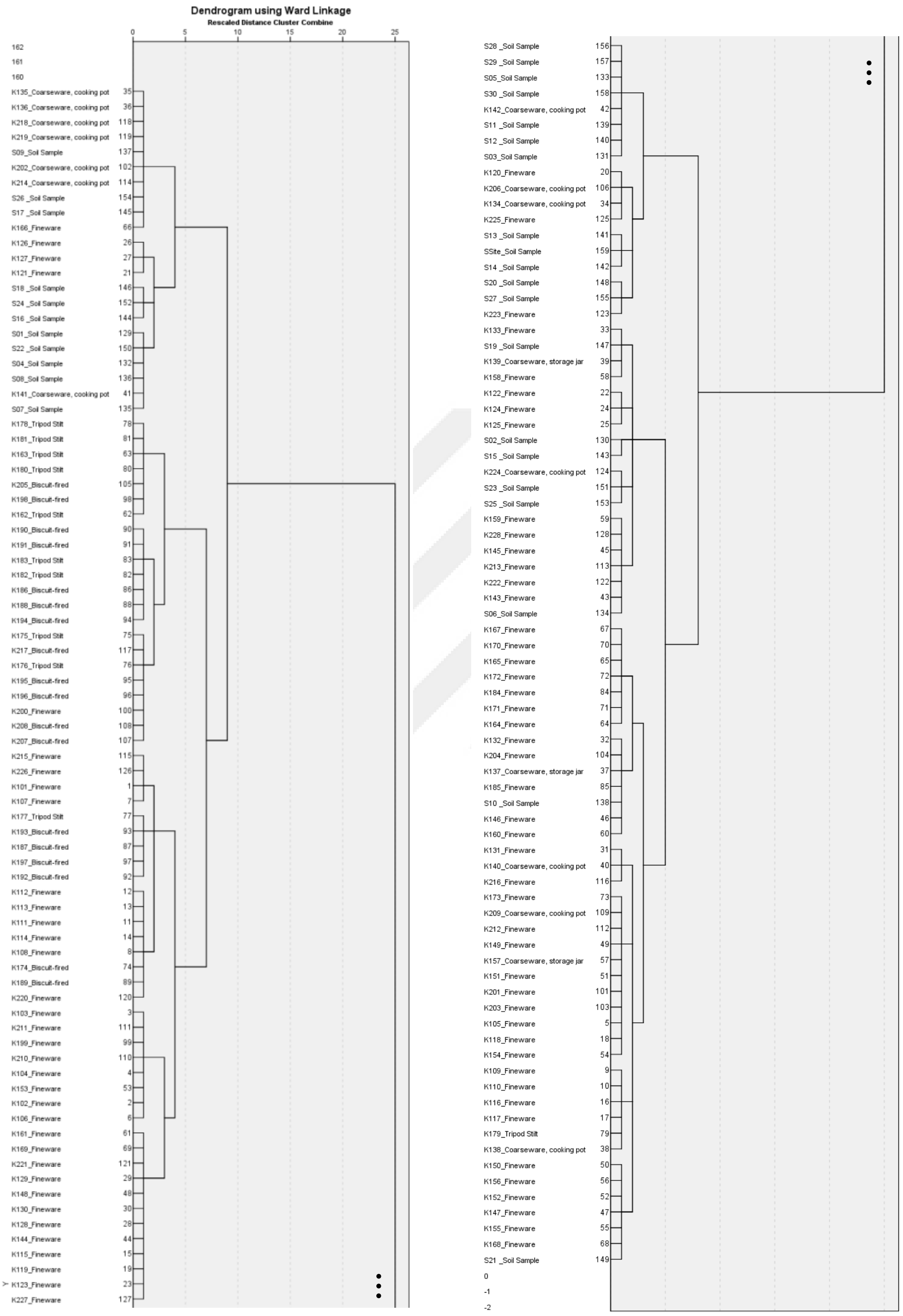
I4. Dendrogram produced by using logratio (Ti) transformed data



