DIFFERENTIATION AND CLASSIFICATION OF COUNTERFEIT AND REAL COINS BY APPLYING STATISTICAL METHODS

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ABSTRACT

DIFFERENTIATION AND CLASSIFICATION OF COUNTERFEIT AND REAL COINS BY APPLYING STATISTICAL METHODS

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In this study, forty coins which were obtained from Museum of Anatolian Civilizations (MAC) in Ankara were investigated. Some of those coins were real (twenty two coins) and the remaining ones (eighteen coins) were fake coins. Forty coins were Greek coins which were dated back to middle of the fifth century BCE and reign of Alexander the Great (323 – 336 BCE). The major aims of this study can be summarized as follow;

- To analyze coins under study to determine elemental contents and to measure physical properties (weights and diameters)
- To illustrate the use of cluster analysis technique for forgery analysis
- Specifically, to carry out cluster analysis for Greek coins (dated back to middle of the fifth century BCE and reign of Alexander the Great (323 – 336 BCE)) that were obtained from MAC.

In chemical analysis, portable X-Ray fluorescence (PXRF) spectrometry was used. By using portable XRF spectrometry chemical compositions of the coins were determined. Results obtained from XRF analysis were analysed statistically.

In statistical analysis, cluster analysis was carried out. Before clustering, correlation - a technique that determines the relation between two or more variables - was used in order to determine the most related elements. The most related elements mean that elements contain high and negative correlation between them. In this study, the most related elements were determined by using Pearson's correlation coeefficient. Pearson's correlation coefficient which was equal or higher than -0.50 was assumed efficient. Variables of clustering was chosen from major elements of the coins ((Ag (silver), Cu (copper), Fe (iron) and Pb (lead)). Pairs were constructed from those four major elements such as Ag-Cu, Ag-Fe, Ag-Pb, Cu-Fe, Cu-Pb, Fe-Pb. In this study, hierarchical agglomerative clustering algorithm and complete linkage were prefered. Results of clustering was visualized by using the most common graphical form of clustering. At this point, dendrograms were constructed. Two dendograms were constructed for each element pair. In the construction of one dendogram ratio of the elements between them were used. On the otherhand, in the construction of other dendogram individual values of the elements were used. Differentiation of fake coins from their real ones realized in many relations. Lastly, independent samples t test was applied in order to determine the magnitude of the difference between groups of real and fake coins.

Key Words: Real Coins, Fake (Counterfeit) Coins, Portable X-Ray Fluorescence Spectrometry (PXRF), SPSS 16.0, R 2.14.0, Correlation, Dendogram, Cluster Analysis,

ÖZ

GERÇEK VE SAHTE SİKKELERİN, İSTATİSTİKİ YÖNTEMLER KULLANILARAK, AYRILMASI VE GRUPLANDIRILMASI

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Bu çalışmada Ankara Anadolu Medeniyetleri Müzesi'nden sağlanan kırk gümüş sikke incelenmiştir. Bu sikkelerin bir kısmı gerçek (yirmi iki sikke) kalan kısmı ise sahte sikkelerden (on sekiz sikke) oluşmaktadır. Kırk sikke Grek sikkeleridir ve bu sikkelerden bazıları M.Ö. 5. yüzyılın ortasına kalanları ise Büyük İskender'in hükümdarlık yılları olan M.Ö. 323 – 336'ya tarihlenmektedir. Bu çalışmanın amaçları aşağıdaki gibi özetlenebilir;

- Araştırma ile çalışılan sikkelerin element içeriklerinin belirlenmesi ve fiziksel özelliklerinin (ağırlık – çap) ölçülerek analiz edilmesi amaçlanmaktadır.
- Genel anlamda gruplandırma analizinin sahte obje analizlerine uygunluğuna bakmak, özel anlamda ise Ankara Anadolu Medeniyetleri Müzesi'nden sağlanan Grek sikkeleri (M.Ö. 5.yüzyıl ortalarına tarihlenen ve Büyük İskender'in hükümdarlık yıllarına tarihlenen sikkeler) için gruplandırma analizi yürütmek oluşturmaktadır.

Kimyasal analizlerde taşınabilir X-ışını floresansı spektrometrisi kullanılmıştır (PXRF). XRF ile sikkelerin element içerikleri belirlenmiştir. XRF analizinden elde edilen sonuçlar istatistiksel olarak analiz edilmiştir.

İstatistiksel analizlerde gruplandırma analizi kullanılmıştır. Gruplandırmadan önce aralarında ilişki olan elementlerin belirlenmesi amacıyla aralarında ilişki olan iki ya da daha fazla değişkenin belirlenmesinde kullanılan bir yöntem olan korelasyon kullanılmıştır. En ilişkili elementler ifadesi ile aralarında yüksek ve negatif korelasyon olan elementler kastedilmektedir. Bu çalışmada aralarında en kuvvetli ilişki olan elementler Pearson'ın korelasyon katsayısı kullanılarak belirlenmiştir. Çalışmada -0,50'ye eşit ve bu değerden büyük olan korelasyon katsayıları anlamlı varsayılmıştır. Gruplandırma analizinin değişkenleri sikkelerin elementler içeriklerinde en etkin olan elementler olarak belirlenmiştir. Bu elementler Ag, Cu, Fe ve Pb. Bu temel elementlerden çiftler oluşturulmuştur. Örneğin; Ag-Cu, Ag-Fe, Ag-Pb, Cu-Fe, Cu-Pb, Fe-Pb. Çalışmada algoritma olarak hiyerarşik yığmacı gruplandırma ve bağlantı olarak da tam bağlantı tercih edilmiştir. Gruplandırma analizinin sonuçları analizin en çok kullanılan grafik biçimi olan dendogram kullanılarak görselleştirilmiştir. Her element çifti için iki dendogram oluşturulmuştur. Bir dendogramın oluşturulmasında elementlerin oranı kullanılmıştır. Diğer yandan diğer dendogramın oluşturulmasında elementlerin değerleri kullanılmıştır. Sahte sikkeler birçok ilişki de gerçek sikkelerden ayrılmıştır. Son olarak, gerçek ve sahte sikke grupları arasındaki farkın büyüklüğünün belirlenmesi amacıyla bağımsız örnekler t testi uygulanmıştır.

Anahtar Kelimeler: Gerçek Sikkeler, Sahte Sikkeler, X – Işını Floresansı Spektrometrisi (PXRF) SPSS 16.0, R 2.14.0, Korelasyon, Dendogram, Gruplandırma Analizi

To the memory of my father

and

to my mother and my grandmother

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CHAPTER 1

INTRODUCTION

It is obvious that commercial activities between people require some materials to be used. Those materials should be sustainable and readily available, if possible should be valuable. Coins have been one of the most significant tools of those valuable materials throughout history uptoday. Increasing in values of the coins is related to their production materials. Coins are produced from precious and noble metals, like gold, silver,…etc.

Coins were used widely. However, as the value of the coins increases in time fake (counterfeit) of the coins have been started to be produced. Thus, forgery in coin minting became a serious problem in the world. Many countries including our country face this drastic problem. There are many counterfeit coins in the museums of Turkey including Museum of Anatolian Civilizations (MAC) in Ankara.

Fake coins are produced as much the same way as the real ones. Besides, fake coins which have similar properties with the real coins can be produced more rapidly than the real ones and distributed more easily.

Studies showed that there are two types of fake coins. One type can be differentiated easily from the real ones by the people who are master in numismatics (branch of science which is related with coins). The other type of the coins can not be distinguished easily by numismatics (Mezzasalma *et al.* 2009). Those require various analysis using sophisticated methods and techniques.

1.1 Literature Review

There are various studies related with ancient coins. The oldest publication seen so far was appeared in 1993 which was carried out in Greece on copper coins (Kallithrahas-Kontos *et al.* 1993). Regarding silver coins ten papers have been seen covering time period from 1999 to 2012. Many of the studies had been related with methods of analysis of the ancient coins.

A study done in India was related with analysis of a number of copper and silver coins dated back to Hindu Shahis Dynasty of Kabul (990 – 1015 CE). In the investigation proton induced X-ray Emission method was used. The elements Ca, Ti, Cr, Fe, Ni, Zn, As, Sb, Pb and Bi were detected in the coins along with the major components of Cu and Ag. A strong positive correlation was observed between Pb (lead) and (Zn) zinc. Besides a strong negative correlation was observed between Cu (copper) and Ag (silver). Weights of the coins were also determined. From the results of the coins the authors estimated that the source mine of Cu (copper) was from Khetri mine in Rajastan and Ag (silver) seemed to come from Afghanistan (Hajivaliei *et al.* 1999).

A number of silver coins from Kreshpan hoard (Albania) of the 3rd century BCE were investigated using Energy Dispersive X-ray Fluorescence Spectrometry (EDXRF) (Civici *et al.* 2007). The results showed that the coins were made of similar silver copper alloy with Ag concentration in the range of 94 – 98 %. The minor elements detected were Pb, Au and Bi. A strong and negative correlation was observed between Ag and Cu. In the study, Bi / Ag ratio was plotted versus Au / Ag ratio. The diagram of Bi versus Au (the concentrations are normalized to that of silver) and ternary plot of Au, Bi and Pb concentrations in the coins clearly indicated the different sources of the coins, namely Dyrrachion, Korkyra and Monounios.

A study was done by Suzuki (2008) to develop a simple and non-destructive examination technique for counterfeit coins using acoustic characteristics. The measurement of the sound by the shock wave and the analysis of the natural frequencies were carried out. Some authentic and five kinds of counterfeit 500-yen coins were analysed. Four peaks of natural frequencies were observed between 5-20 kHz for authentic coins. On the other hand, only three peaks were observed for some kinds of counterfeit coins.

In a later study done by Hajivaliei *et al.* (2008) a number of ancient Iranian silver coins dated back to reign of Khosrau II (592 – 626 AD) (Sasanians dynasty) were investigated. In analysis, proton induced X-ray emission (PIXE) was used. The elements Cl, Ca, Ti, Mn, Fe, Cu, Au and Pb were detected in the coins along with the major component Ag. Weights of the coins were measured. There was a negative and strong correlation between Cu and Ag. In addition, there were negative correlations between Ag and Au and Ag and Pb. On the other hand, there were positive correlations between Cu and Pb, Ti and Pb. A few coins did not have Au in their compositions. This showed that they might be forged.

In another study done by Tripathy *et al.* (2009) a number of Indian silver coins minted in Calcutta and Bombay during British rule were investigated by using proton induced X-ray emission (PIXE) spectrometry. The elements Cr, Fe, Ni, As and Pb were detected as trace elements in the coins along with the major components Ag and Cu, Zn was the minor element. A strong and negative correlation between Ag and Cu was observed. By using the graph of Ag percents versus minting times (in the range of 1904 - 1933) it was seen that percentage of Ag was highest in 1918 and 1919. The variation of the elemental concentration was attributed to the use of different ores for making coins.

A study was done by Pistofidis *et al.* (2010) to determine the microstructure of a number of silver coins belonging to the Kreshpan hoard and dated back to 3rd century BCE. In the study, XRD and transmission electron microscopy (TEM) were used in order to determine minting method of the coins. In the investigation, it was seen that coins had a large number of structural defects such as dislocations, twins and microtwins. Since twins in FCC (Face Centered Cubic) metals should be formed with thermal treatment and mechanical twinning should be rather improbable. It was deduced that coins were initially hot worked and working continued during cooling.

A number of Late Roman (nummi) coins dated back to 308 – 311 CE and produced in Carthago were investigated (Rizzo *et al.* 2010). The aim of the study was determination of the silver content of the coins produced in different periods of time and the technique used in their manifacturing. In the study, portable PIXE (proton induced X-ray emission) – alpha, XRF spectrometry and DPAA (deep proton activation analysis) methods were used. Results of this study indicated that the Ag content of the interior of the coin (DPAA data) was very low (about 1 %) and followed the general trend of fineness during the period (308 – 311 CE) was supported.

In another study done by Kantarelou *et al.* (2011) a number of Hellenistic silver coins dated back to 180 – 321 BCE were investigated. The coins were analysed in-situ by using milli-probe XRF spectrometer. The elements Au, Pb, Bi, Fe, Zn and Hg were detected in the coins along with the major components of Cu and Ag. The presence of an Ag-enriched layer was excluded for the majority of them. The silver fineness was found to be high, with very low concentrations of copper and lead. The composition data provided important information about possible sources of silver during the mentioned period. And indications of a gradual coinage debasement after 270 BCE due to economic or technical results.

A study done in India in 2011 was related with a number of silver punch-marked coins. In the analysis, external proton induced X-ray emission (PIXE) spectrometry was used. The main elements were Ag and Cu. Au was also found in all coins and varied between 0.7 % and 6.2 %. Along with those elements K, Ca, Ti, V, Cr, Mn, Co, Ni, Rb, Pb and Fe were also detected. Presence of Au was attributed as the indication of the better economic condition of the period under study (Rautray *et al.* 2011).

The recent study found in literature was related with investigation patina profiles of ancient silver coins (Caridi *et al.* 2012). In this study, silver coins of different periods from 4th century BCE to 19th century coming from different Mediterranean countries were investigated. In the analysis, X-ray photoelectron spectroscopy (XPS), X-ray fluorescence (XRF) spectrometry and Scanning electron microscopy (SEM) were used. In the study, patina composition and trace elements as a function of sample depth were investigated. As a result it was found out that the Ag/O ratio in the patina was lower in old coins and it was increased in recent ones. The result was attributed that coin patina was generally rich in silver oxide proportionally with the age of the coin.

1.2 Aim of the Study

To the best of our knowledge there is no study done in Turkey for differentiation betwen real and fake coins. However, many fake coins have been released in various fields especially in museums. Also, to the best of our knowledge, the literature is lacking studies that employ cluster analysis technique for forgery analysis of the coins. In light of this fact the major aims of this study can be summarized as follow;

- To analyze coins under study to determine elemental contents and to measure physical properties (weights and diameters)
- To illustrate the use of cluster analysis technique for forgery analysis
- Specifically, to carry out cluster analysis for Greek coins (dated back to middle of the fifth century BCE and reign of Alexander the Great (323 – 336 BCE)) that were obtained from MAC.

The primary research question addressed in this thesis is; *Which chemical or physical coin characteristics are effective in distinguishing fake coins from the real ones?*

To address these questions we employ cluster analysis technique which is a statistical approach to group the objects based on different measurements taken on each subject. The secondary research questions are then defined as follows;

- Which element(s) are characteristic to construct different clusters for either real or fake?
- Which element(s) are characteristic to distinguish clusters obtained by being genuine or fake coins?

Data are multivariate in nature since each coin has many variables such as element contents, weight, and diameter. Therefore it would be more advantageous to use methods that take the account for the multivariate aspect of the data. Statistical cluster analysis is such a method. Through the use of this method, our main contribution is offering a unified framework in which chemical and physical characteristics of the coins are analyzed simultaneously while accounting for the relationships between them.