I5. Dendrogram produced by using logratio (U) transformed data



I6. Dendrogram produced by using rank transformed data



J. CORRELATION ANALYSIS

Table J1. Correlation analysis of element concentrations

		Na	Mg	Al	K	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Sr	Y	Zr	Ba	La	Ce	Pr	Nd	Sm	Eu	Tb	Dy	Ho	Er	Tm	Yb	Lu	Pb	Th	U
Na	**Corr.**	1.000	-0.042	0.141	.292**	0.145	0.137	0.012	0.092	0.148	.185*	-0.149	-0.108	.472**	.196*	0.112	-.326**	.231**	-0.101	-.192*	0.048	0.095	.166*	0.127	.222*	.314**	.283**	.344**	.303**	.324**	0.106	0.087	-0.103	-.361**
	Sig.		0.596	0.077	0.000	0.071	0.086	0.897	0.251	0.073	0.027	0.088	0.372	0.000	0.015	0.301	0.000	0.003	0.211	0.015	0.551	0.234	0.037	0.110	0.010	0.000	0.000	0.000	0.000	0.000	0.189	0.325	0.198	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Mg	**Corr.**	-0.042	1.000	0.134	-0.042	0.144	.389**	.304**	.475**	.528**	.463**	.463**	-0.057	0.190	.255**	0.108	0.058	-0.023	-.162*	-.176*	-.183*	-0.148	-0.083	0.134	-0.040	-0.067	-0.082	-0.036	-0.121	-0.041	-0.055	0.057	-.301**	-.261**
	Sig.	0.596		0.092	0.604	0.073	0.000	0.000	0.000	0.000	0.000	0.000	0.639	0.113	0.001	0.320	0.474	0.775	0.044	0.026	0.021	0.062	0.298	0.091	0.646	0.402	0.304	0.649	0.129	0.610	0.499	0.520	0.000	0.001
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Al	**Corr.**	0.141	0.134	1.000	.525**	.459**	.352**	0.060	.301**	.528**	.227**	0.145	0.121	0.064	0.034	.477**	.165*	.545**	.224**	.507**	.488**	.466**	.457**	.469**	.233**	.414**	.358**	.491**	.342**	.465**	.250**	.189*	.384**	.320**
	Sig.	0.077	0.092		0.000	0.000	0.000	0.499	0.000	0.000	0.007	0.096	0.319	0.596	0.679	0.000	0.040	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.002	0.031	0.000	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
K	**Corr.**	.292**	-0.042	.525**	1.000	-0.013	0.066	-0.124	0.041	0.019	0.041	-0.114	-0.223	.575**	0.049	.359**	-.179*	.793**	.300**	.458**	.661**	.603**	.623**	.323**	.194*	.577**	.494**	.687**	.492**	.656**	.379**	-0.096	.685**	.390**
	Sig.	0.000	0.604	0.000		0.876	0.413	0.168	0.616	0.821	0.629	0.197	0.068	0.000	0.549	0.001	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.275	0.000	0.000
	N	155	155	155	155	154	155	125	155	144	139	130	68	71	150	87	151	155	150	155	155	155	154	155	130	154	155	155	155	155	152	130	154	153
Ti	**Corr.**	0.145	0.144	.459**	-0.013	1.000	.412**	.286**	.431**	.714**	.464**	.239**	.332**	-0.226	.317**	0.210	.354**	.405**	.233**	.461**	.305**	.368**	.339**	.564**	.389**	.309**	.164*	.245**	0.139	0.142	0.151	.362**	-0.085	0.036
	Sig.	0.071	0.073	0.000	0.876		0.000	0.001	0.000	0.000	0.000	0.006	0.006	0.060	0.000	0.052	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.002	0.084	0.078	0.063	0.000	0.293	0.663
	N	156	156	156	154	156	156	126	156	146	140	130	67	70	151	86	152	156	151	156	156	156	155	156	129	155	156	156	156	156	153	130	155	153
V	**Corr.**	0.137	.389**	.352**	0.066	.412**	1.000	.269**	.752**	.677**	.612**	.301**	0.087	0.212	-0.150	.220*	.285**	0.001	-0.036	.159*	0.075	0.102	0.132	.176*	0.089	.158*	0.126	.194*	0.104	0.155	0.147	0.012	-0.092	-0.042
	Sig.	0.086	0.000	0.000	0.413	0.000		0.002	0.000	0.000	0.000	0.000	0.475	0.076	0.064	0.041	0.000	0.988	0.659	0.045	0.350	0.199	0.097	0.026	0.313	0.047	0.113	0.014	0.192	0.051	0.068	0.889	0.250	0.602
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Cr	**Corr.**	0.012	.304**	0.060	-0.124	.286**	.269**	1.000	.284**	.260**	.442**	.499**	0.185	0.057	.201*	0.092	0.073	0.042	0.041	0.072	0.099	0.133	0.150	.245**	0.031	0.116	0.071	0.109	0.025	0.066	0.089	-0.025	-0.021	0.002