The thesis is organized as follows:

- Chapter 2 includes a brief history of coins especially the silver Greek coins which were investigated in the context of this study.
- Chapter 3 presents the materials, physical and chemical methods used in their analysis and statistical methodology employed for them.
- Chapter 4 is concerned with results and discussions.
- Chapter 5 includes the conclusion and proposed further studies.

CHAPTER 2

HISTORY OF COINS AND THEIR DISTRIBUTION IN ANCIENT TIMES

History of coins in general and Greek silver coins are given in three subsections.

2.1 Definition of Coin

Coin is a paying tool made of metal and having circular shape (Tekin; 2000). An example coin is given in Figure 2.1 (Photo of the coin is obtained from İçten Tansel in March 2011 at MAC.).

Figure 2.1 Obverse and reverse sides of a real coin which were dated back to middle of the fifth century BCE

2.2 Brief History of Distribution of Coin

First coins were supposed to be minted seventh century BCE and used by Lydians. Lydian Civilization was settled in Western part of Anatolia (between Gediz and Menderes Rivers) (Tekin; 2000). Location of Lydian Civilization is given in Figure 2.2(http://tr.wikipedia.org/wiki/Lidyal%C4%B1lar).

Figure 2.2 Map of Anatolia; Location of Lydia is shown as yellow.

First historical information about the invention of coin was given by Herodotus (an ancient Greek historian who was born in Halicarnassus (at present Bodrum, Turkey) and lived in the fifth century BCE (c. 484 BCE - c. 425 BCE) (http://en. wikipedia.org /wiki/Herodotus).

From written sources, it is known that before the invention of coin many things such as (various) metals, bovines, tripod couldrons, axes (Tekin; 2000), sea shells, belt made of sea shells, metal ring, iron paddle, copper axe, iron sword, bronze weights and raw copper pieces were used as paying tools. Some examples from those objects are given in Figure 2.3 (Atlan;1993).

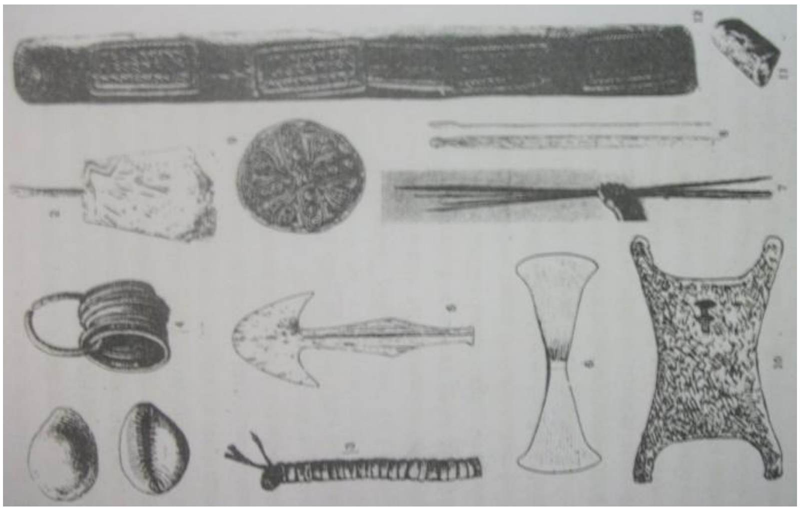


Figure 2.3 Some objects which were used instead of coin before coin was invented

Fortunately, invention of coin ended the diversity of paying tools. Invention of coin also provides people a standard paying tool. According to ancient written sources and archaeological findings, gold, silver, copper and bronze were used in the minting of coin in ancient time (Tekin; 2000).

First coins were minted from electron ("electrum" in Latin) in Anatolia (Tekin; 2000). Electrum is a naturally occurring alloy of gold and silver, with trace amounts of copper and other metals (http://en.wikipedia.org/wiki/Electrum). The gold content of naturally occurring electrum in Western Anatolia ranges 70% - 90%. However, gold content of electrum used in Ancient Lydian coinage was found to be 45 % – 55% (http://en.wikipedia.org/wiki/Electrum). The decrease in gold might be due to economical reason. A Lydian electron which dated back to early periods of the sixth century BCE is given in Figure 2.4 (http://en.wikipedia.org/wiki/File:BMC_06.jpg).

Figure 2.4 A Lydian electron which were dated back to the early periods of the sixth century BCE

In Classic Period (between 480 BCE and 330 BCE) and Helenistic Period (between 330 BCE and 30 BCE) metal of the coins minted in Anatolia was mainly silver or bronze and partly gold. Silver was the most important coin metal until Roman period (~ 753 BCE) in Greece. After Roman period, coin minting from copper was increased. This increase was the result of a depletion and also an extinction of precious mineral deposits of ancient period (Tekin; 2000).

Information obtained from the inscriptions of a coin can be given as follow (Tekin; 2000).

- Name of the public which were minted the coin,
- When the coin was minted? Who was minted the coin? or Coin was minted in the reign of which emperor?
- Name of the people who was in charge of minting in coinage,

- Type of the coin
- Name of coin moulder,
- Date (from Helenistic period)
- Unit (from Helenistic period but rarely)

There are three types of ancient coins; those are Greek, Roman and Byzantine coins (Atlan;1993). Those three groups can be split up into two subgroups by themselves. Those two subgroups are ***city coins*** and ***imperial coins*** (Devecioğlu, personal communication in 16 March 2011). For instance; Greek city coins were minted in ancient Greek language and on the obverse sides of those coins icons of gods, goddes and monks were drawn. An example of a city coin is given in Figure 2.5 (Photo of the coin was taken by İçten Tansel in October 2011 at Eskişehir Archaeology Museum.). On the other hand, imperial coins were minted in Latin and on the obverse sides of these coins potrait of the emperors were drawn. An example of an imperial coin is given in Figure 2.6 (Photo of the coin was taken by İçten Tansel in March 2011 at MAC.).

Figure 2.5 An example city coin

Figure 2.6 An example imperial coin

2.3 Brief History of Greek Silver Coins

Although coin was invented by Lydians, Ionia cities which settled in Western Anatolia brought identity and usage habitation to coins (Tekin; 2000). Ion cities with other important cities are given in Figure 2.7 (http://tr.wikipedia. org/w/index. php?title=Dosya:Aiol-iondor_%C5%9Fehirleri.jpg&filetimestamp=201106301345 06).

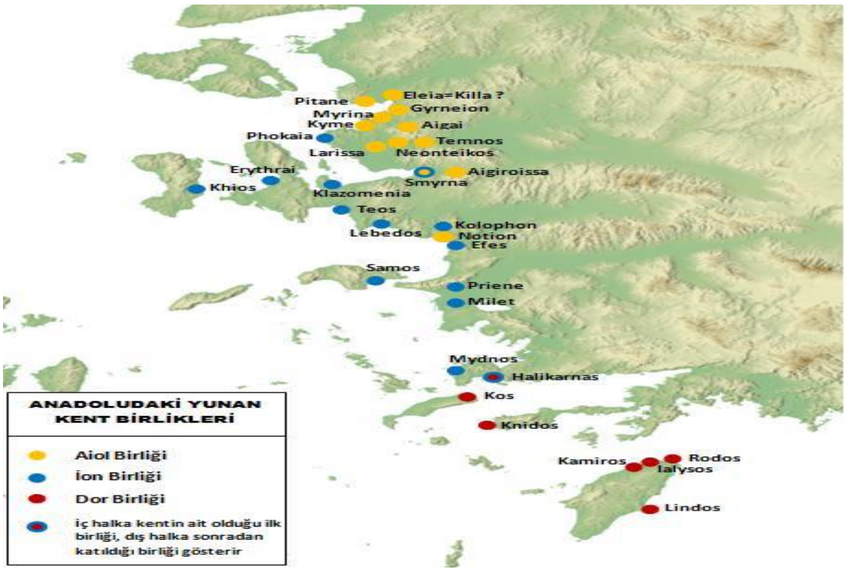


Figure 2.7 Significant Ion cities that were located in Western part of Anatolia

Coin minting was initiated in Western Anatolia. Coin minting was accumulated from Greece to Aegean and on a large district of Mediterranean. As a result, coins which were minted in different parts of Mediterranean region (from Cebelitarık Gate to North and West India) in Archaic (800 – 490 BCE), Classic (490 - 323 BCE) and Helenistic (323 – 146 BCE) periods were called *"Greek Coins"* (Tekin, 2000)

Greek coins can be split up into four groups by themselves. Those four groups can be constituted by Greek coins which dated back to Archaic period (~ 640/630 BCE - 480 BCE), Classic(al) period (480 BCE - 330 BCE), Late classic(al) period and Helenistic period (330 BCE - 30 BCE) (Atlan; 1993).

District which was mentioned above is such a large disrict. It is not right something to yield all the coins which belong to this large district as Greek coins. Although inscriptions of many of those coins were written in old Greek language, some of them also contained unique inscriptions (Tekin; 2000).

First coins were minted by Lydians. Some coins were found in an excavation which was executed between 1904 – 1905 in Ephesos, Temple of Artemis. Coins which were found in this excavation were minted from electrum and those coins were dated back to the second half of the seventh century BCE. Some of those coins were minted in *Sardeis* by Lydian Kingdom. A view from Sardeis is given in Figure 2.8 (Karul;2012). City plan of Sardeis is given in Figure 2.9 (Karul;2012). Electrum was used in minting of those first coins by Lydians because electrum was existing naturally in alluvium of *Paktolos River* (Sart River) which rised from *Tmolos Mountain* (Bozdağ). A view from a gold production workshop is given in Figure 2.10 (Karul;2012).

Figure 2.8 A view from Sardeis

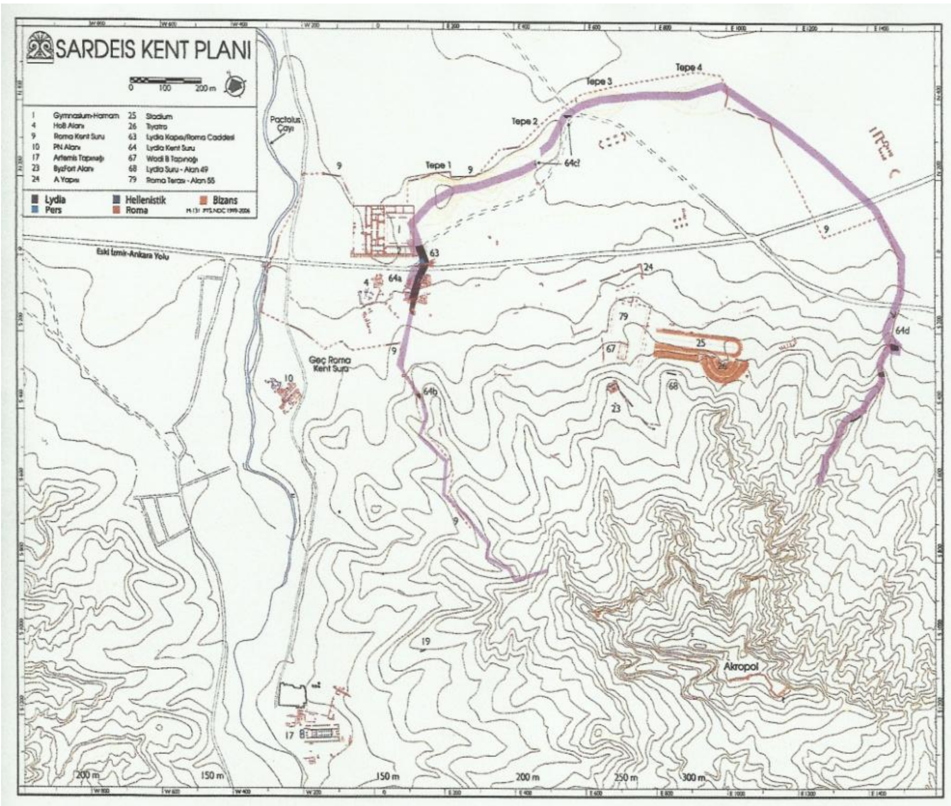


Figure 2.9 City plan of Sardeis

Figure 2.10 A view from gold production workshops which were settled by the shore of Paktolos River

After coin was invented by Lydians, coin minting was accumulated firstly in Ionia and gradually in all western part of Anatolia. Later coin minting was accumulated from western part of Anatolia to Greece. Lastly, coin minting was accessed to cities which were settled by Greek colonies in south parts of Italy and also in Sicily (Tekin, 2000).

First Greek silver coins were minted in South part of Italy in the second half of sixth century BCE. Coin minting from electrum was resigned in the middle of the sixth century BCE and coins were minted from silver (Tekin, 2000).

Types of coins and cities which were minting coin were reached a large diversity in Helenistic period. An unique example coin which was minted in Helenistic period is given in Figure 2.11 (http://www.mlahanas.de/Greeks/Alexander.htm).

Figure 2.11 An example of Greek Coin

Portrait of Herakles was engraved obverse side of this coin. Zeus who sitting on his throne was engraved reverse side of this coin. Those coins were minted in *drachmae* and *tetradrachmae.*

CHAPTER 3

MATERIALS AND METHODS

In this chapter, informations about the real and fake coins studied and the methods used in their investigation were presented in three sub-sections; materials, physical and chemical methods used in their analysis and statistical methodology.

3.1 Materials

In this study, twenty two real and eighteen fake coins which belong to Greek civilization and its two different periods were investigated. Some information about the coins studied are given in Table 3.1.

Table 3.1 The coins studied

Coin Type	Archaeological Information	Number of Coins
REAL COINS	Greek Attica Athens Tetradrachmae City Coin Middle of the fifth century BCE	6
	Greek Alexander the Great 323 – 336 BCE	16
FAKE COINS	Greek Attica Athens Tetradrachmae City Coin Middle of the fifth century BCE	8
	Greek Alexander the Great 323 – 336 BCE	10

All coins were taken from coin section of Museum of Anatolian Civilizations (MAC) (Ankara).

One group of real Greek coins were brought to museum as *confiscation* (Table 3.1) (Aydın personal communication in 18 March 2011). The other group of real Greek coins were found in different Gordion excavations (Aydın personal communication in 28 March 2011) (Table 3.1). Before studying samples were coded. Nomenclature of the coins (coding) was given as follow;

First capital letter shows whether the coin is real or fake. Real coins were demonstrated by capital R and fake coins were demonstrated by capital F. Second capital letter shows the civilization to which sample belongs. Greek is demonstrated by capital G. Following, Roman number is given to show period of the culture; I shows the first period (middle of the fifth century BCE), II shows fourth century BCE of Greek. Following, sample number is placed with hyphen. For example: RGI-1 shows real sample 1 coming from fifth century Greek. FGII-1 fake sample 1 coming from reign of Alexander the Great (323 – 336 BCE).

Description of the coins are given in Table 3.2.