	Sig.	0.897	0.000	0.499	0.168	0.001	0.002		0.001	0.003	0.000	0.000	0.131	0.653	0.023	0.432	0.419	0.634	0.656	0.419	0.264	0.134	0.093	0.005	0.741	0.196	0.426	0.222	0.780	0.461	0.321	0.796	0.811	0.984
	N	128	128	128	125	126	128	128	128	127	126	121	68	64	128	75	125	128	123	128	128	128	127	128	115	127	128	128	128	128	127	106	127	125
Mn	**Corr.**	0.092	.475**	.301**	0.041	.431**	.752**	.284**	1.000	.681**	.660**	.288**	0.103	.258*	0.066	0.117	.167*	0.102	-0.061	.187*	0.074	0.104	.187*	.263**	0.128	.222**	0.133	.224**	0.016	.170*	0.090	0.088	-0.146	-0.082
	Sig.	0.251	0.000	0.000	0.616	0.000	0.000	0.001		0.000	0.000	0.001	0.394	0.030	0.413	0.282	0.038	0.201	0.453	0.018	0.353	0.193	0.019	0.001	0.142	0.005	0.095	0.005	0.841	0.032	0.264	0.322	0.067	0.309
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Fe	**Corr.**	0.148	.528**	.528**	0.019	.714**	.677**	.260**	.681**	1.000	.554**	.334**	0.165	0.018	.219**	.258*	.255**	.210*	-0.003	.239**	0.078	0.150	0.144	.361**	.242**	0.160	0.086	0.146	-0.002	0.099	0.096	.300**	-.229**	-0.148
	Sig.	0.073	0.000	0.000	0.821	0.000	0.000	0.003	0.000		0.000	0.000	0.176	0.884	0.008	0.016	0.002	0.011	0.971	0.003	0.348	0.068	0.082	0.000	0.005	0.053	0.299	0.076	0.981	0.231	0.253	0.001	0.005	0.076
	N	148	148	148	144	146	148	127	148	148	138	128	69	70	148	86	144	148	143	148	148	148	147	148	131	147	148	148	148	148	144	121	147	144
Co	**Corr.**	.185*	.463**	.227**	0.041	.464**	.612**	.442**	.660**	.554**	1.000	.417**	-0.088	.258*	.182*	0.115	0.058	0.142	-0.008	-0.014	0.113	0.145	.260**	.331**	0.164	.322**	.309**	.315**	.277**	.263**	0.149	0.098	-0.129	-.191*
	Sig.	0.027	0.000	0.007	0.629	0.000	0.000	0.000	0.000	0.000		0.000	0.478	0.032	0.031	0.309	0.494	0.091	0.924	0.868	0.180	0.085	0.002	0.000	0.071	0.000	0.000	0.000	0.001	0.002	0.081	0.292	0.129	0.025
	N	142	142	142	139	140	142	126	142	138	142	131	68	69	141	81	139	142	137	142	142	142	141	142	123	141	142	142	142	142	139	118	141	138
Ni	**Corr.**	-0.149	.463**	0.145	-0.114	.239**	.301**	.499**	.288**	.334**	.417**	1.000	0.057	0.114	0.097	0.181	.182*	-0.036	-0.033	0.024	-0.003	0.016	0.041	.221*	-0.050	0.021	-0.001	0.005	-0.006	0.019	0.031	0.182	-0.139	0.013
	Sig.	0.088	0.000	0.096	0.197	0.006	0.000	0.000	0.001	0.000	0.000		0.654	0.361	0.269	0.113	0.038	0.678	0.712	0.781	0.972	0.858	0.640	0.011	0.594	0.810	0.987	0.959	0.943	0.830	0.728	0.055	0.113	0.885
	N	132	132	132	130	130	132	121	132	128	131	132	64	66	131	78	129	132	127	132	132	132	131	132	116	131	132	132	132	132	130	112	131	130
Cu	**Corr.**	-0.108	-0.057	0.121	-0.223	.332**	0.087	0.185	0.103	0.165	-0.088	0.057	1.000	-.399*	0.105	-0.063	0.043	-0.077	-0.034	.241*	-0.038	-0.085	-0.150	0.011	0.169	-0.079	-0.130	-0.197	-0.065	-0.148	-0.140	0.217	-0.067	0.148
	Sig.	0.372	0.639	0.319	0.068	0.006	0.475	0.131	0.394	0.176	0.478	0.654		0.016	0.387	0.689	0.730	0.526	0.784	0.045	0.754	0.485	0.218	0.931	0.183	0.514	0.285	0.102	0.592	0.221	0.251	0.087	0.583	0.227
	N	70	70	70	68	67	70	68	70	69	68	64	70	36	70	43	67	70	67	70	70	70	69	70	64	70	70	70	70	70	69	63	70	68
Zn	**Corr.**	.472**	0.190	0.064	.575**	-0.226	0.212	0.057	.258*	0.018	.258*	0.114	-.399*	1.000	0.156	0.225	-.468**	.418**	0.011	-0.205	.242*	.306**	.413**	0.135	0.157	.607**	.546**	.577**	.343**	.571**	.313**	-0.146	0.231	-.292*
	Sig.	0.000	0.113	0.596	0.000	0.060	0.076	0.653	0.030	0.884	0.032	0.361	0.016		0.195	0.089	0.000	0.000	0.925	0.087	0.042	0.009	0.000	0.261	0.193	0.000	0.000	0.000	0.003	0.000	0.008	0.237	0.054	0.014
	N	71	71	71	71	70	71	64	71	70	69	66	36	71	71	58	67	71	70	71	71	71	70	71	70	70	71	71	71	71	71	67	70	71