Table 3.2 Description of the samples

Coin Type	Coding	Inventory Number	Information about the Origin of the Samples
Middle of the Fifth Century BCE			
Real	RGI-1	1476-103/11	Greek Middle of the fifth century BCE
	RGI-2	1476-103/12	
	RGI-3	1476-103/13	
	RGI-4	1476-103/15	
	RGI-5	1476-103/16	
	RGI-6	1476-103/17	
Fake	FGI-1	-	Confiscation
	FGI-2	-	
	FGI-3	-	
	FGI-4	-	
	FGI-5	-	
	FGI-6	-	
	FGI-7	-	
	FGI-8	-	
Reign of Alexander the Great (323 – 336 BCE)			
Real	RGII-1	Gor 3	Greek – Amphipolis from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-2	Gor 5	Greek – Amphipolis or Uronopolis from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-3	Gor 6	Greek – Amphipolis or Uronopolis – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-4	Gor 7	Greek – Amphipolis or Uronopolis – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-5	Gor 8	Greek – Unknown Macedonia – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-6	Gor 9	Greek – Sinop, Turkey – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-7	Gor 10	Greek – Unknown Anatolia Pontus? – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-8	Gor 11	Greek – Pergamon – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)

Table 3.2 continued

Real	RGII-9	Gor 13	Greek – Sigeum – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-10	Gor 14	Greek – Tenedos – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-11	Gor 15	Greek – Tenedos – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-12	Gor 16	Greek – Mytilene – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-13	Gor 17	Greek – Erythrae – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-14	Gor 18	Greek – Magnesia – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-15	Gor 19	Greek – Miletos – from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
	RGII-16	Gor 20	Greek – Miletos from different Gordion excavations Reign of Alexander the Great (323 – 336 BCE)
Fake	FGII-1	-	Confiscation
	FGII-2	-	
	FGII-3	-	
	FGII-4	-	
	FGII-5	-	
	FGII-6	-	
	FGII-7	-	
	FGII-8	-	
	FGII-9	-	
	FGII-10	-	

The coins were evaluated visually in order to find out whether the corrosion layers are present or not. Generally, the corrosion layer or patina was seen only on one side of the coin. If there is patina cleaning process was applied (Figures 3.1 – 3.2.) Cleaning of the patina was done by sweeping the surface of the coin with an ear bud.

Figure 3.1 Cleaning of the patina of a fake coin

Figure 3.2 Patina on the ear bud

Investigations of the coins have been carried out on the cleanest side of the coins. Photos of the coins were taken from both obverse and reverse sides using KODAK C182 digital photo camera. Some photos were taken by photographer of MAC. Some of the photographs of coins were taken from the database of MAC. Photographs of all coins studied are given as follow;

Figure 3.3 RGI-1

Figure 3.4 RGI-2

Figure 3.5 RGI-3

Figure 3.6 RGI-4

Figure 3.7 RGI-5

Figure 3.8 RGI-6

Figure 3.9 FGI-1

Figure 3.10 FGI-2

Figure 3.11 FGI-3

Figure 3.12 FGI-4

Figure 3.13 FGI-5

Figure 3.14 FGI-6

Figure 3.15 FGI-7

Figure 3.16 FGI-8

Figure 3.17 RGII-1

Figure 3.18 RGII-2

Figure 3.19 RGII-3

Figure 3.20 RGII-4

Figure 3.21 RGII-5

Figure 3.22 RGII-6

Figure 3.23 RGII-7

Figure 3.24 RGII-8

Figure 3.25 RGII-9

Figure 3.26 RGII-10

Figure 3.27 RGII-11

Figure 3.28 RGII-12

Figure 3.29 RGII-13

Figure 3.30 RGII-14

Figure 3.31 RGII-15

Figure 3.32 RGII-16

Figure 3.33 FGII-1

Figure 3.34 FGII-2

Figure 3.35FGII-3

Figure 3.36 FGII-4

Figure 3.37 FGII-5

Figure 3.38 FGII-6

Figure 3.39 FGII-7

Figure 3.40 FGII-8

Figure 3.41 FGII-9

Figure 3.42 FGII-10

3.2 Methods

In the study, physical and chemical properties of the coins were determined. As physical properties, weights and diameters of the coins were measured. In the weight determination of the coins analytical balance of PRECISSA 310c was used. The sensitivity of the balance is 0.1 mg. In the measuring of diameters of the coins metal calper rule was used (Figure 3.43) (Photo was taken by İçten Tansel in March 2011 at MAC). The minimum scale of the calper rule is 1 mm.

Figure 3.43 Metal calper rule

As chemical property of the samples element composition was determined. Elemental compositions of the coins which do not have corrosion or patina but have icon (in most of the cases) were determined by using wavelength-dispersive portable X - ray fluorescence spectrometry. In this study, coins that were analyzed from their obverse side were investigated. The instrument used was Innov - X Omega portable X – ray fluorescence spectrometer (PXRF) (Figure 3.44 - 3.46) (All photos were taken by İçten Tansel in March 2011 at Restoratoration and Conservation Laboratory of MAC.). Detector of the spectrometer is an ultra high resolution Silicon Drift Detector (<165 eV resolution). In the instrument X-ray tube is used as excitation source (Ag anode 10 - 40 keV, 5 - 100 μA, up to 5 filter positions). In the analysis thirty second analysis mode was chosen (Aydın, personal communication).

Figure 3.44 Spectrometer

Figure 3.45 Sample Holder

Figure 3.46 Screen

In XRF spectrometry, high-energy X-ray *photons* (wavelength in the range of 0.01 - 10 nm) are emitted from a source (X-ray tube) and strike the sample. The photons have enough energy to knock electrons out of the innermost orbital of atoms in the sample (Figure 3.47) (http://www.olympus-ims.com/en/knowledge/#/).

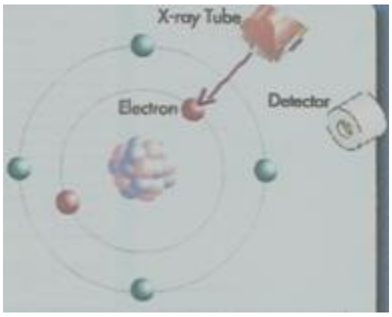


Figure 3.47 Process of XRF analysis (First Step)

When this occurs, the atoms become ions, which are unstable (Figure 3.48) (http://www.olympus-ims.com/en/knowledge/#/).

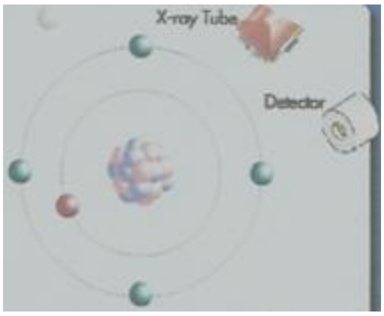


Figure 3.48 Process of XRF analysis (Second Step)

Normally, electrons try to get stability and have the lowest energy state possible. Then, a more energetic electron from an outer orbital will move into the newly vacant space in the inner orbital (Figure 3.49) (http://www.olympus- ims.com/en /knowledge/#/).

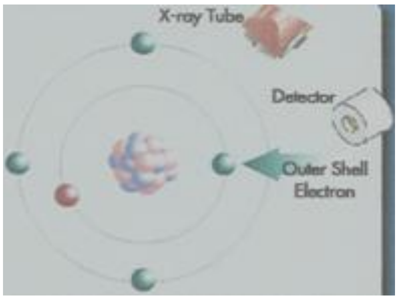


Figure 3.49 Process of XRF analysis (Third Step)

Electrons in outer shells have more energy than in inner orbitals. They need to release this excess energy as they drop down to fill the vacancy in the inner shell. This released energy is given off as a photon which can be detected by an X-ray detector. The energy emitted is equal to the difference in energies between two orbitals and is characteristic of the element *fluorescing* (Figure 3.50) (http://www.olympus- ims.com/en /knowledge/#/).