Sr	**Corr.**	.196*	.255**	0.034	0.049	.317**	-0.150	.201*	0.066	.219**	.182*	0.097	0.105	0.156	1.000	0.151	-0.062	.343**	0.004	0.022	0.145	0.146	.209**	.319**	.312**	0.141	.167*	0.149	0.091	0.150	.193*	.216*	-0.079	-0.061
	Sig.	0.015	0.001	0.679	0.549	0.000	0.064	0.023	0.413	0.008	0.031	0.269	0.387	0.195		0.162	0.452	0.000	0.965	0.791	0.072	0.070	0.010	0.000	0.000	0.083	0.038	0.066	0.260	0.064	0.018	0.016	0.334	0.459
	N	154	154	154	150	151	154	128	154	148	141	131	70	71	154	87	150	154	149	154	154	154	153	154	132	153	154	154	154	154	150	125	153	150
Y	**Corr.**	0.112	0.108	.477**	.359**	0.210	.220*	0.092	0.117	.258*	0.115	0.181	-0.063	0.225	0.151	1.000	0.078	.320**	.419**	0.207	.480**	.400**	.522**	.415**	.261*	.381**	.349**	.538**	.257*	.574**	.343**	.227*	.314**	0.018
	Sig.	0.301	0.320	0.000	0.001	0.052	0.041	0.432	0.282	0.016	0.309	0.113	0.689	0.089	0.162		0.480	0.003	0.000	0.054	0.000	0.000	0.000	0.000	0.016	0.000	0.001	0.000	0.016	0.000	0.001	0.049	0.003	0.873
	N	87	87	87	87	86	87	75	87	86	81	78	43	58	87	87	84	87	85	87	87	87	86	87	85	87	87	87	87	87	87	76	87	85
Zr	**Corr.**	-.326**	0.058	.165*	-.179*	.354**	.285**	0.073	.167*	.255**	0.058	.182*	0.043	-.468**	-0.062	0.078	1.000	0.012	0.038	.345**	0.065	0.044	-0.021	0.124	-0.003	-.196*	-.169*	-.200*	-.164*	-.220**	0.007	-0.073	-0.006	.295**
	Sig.	0.000	0.474	0.040	0.028	0.000	0.000	0.419	0.038	0.002	0.494	0.038	0.730	0.000	0.452	0.480		0.878	0.647	0.000	0.424	0.590	0.793	0.123	0.971	0.015	0.036	0.013	0.042	0.006	0.934	0.414	0.941	0.000
	N	155	155	155	151	152	155	125	155	144	139	129	67	67	150	84	155	155	150	155	155	155	154	155	128	154	155	155	155	155	151	127	154	151
Ba	**Corr.**	.231**	-0.023	.545**	.793**	.405**	0.001	0.042	0.102	.210*	0.142	-0.036	-0.077	.418**	.343**	.320**	0.012	1.000	.384**	.570**	.722**	.705**	.704**	.621**	.391**	.659**	.525**	.677**	.506**	.618**	.467**	0.091	.578**	.423**
	Sig.	0.003	0.775	0.000	0.000	0.000	0.988	0.634	0.201	0.011	0.091	0.678	0.526	0.000	0.000	0.003	0.878		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.303	0.000	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
La	**Corr.**	-0.101	-.162*	.224**	.300**	.233**	-0.036	0.041	-0.061	-0.003	-0.008	-0.033	-0.034	0.011	0.004	.419**	0.038	.384**	1.000	.508**	.569**	.570**	.496**	.566**	.317**	.418**	.291**	.422**	.270**	.330**	.295**	-0.029	.503**	.278**
	Sig.	0.211	0.044	0.005	0.000	0.004	0.659	0.656	0.453	0.971	0.924	0.712	0.784	0.925	0.965	0.000	0.647	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.748	0.000	0.001
	N	154	154	154	150	151	154	123	154	143	137	127	67	70	149	85	150	154	154	154	154	154	153	154	131	154	154	154	154	154	150	125	153	150
Ce	**Corr.**	-.192*	-.176*	.507**	.458**	.461**	.159*	0.072	.187*	.239**	-0.014	0.024	.241*	-0.205	0.022	0.207	.345**	.570**	.508**	1.000	.736**	.708**	.601**	.438**	0.150	.403**	.267**	.405**	0.155	.320**	.276**	0.004	.634**	.685**
	Sig.	0.015	0.026	0.000	0.000	0.000	0.045	0.419	0.018	0.003	0.868	0.781	0.045	0.087	0.791	0.054	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.086	0.000	0.001	0.000	0.051	0.000	0.001	0.961	0.000	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Pr	**Corr.**	0.048	-.183*	.488**	.661**	.305**	0.075	0.099	0.074	0.078	0.113	-0.003	-0.038	.242*	0.145	.480**	0.065	.722**	.569**	.736**	1.000	.939**	.944**	.612**	.382**	.754**	.699**	.815**	.583**	.765**	.581**	0.023	.832**	.527**
	Sig.	0.551	0.021	0.000	0.000	0.000	0.350	0.264	0.353	0.348	0.180	0.972	0.754	0.042	0.072	0.000	0.424	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.797	0.000	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155