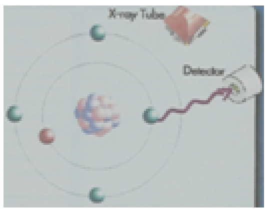


Figure 3.50 Process of XRF analysis (Fourth Step)

There are two types of XRF spectrometers; one of them is wavelength dispersive and the other one is energy dispersive. Layout of a wavelength-dispersive XRF spectrometer and layout of a portable XRFspectrometer are given in Figure 3.51 and Figure 3.52 (Ferretti;2000).

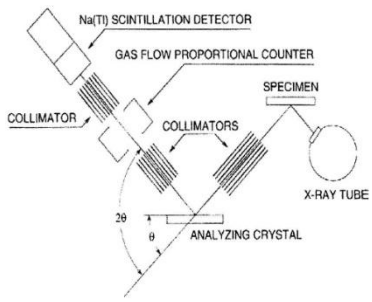


Figure 3.51 Layout of a wavelength-dispersive XRF spectrometer

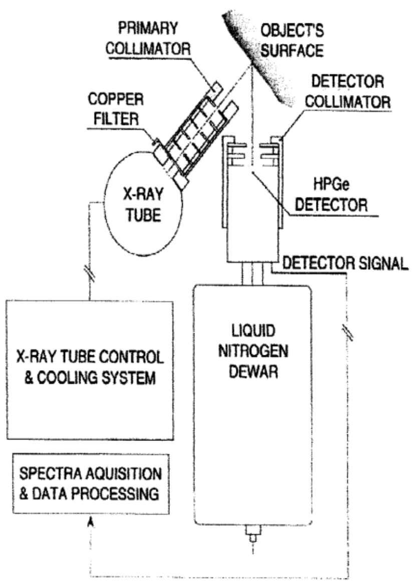


Figure 3.52 Layout of a portable XRFspectrometer using X-ray tube as excitation source

In XRF method, the elements with atomic number 16 (Sulphur) to atomic number 92 (Uranium) can be determined. The instrument can determine twenty-six elements in *analytical mode* which are Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Nb, Mo, Rh, Pd, Ag, Sn, Sb, Hf, Ta, W, Re, Ir, Pt, Au, Pb, Bi. Minimum and maximum detection limits of the elements are given in Table 3.3 (Aydın and Mutlu;2012).

Table 3.3 Detected elements in analytical mode and minimum – maximum detection limits of the elements

Elements	Detection Limits
Titanyum (Ti)	10–100 ppm
Vanadium (V)	10–100 ppm
Chromium (Cr)	10–100 ppm
Mangan (Mn)	10–100 ppm
Iron (Fe)	10–100 ppm
Cobalt (Co)	10–100 ppm
Nicel (Ni)	10–100 ppm
Copper (Cu)	10–100 ppm
Zinc (Zn)	10–100 ppm
Zirconium (Zr)	10–100 ppm
Niobium (Nb)	10–100 ppm
Molybdenum (Mo)	10–100 ppm
Rhodium (Rh)	50–150 ppm
Palladium (Pd)	50–150 ppm
Silver (Ag)	50–150 ppm
Tin (Sn)	50–150 ppm
Antimony (Sb)	50–150 ppm
Hafnium (Hf)	10–100 ppm
Tantalum (Ta)	10–100 ppm
Tungsten (W)	10–100 ppm
Rhenium (Re)	10–100 ppm
Iridium (Ir)	10–100 ppm
Platinum (Pt)	10–100 ppm
Gold (Au)	10–100 ppm
Lead (Pb)	10–100 ppm
Bismuth (Bi)	10–100 ppm

Before starting analysis of the coins, PXRF spectrometer was standardized. Standardization of the spectrometer was done by using stainless steel 316 calibration reference coin. Chemical composition of 316 stainless steel is given in Table 3.4 (http://www.azom.com/article.aspx?ArticleID=2868#_Chemical_ Composition).

Table 3.4 Chemical composition of stainless steel 316 (%)

%	
C	0 – 0.08
Mn	0 – 2
Si	0 - 1
P	0 - 0.05
S	0 - 0.02
Cr	16.5 - 18.5
Mo	2 – 2.5
Ni	10 - 13
Ti	-
Fe	balance

In the analysis samples were fixed onto the sample holder of the spectrometer (Figure 3.45). There is not any sample preparation step. All coins were analysed directly. According to the quantity, the elements can be classified into three types; major (>2 % by weight), minor (2 – 0.1 % by weight) and trace elements (< 0.1 % by weight).