Table J1 Continued

Nd	**Corr.**	0.095	-0.148	.466**	.603**	.368**	0.102	0.133	0.104	0.150	0.145	0.016	-0.085	.306**	0.146	.400**	0.044	.705**	.570**	.708**	.939**	1.000	.920**	.613**	.389**	.812**	.689**	.819**	.543**	.742**	.645**	0.016	.727**	.445**
	Sig.	0.234	0.062	0.000	0.000	0.000	0.199	0.134	0.193	0.068	0.085	0.858	0.485	0.009	0.070	0.000	0.590	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.855	0.000	0.000
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Sm	**Corr.**	.166*	-0.083	.457**	.623**	.339**	0.132	0.150	.187*	0.144	.260**	0.041	-0.150	.413**	.209**	.522**	-0.021	.704**	.496**	.601**	.944**	.920**	1.000	.663**	.418**	.845**	.800**	.889**	.622**	.842**	.603**	0.042	.696**	.325**
	Sig.	0.037	0.298	0.000	0.000	0.000	0.097	0.093	0.019	0.082	0.002	0.640	0.218	0.000	0.010	0.000	0.793	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.634	0.000	0.000
	N	158	158	158	154	155	158	127	158	147	141	131	69	70	153	86	154	158	153	158	158	158	158	158	131	157	158	158	158	158	154	129	157	154
Eu	**Corr.**	0.127	0.134	.469**	.323**	.564**	.176*	.245**	.263**	.361**	.331**	.221*	0.011	0.135	.319**	.415**	0.124	.621**	.566**	.438**	.612**	.613**	.663**	1.000	.455**	.587**	.554**	.584**	.404**	.546**	.438**	.238**	.292**	.204*
	Sig.	0.110	0.091	0.000	0.000	0.000	0.026	0.005	0.001	0.000	0.000	0.011	0.931	0.261	0.000	0.000	0.123	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.011
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Tb	**Corr.**	.222*	-0.040	.233**	.194*	.389**	0.089	0.031	0.128	.242**	0.164	-0.050	0.169	0.157	.312**	.261*	-0.003	.391**	.317**	0.150	.382**	.389**	.418**	.455**	1.000	.416**	.449**	.450**	.378**	.482**	.450**	0.065	.203*	-0.011
	Sig.	0.010	0.646	0.007	0.027	0.000	0.313	0.741	0.142	0.005	0.071	0.594	0.183	0.193	0.000	0.016	0.971	0.000	0.000	0.086	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.498	0.020	0.898
	N	132	132	132	130	129	132	115	132	131	123	116	64	70	132	85	128	132	131	132	132	132	131	132	132	131	132	132	132	132	131	110	132	129
Dy	**Corr.**	.314**	-0.067	.414**	.577**	.309**	.158*	0.116	.222**	0.160	.322**	0.021	-0.079	.607**	0.141	.381**	-.196*	.659**	.418**	.403**	.754**	.812**	.845**	.587**	.416**	1.000	.786**	.899**	.672**	.828**	.603**	0.021	.540**	0.141
	Sig.	0.000	0.402	0.000	0.000	0.000	0.047	0.196	0.005	0.053	0.000	0.810	0.514	0.000	0.083	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.809	0.000	0.082
	N	158	158	158	154	155	158	127	158	147	141	131	70	70	153	87	154	158	154	158	158	158	157	158	131	158	158	158	158	158	154	129	157	154
Ho	**Corr.**	.283**	-0.082	.358**	.494**	.164*	0.126	0.071	0.133	0.086	.309**	-0.001	-0.130	.546**	.167*	.349**	-.169*	.525**	.291**	.267**	.699**	.689**	.800**	.554**	.449**	.786**	1.000	.837**	.734**	.862**	.600**	-0.007	.509**	.185*
	Sig.	0.000	0.304	0.000	0.000	0.041	0.113	0.426	0.095	0.299	0.000	0.987	0.285	0.000	0.038	0.001	0.036	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.940	0.000	0.021
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Er	**Corr.**	.344**	-0.036	.491**	.687**	.245**	.194*	0.109	.224**	0.146	.315**	0.005	-0.197	.577**	0.149	.538**	-.200*	.677**	.422**	.405**	.815**	.819**	.889**	.584**	.450**	.899**	.837**	1.000	.732**	.938**	.681**	0.027	.655**	.215**
	Sig.	0.000	0.649	0.000	0.000	0.002	0.014	0.222	0.005	0.076	0.000	0.959	0.102	0.000	0.066	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.759	0.000	0.007