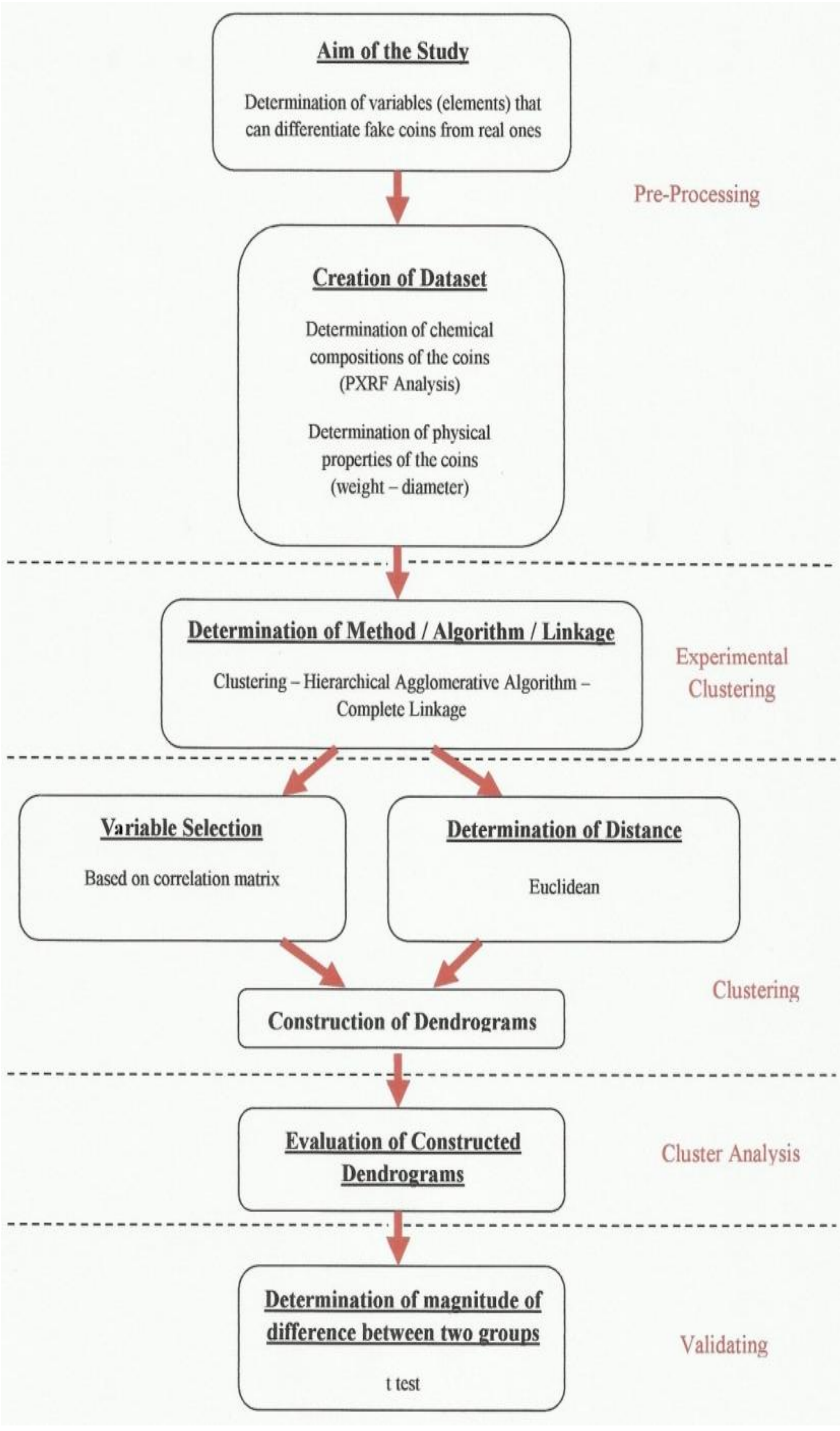
3.3 Statistical Methods

In this thesis it is compulsory to use multivariate statistical methods because every coin was analysed in terms of more than one variable. Thus, multiple variables were used in the analysis of the coins. Statistical literature has various multivariate methods in which multiple variables are analyzed simultaneously taking the relationship among them into account. The methods we consider here are correlation analysis, cluster analysis and dendogram representation, and finally two sample t-test. Correlation analysis is carried out in order to determine the most related elements which can constitute chemical compositions of the coins. Cluster analysis is used to determine the elements that can differentiate the fake and real coins. Dendograms are used to visualize the results which were obtained from cluster analysis. Lastly, t-test is applied to determine the statistical difference between the clusters.

For the statistical computations, two different statistical programs were used. In constructing dendrograms and calculating averages or ratios of them R 2.14.0 software package was used. R 2.14.0 is a software package which can be downloaded easily from the Internet (http://cran.r-project.org/). R 2.14.0 was chosen because it was more convenient than SPSS in processing compositional data. On the other hand, SPSS 16.0 was used for correlation analyses and t tests of this study.

Shematic presentation of the methodology is shown below in Table 3.5.

Table 3.5 Stages of Cluster Analysis for this study



3.3.1 Correlation Analysis

Correlation is a technique which determines the relation between two or more variables. Correlation coefficent, *r*, is used efficiently in order to represent relation(s) between variables (Tekin;2009).

It is possible to measure the strength of the relationship between two variables by applying correlation coefficient. Correlation coefficient is a measure of linear or straight line correlation (Shennan;1997).

The value of *r* changes between -1(or -100) and +1 (or +100) (Tekin;2009). If this coefficent is close to +1 (or +100), there is a perfect positive correlation between two variables. In positive correlation, two variables either increase or decrease at the same time. If there is a high and positive correlation between two variables, one of the two will be used for clustering the samples. On the other hand, negative correlation (coefficient is close to -1 (or – 100) indicates that one of the two varibles increases (or decreases) and other one decreases (or increases) (Kalaycı;2010).

Correlation analysis is carried out in this thesis to determine the most related elements which constitute the chemical composition of the coins. From chemical point of view, 50% correlation was considered in the context of interest. The most significant correlations were observed between Ag and Cu elements (high and negative) in all the coins which belong to two different periods of a civilization. The results of the correlation analysis provide input for cluster analysis. The following strategy is proposed in this thesis for forming the clusters for forgery analysis:

- If there is high and negative ($r \geq -0.50$) correlation between the two elements (e.g. r = -0.97), use both of them for forming the clusters.
- If there is high and positive ($r \geq 0.50$) correlation between the two elements (e.g. 0.60), use one of them for forming the clusters.

This is the strategy used in section 3.3.2

Correlation matrices are given in Table 3.6 – 3.7.

Table 3.6 Correlation matrix of Greek coins which were dated back to middle of the fifth century BCE

Table 3.7 Correlation matrix of Greek coins which were dated back to reign of Alexander the Great (323 - 336 BCE)

3.3.2 Cluster Analysis for the Purpose of Forgery Determination

Cluster Analysis is a multivariate statistical method which is used for grouping the subjects in terms of their similarities. In this thesis, it is used to determine the main components that differentiate fake coins from the real ones (i.e. for forgery determination). The cluster analysis consists of two major stages: Clustering the objects based on certain mathematical/statistical algorithms and constructing dendograms that graphically represent the resulting groups (clusters). In this thesis, cluster analysis of compositional data is used since chemical data are compositional data. The following parts explain the properties of compositional data, clustering methodology in a general sense and its application in this thesis, and construction of dendograms respectively.

Compositional Data

In this study, dataset consists of diameter, weight and chemical composition of the coins. The proportion of each component add up to 1 (or 100 in percentages). Such data are called compositional data. In this thesis, first four main components are taken as the basic elements of the coins. These are silver, copper, iron and lead and constitute subcompositional data.

Prior to cluster analysis, the compositional data are transformed to a log-ratio scale. Transforming compositional data into log-ratio scale provides the comparison of the coins based on their element ratios. An example for log ratio transformation is given in Table 3.8.

Table 3.8 Log ratio transformation

Coin	Ag / Cu	Ag / Pb	Cu / Pb
1	log (Ag_1 / Cu_1)	log (Ag_1 / Pb_1)	log (Cu_1 / Pb_1)
2	log (Ag_2 / Cu_2)	log (Ag_2 / Pb_2)	log (Cu_2 / Pb_2)
3	log (Ag_3 / Cu_3)	log (Ag_3 / Pb_3)	log (Cu_3 / Pb_3)

In Table 3.8, three coins are used for illustration purpose. Log ratio transformation was applied on Ag, Cu and Pb. For example; in the first column, the ratio of the Ag (silver) value of the coin and its Cu (copper) value is obtained and transformed to the logarithmic scale. Those two mentioned steps were applied to other columns and relations. This enables us to compare the coins based on element ratios.

Clustering Methodology

Grouping is the major goal of the method. Grouping is based on the major properties of the samples. Cluster Analysis is done by choosing a grouping *algorithm*.

Hierarchical clustering algorithm was preferred in this study because of its certain advantages. For instance we are not required to prespecify the number of clusters. Hierarchical clustering groups data. Grouping of the data in hierarchical clustering was done by grouping data with a sequence of nested partitions. Hierarchical clustering does this grouping from singleton clusters to a cluster including all individuals or vice versa (Xu and Wunsch;2009).

There are two types of hierarchical clustering algorithm. These are agglomerative and divisive hierarchical algorithms. In this study hierarchical agglomerative method was used. The first step of an agglomerative algorithm considers $n(n-1)/2$ possible combinations of observations to find the closest pair where n is the number of observations in the data set. This number grows quadratically with n.

As mentioned above hierarchical agglomerative method first gathers all the data into a single group and then groups the objects so that similar ones are gathered into the same group whereas dissimilar ones fall into separate groups. In this study, agglomerative method provided better detection of fake coins beside real ones compared to other clustering methods.

In this study, complete linkage method is used in order to find the similar clusters. Similarities/ dissimilarities are determined based on the distances between the objects. Complete linkage produces spatially compact clusters.

In this study, the distance is calculated by using Eucledian distance formula. A data set with (n) objects, each of which is described by (d) attributes, is denoted by $D=\{x_1,x_2,\ldots,x_n\}$, where $x_i=(x_{i1},x_{i2},...,x_{id})^T$ is a vector denoting the i th object and x_{ij} is a scalar denoting the j th component or attribute of x_i. The number of attributes (d) is also called the dimensionality of the data set. Consider the two data points $x=(x_1,x_2,\ldots,x_d)^T$ and $y=(y_1,y_2,\ldots,y_d)^T$.