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Tm	**Corr.**	.303**	-0.121	.342**	.492**	0.139	0.104	0.025	0.016	-0.002	.277**	-0.006	-0.065	.343**	0.091	.257*	-.164*	.506**	.270**	0.155	.583**	.543**	.622**	.404**	.378**	.672**	.734**	.732**	1.000	.727**	.669**	0.034	.503**	.167*
	Sig.	0.000	0.129	0.000	0.000	0.084	0.192	0.780	0.841	0.981	0.001	0.943	0.592	0.003	0.260	0.016	0.042	0.000	0.001	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.704	0.000	0.038
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Yb	**Corr.**	.324**	-0.041	.465**	.656**	0.142	0.155	0.066	.170*	0.099	.263**	0.019	-0.148	.571**	0.150	.574**	-.220**	.618**	.330**	.320**	.765**	.742**	.842**	.546**	.482**	.828**	.862**	.938**	.727**	1.000	.695**	-0.001	.641**	.240**
	Sig.	0.000	0.610	0.000	0.000	0.078	0.051	0.461	0.032	0.231	0.002	0.830	0.221	0.000	0.064	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.990	0.000	0.003
	N	159	159	159	155	156	159	128	159	148	142	132	70	71	154	87	155	159	154	159	159	159	158	159	132	158	159	159	159	159	155	130	158	155
Lu	**Corr.**	0.106	-0.055	.250**	.379**	0.151	0.147	0.089	0.090	0.096	0.149	0.031	-0.140	.313**	.193*	.343**	0.007	.467**	.295**	.276**	.581**	.645**	.603**	.438**	.450**	.603**	.600**	.681**	.669**	.695**	1.000	-0.022	.477**	.293**
	Sig.	0.189	0.499	0.002	0.000	0.063	0.068	0.321	0.264	0.253	0.081	0.728	0.251	0.008	0.018	0.001	0.934	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.801	0.000	0.000
	N	155	155	155	152	153	155	127	155	144	139	130	69	71	150	87	151	155	150	155	155	155	154	155	131	154	155	155	155	155	155	129	154	151
Pb	**Corr.**	0.087	0.057	.189*	-0.096	.362**	0.012	-0.025	0.088	.300**	0.098	0.182	0.217	-0.146	.216*	.227*	-0.073	0.091	-0.029	0.004	0.023	0.016	0.042	.238**	0.065	0.021	-0.007	0.027	0.034	-0.001	-0.022	1.000	-0.136	-0.088
	Sig.	0.325	0.520	0.031	0.275	0.000	0.889	0.796	0.322	0.001	0.292	0.055	0.087	0.237	0.016	0.049	0.414	0.303	0.748	0.961	0.797	0.855	0.634	0.006	0.498	0.809	0.940	0.759	0.704	0.990	0.801		0.124	0.322
	N	130	130	130	130	130	130	106	130	121	118	112	63	67	125	76	127	130	125	130	130	130	129	130	110	129	130	130	130	130	129	130	129	130
Th	**Corr.**	-0.103	-.301**	.384**	.685**	-0.085	-0.092	-0.021	-0.146	-.229**	-0.129	-0.139	-0.067	0.231	-0.079	.314**	-0.006	.578**	.503**	.634**	.832**	.727**	.696**	.292**	.203*	.540**	.509**	.655**	.503**	.641**	.477**	-0.136	1.000	.675**
	Sig.	0.198	0.000	0.000	0.000	0.293	0.250	0.811	0.067	0.005	0.129	0.113	0.583	0.054	0.334	0.003	0.941	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.124		0.000
	N	158	158	158	154	155	158	127	158	147	141	131	70	70	153	87	154	158	153	158	158	158	157	158	132	157	158	158	158	158	154	129	158	154
U	**Corr.**	-.361**	-.261**	.320**	.390**	0.036	-0.042	0.002	-0.082	-0.148	-.191*	0.013	0.148	-.292*	-0.061	0.018	.295**	.423**	.278**	.685**	.527**	.445**	.325**	.204*	-0.011	0.141	.185*	.215**	.167*	.240**	.293**	-0.088	.675**	1.000
	Sig.	0.000	0.001	0.000	0.000	0.663	0.602	0.984	0.309	0.076	0.025	0.885	0.227	0.014	0.459	0.873	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.011	0.898	0.082	0.021	0.007	0.038	0.003	0.000	0.322	0.000	
	N	155	155	155	153	153	155	125	155	144	138	130	68	71	150	85	151	155	150	155	155	155	154	155	129	154	155	155	155	155	151	130	154	155

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

K. IN-GROUP VARIATIONS

Table K1. In group variations of element concentrations

		G01 Local Glazed Pottery N=56			**G02 Glazed Pottery N=14**			**G03 Moulded ware N=5**			**G04 Turquoise Glazed Pottery N=2**			**G05 Local Common Coarsewares N=13**			**G06 Mica Tempered Coarsewares N=2**		
		m	**s**	**C_{var}**	**m**	**s**	**C_{var}**	**m**	**s**	**C_{var}**	**m**	**s**	**C_{var}**	**m**	**s**	**C_{var}**	**m**	**s**	**C_{var}**
Na	**w.%**	1.06	0.29	28	0.68	0.14	20	0.95	0.17	18	1.14	0.78	68	0.72	0.19	27	0.48	0.14	29
Mg	**w.%**	4.82	1.16	24	4.21	1.03	25	3.28	0.87	27	0.66	0.14	21	3.08	2.24	73	1.38	0.04	3
Al	**w.%**	15.07	3.35	22	13.67	2.28	17	14.64	2.88	20	8.33	2.72	33	13.69	2.36	17	14.06	1.27	9
K	**w.%**	1.54	0.52	34	0.87	0.24	27	1.91	0.55	29	0.58	0.19	32	1.33	0.57	43	2.72	0.12	4
Ti	**w.%**	1.51	0.55	36	1.64	0.45	28	1.46	0.47	32	0.10	0.01	15	1.03	0.20	19	0.55	0.01	1
V	**mg/kg**	290.9	67.4	23	261.7	57.65	22	260.2	70.72	27	10.69	2.86	27	195.0	117.9	60	122.15	6.52	5
Cr	**mg/kg**	508.7	141.6	28	524.7	144.4	28	405.0	263.0	65	67.28	66.45	99	532.7	213.7	40	239.86	239.03	100
Mn	**w.%**	0.20	0.06	30	0.18	0.03	18	0.13	0.03	25	0.04	0.01	15	0.12	0.08	64	0.06	0.01	16
Fe	**w.%**	11.45	4.09	36	12.25	3.46	28	9.40	2.86	30	0.78	0.30	38	5.81	3.65	63	4.29	0.10	2
Co	**mg/kg**	67.61	19.81	29	62.40	11.38	18	42.37	10.05	24	0.08	-*	-*	45.91	9.91	22	22.17	0.44	2
Ni	**mg/kg**	289.7	106.0	37	321.8	87.07	27	201.6	81.06	40	0.79	0.00	0	233.8	95.22	41	40.70	39.91	98
Cu	**mg/kg**	251.4	196.6	78	320.0	87.92	27	389.1	67.48	17	133.5	132.2	99	317.4	51.33	16	1.31	-*	-*
Zn	**mg/kg**	156.3	168.8	108	3.60	10.01	278	111.2	-*	-*	55.5	54.69	99	88.81	0.00	0	47.08	46.26	98
Sr	**mg/kg**	238.4	99.37	42	291.1	213.9	73	285.4	56.12	20	188.1	94.54	50	134.9	68.96	51	101.47	18.52	18
Y	**mg/kg**	21.24	26.06	123	242.0	600.0	248	201.1	100.5	50	3.5	3.11	89	67.95	137.0	202	18.08	1.14	6
Zr	**mg/kg**	113.5	79.38	70	194.3	56.66	29	247.8	100.5	41	33.19	28.51	86	113.2	98.08	87	67.20	53.94	80
Ba	**mg/kg**	358.1	83.70	23	256.9	60.17	23	491.3	111.7	23	117.9	46.82	40	267.0	95.05	36	538.31	61.56	11
La	**mg/kg**	20.4	6.75	33	16.74	4.18	25	26.6	11.96	45	17.17	8.17	48	27.43	18.12	66	36.10	2.91	8
Ce	**mg/kg**	76.9	20.54	27	71.91	7.28	10	109.1	27.03	25	21.03	4.00	19	87.01	30.33	35	113.89	4.78	4
Pr	**mg/kg**	4.92	0.97	20	4.04	0.90	22	5.10	1.16	23	1.40	0.51	36	4.63	1.68	36	8.56	0.71	8
Nd	**mg/kg**	19.8	3.95	20	15.42	2.71	18	19.28	4.36	23	4.94	1.18	24	18.54	5.75	31	31.79	3.35	11
Sm	**mg/kg**	4.27	1.18	28	3.53	0.79	22	3.46	0.78	22	1.10	0.15	14	3.66	1.15	31	5.76	0.41	7
Eu	**mg/kg**	1.57	0.32	21	1.41	0.33	23	1.43	0.30	21	0.42	0.04	8	1.20	0.29	24	1.56	0.18	12
Tb	**mg/kg**	0.91	0.71	78	0.69	0.25	36	0.45	0.17	37	0.29	0.10	33	0.81	0.18	23	1.11	0.05	4
Dy	**mg/kg**	3.98	0.84	21	3.11	0.82	26	2.77	0.71	25	2.40	1.20	50	3.58	0.95	27	4.39	0.16	4
Ho	**mg/kg**	0.82	0.16	20	0.76	0.29	38	0.60	0.10	16	0.28	0.08	31	0.69	0.27	39	0.94	0.02	2
Er	**mg/kg**	2.43	0.43	18	1.87	0.40	21	1.88	0.38	20	0.70	0.08	11	2.17	0.62	28	2.70	0.10	4
Tm	**mg/kg**	0.35	0.09	25	0.24	0.06	26	0.32	0.05	16	0.19	0.06	32	0.33	0.10	30	0.35	0.11	31
Yb	**mg/kg**	2.28	0.38	17	1.73	0.42	24	1.79	0.21	12	0.74	0.05	6	1.90	0.65	34	2.38	0.08	3
Lu	**mg/kg**	0.35	0.06	17	0.28	0.17	60	0.36	0.10	28	0.04	0.00	8	0.32	0.14	42	0.36	0.06	18
Pb	**w.%**	1.08	1.7	155	1.02	1.07	104	0.02	0.01	75	0.22	0.01	3	0.01	0.01	118	078	0.77	99
Th	**mg/kg**	5.94	1.36	23	4.20	0.72	17	7.96	2.62	33	1.64	1.09	67	8.02	4.27	53	17.19	0.60	3
U	**mg/kg**	2.63	0.68	26	3.03	0.79	26	5.34	1.83	34	1.28	1.11	87	3.29	1.50	46	5.81	0.87	15

L. STATISTICAL POWER ANALYSIS

		Pottery	**Local references**	**Soil**		**Power**		
	Number of sample	99	29	31	**St. Dev. Within Each Group**	**Pottery vs Local**	**Pottery vs Soil**	**Local vs Soil**
Na	Mean, mg/kg	8795	12280	8005				
	St. Dev	3000	2465	6322	5000 mg/kg	0.91	**0.12**	0.90
Mg	Mean, mg/kg	41705	49508	41678				
	St. Dev	16621	7790	21882	20000 mg/kg	**0.45**	**0.05**	**0.32**
Al	Mean, mg/kg	144747	147899	136947				
	St. Dev	32762	31143	46488	50000 mg/kg	**0.06**	**0.12**	**0.13**
K	Mean, mg/kg	12845	19619	11410				
	St. Dev	5606	3362	8707	5000 mg/kg	0.99	**0.26**	0.99
Ti	Mean, mg/kg	15201	10591	11479				
	St. Dev	6007	1780	7581	5000 mg/kg	0.99	0.95	**0.10**
Mn	Mean, mg/kg	1694	2167	1663				
	St. Dev	675	594	576	1000 mg/kg	0.60	**0.05**	**0.48**
Fe	Mean, mg/kg	104368	106169	95705				
	St. Dev	47585	33204	31706	10000 mg/kg	**0.13**	0.98	0.97
V	Mean, mg/kg	253	312	302				
	St. Dev	90	56	112	75 mg/kg	0.96	0.88	**0.08**
Cr	Mean, mg/kg	521	472	565				
	St. Dev	183	102	698	250 mg/kg	**0.14**	**0.12**	**0.27**
Co	Mean, mg/kg	65.76	67.51	48.81				
	St. Dev	52.05	14.44	36.55	25 mg/kg	**0.06**	0.89	0.81
Ni	Mean, mg/kg	319	262	272				
	St. Dev	279	70	236	100 mg/kg	0.74	0.54	**0.06**
Cu	Mean, mg/kg	399	207	353				
	St. Dev	225	53	85	75 mg/kg	0.99	**0.46**	0.99
Sr	Mean, mg/kg	245	185	139				
	St. Dev	125	36	132	75 mg/kg	0.96	0.99	0.64
Zr	Mean, mg/kg	148.62	65.04	130.37				
	St. Dev	85.93	43.51	65.5	50 mg/kg	1.00	**0.41**	0.99
Ba	Mean, mg/kg	329	366	189				
	St. Dev	116	45	122	100 mg/kg	0.99	0.99	0.99
La	Mean, mg/kg	27.25	20.94	14.82				
	St. Dev	28.39	9.23	9.74	10 mg/kg	0.84	0.99	0.64
Ce	Mean, mg/kg	82.35	67.19	75.51				
	St. Dev	25.92	10.44	45.74	25 mg/kg	0.81	**0.26**	**0.24**
Pr	Mean, mg/kg	4.69	4.87	3.73				
	St. Dev	1.37	0.86	2.26	1 mg/kg	**0.14**	0.99	0.99
Nd	Mean, mg/kg	18.9	20.08	14.47				
	St. Dev	5.95	3.67	8.16	5 mg/kg	**0.19**	0.98	0.98
Sm	Mean, mg/kg	3.91	4.31	2.9				
	St. Dev	1.33	0.67	1.43	1 mg/kg	0.99	0.99	0.99
Eu	Mean, mg/kg	1.52	1.4	1.01				
	St. Dev	0.45	0.23	0.44	0.5 mg/kg	**0.20**	0.99	0.84
Tb	Mean, mg/kg	1.46	1.04	0.57				
	St. Dev	2.68	0.97	0.15	0.5 mg/kg	0.97	1.00	0.91
Dy	Mean, mg/kg	3.74	4.36	2.54				
	St. Dev	2.36	0.56	0.93	1 mg/kg	0.82	0.99	0.99
Ho	Mean, mg/kg	0.73	0.9	0.55				
	St. Dev	0.21	0.16	0.18	0.5 mg/kg	**0.35**	**0.41**	0.75
Er	Mean, mg/kg	2.13	2.7	1.68				
	St. Dev	0.51	0.31	0.55	0.5 mg/kg	0.99	0.99	1.00
Tm	Mean, mg/kg	0.31	0.37	0.23				
	St. Dev	0.08	0.11	0.09	0.10 mg/kg	0.80	0.97	0.99
Yb	Mean, mg/kg	1.98	2.5	1.66				
	St. Dev	0.49	0.27	0.51	0.5 mg/kg	0.99	0.86	0.99
Lu	Mean, mg/kg	0.32	0.36	0.28				
	St. Dev	0.11	0.05	0.11	0.10 mg/kg	**0.46**	**0.44**	0.83
Th	Mean, mg/kg	5.97	6.61	5.32				
	St. Dev	2.92	1.13	4.04	2 mg/kg	**0.32**	**0.34**	0.68
U	Mean, mg/kg	3.15	2.11	3.13				
	St. Dev	1.23	0.62	1.99	1 mg/kg	0.99	**0.05**	0.96

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PUBLICATIONS

1. Er MB, Ertaş G. Komana Orta Bizans Dönemi Çanak Çömlekleri Üzerine Arkeometrik Araştırmalar. In: Erciyas DB, Tatbul MN, eds. Komana Ortaçağ Yerleşimi, Yerleşim Arkeolojisi Serisi 5 Monografi 1. Ege Yayınları; 2015

HOBBIES

Computer Technologies, Books, Rock Music