In calculating Euclidean distance following formula is used;

$$d(x,y) = \left[\sum_{j=1}^{d}(x_j - y_j)^2\right]^{1/2}$$

Except Euclidean distance, there are some other distance measures. Besides, Euclidean distance formulas of other distances measures were presented as follows:

- Manhattan Distance

$$d_{man}(x,y) = \sum_{j=1}^{d}|x_j - y_j|$$

- Maximum Distance

$$d_{max}(x,y) = max_{1\leq k\leq d}|x_j - y_j|$$

- Minkowski Distance

$$d_{mink}(x,y) = \left[\sum_{j=1}^{d}|x_j - y_j|^r\right]^{\frac{1}{r}}, r \geq 1$$

(r) is called the order of the Minkowski distance.

- Mahalanobis Distance

$$d_{mah}(x,y) = (x-y)\Sigma^{-1}(\mathrm{x}-\mathrm{y})^{\mathrm{T}}$$

- Average Distance

$$d_{ave}(x,y) = (1/d)\left[\sum_{j=1}^{d}(x_j - y_j)^2\right]^{1/2}$$

Euclidean distance can be used as a measure of dissimilarity and can be used with various kinds of variables. Euclidean distance is more convenient to use when the variables are real measurements (Drennan;2009). For instance; the distance between a coin that consists of (Ag, Pb, Cu, Fe) = (97.51, 0.63, 0.90, 0.50) and a coin that has (Ag, Pb, Cu, Fe) = (97.10. 0.54. 1.38. 0.49) is $[(97.51 - 97.10)^2 + (0.63 - 0.54)^2 + (0.90 – 1.38)^2 + (0.50 – 0.49)^2]^{1/2} = 0.20$.

In this study, the clustering methodology described above was used in two different ways to group the coins into different clusters based on their element contents.

Way 1

The groups are constructed based on element ratios. This method takes the compositional property into account. The ratio of the elements for which all the fake coins are grouped into one cluster and real ones into another is determined to be a discriminator that can be used in a forgery analysis.

Way 2

The groups are constructed based on individual element contents. This method ignores the compositional nature of the elemental data. When the data set consists of compositional data. Way 1 is more efficient approach than Way 2. The reason for considering Way 2 in the thesis is to examine the differences between the two approaches.

Dendogram (Tree Graph)

Dendogram is a scheme used in the visual representation of the groups. An example dendogram was given in Figure 3.53 (http://www.mathworks.com/help /toolbox/stats/dendrogram.html). Those groups were determined by using cluster analysis.

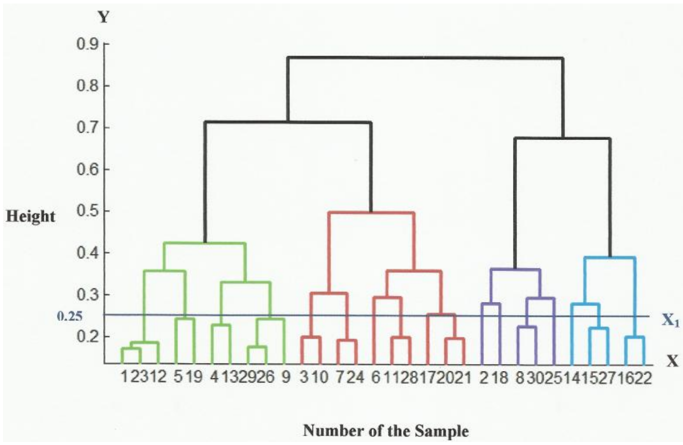


Figure 3.53 An example dendogram

Evaluation of the dendogram (Figure 3.53) is given as follow;

- The root node of the dendogram (x axis) represents the dataset. Each leaf node is regarded as a data point. For instance; three samples (1, 12 and 23) were collected in the first leaf of this constructed dendogram. The height of the dendogram usually expresses the distance between each pair of data points or clusters, or a data point and a cluster. Height (distance) of this dendogram is determined as 0.25. Dendogram was cut from drawing a horizontal line ($X_{1)}$ parallel to x axis.
- Investigated thirty samples are collected in seventeen groups when we consider height value as 0.25. This dendogram can be cut from different height values (distance values) subjectively.
- Three samples (1, 12 and 23) are collected in one group. Two samples (5 and 19) are collected in a second group. Other two samples (4 and 13) are collected in a third group. Other three samples (9, 26 and 29) are collected in a fourth group. Other two samples (3 and 10) are collected in a fifth group. Other two samples (7 and 24) are collected in a sixth group. One sample (6) is collected in a seventh group. Other two samples (11 and 28) are collected in an eigth group. Other one sample (17) is collected in a ninth group. Other two samples (20 and 21) are collected in a tenth group. Other one sample (8) is collected in an eleventh group. Other one sample (18) is collected in a twelfth group. Other two samples (8 and 30) are collected in a thirteenth

group. Other one sample (25) is collected in a fourteenth group. Other one sample (14) is collected in a fifteenth group. Other two samples (15 and 27) are collected in a sixteenth group. Other two samples (16 and 22) are collected in a seventeenth group.

- Subgroup relations are observed in the groups. Subgroup relations in the groups are given as follow;

    1. Two subgroup relations are observed in first group. First subgroup relation is observed between two samples (1 and 23). Second subgroup relation is observed between three samples (1, 23 and 12) in the group.
    2. Other two subgroup relations are observed in fourth group. First subgroup relation is observed between two samples (26 and 29). Second subgroup relation is observed between three samples (26, 29 and 9) in the group.

- Using a smaller distance (namely X_1 in the figure) increases the number of groups and may provide more detailed grouping scheme.

In this thesis, dendograms are used to provide visual aid for determining the discriminatory element ratios for authenticity of the coins.

3.3.3 t-test

In our study, t-test is used to determine the significance of the difference between the average of a group of fake coins and a group of real coins.

There are two types of t-tests. One of them is *dependent samples t-test* and the other one is *independent samples t-test*. For instance; academic success difference between midterm and final results of a group of university students can be calculated by using dependent samples t-test. However, in this study the magnitude of the difference between real and fake coins were compared. Real and fake coins are example to independent samples so independent samples t-test was used in this study.

t-test was done by using SPSS 16.0 software package. SPSS uses two screen simultaneously. Necessary adjustments were done on variable view and then data which were obtained via XRF analysis were entered to the data view. Steps which were written above were followed in order to realize t-test in SPSS 16.0;

- Click **Analyze** from toolbar.
- From **Analyze** click **Compare Means** and **Independent-Samples t test** respectively.
- From opened screen move your variables to **test variable column** by using button which arrow on it then click **Define Groups** button in order to determine the groups (In this study, this grouping was done by labeling real coins with zero and fake coins with one). Click **Continue** to close this small screen.
- Click **OK**. Later following type of results will be appeared on the screen.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, results of the physical and chemical examinations of the coins (4.1.1 – 4.1.2) and the results of the statistical analyses (4.2) are presented.

4.1 Results of the Physical and Chemical Examinations of the Coins

In this study, forty Greek coins were investigated. Fourteen (six real and eight fake coins) of forty Greek coins were dated back to middle of the fifth century BCE. Remaining twenty six (sixteen real and ten fake) Greek coins were dated back to reign of Alexander the Great 323 – 336 BCE.

Physical properties (weights and diameters) and chemical compositions of those coins were given in Table 4.1 - 4.2.

Table 4.1 Data obtained from Greek coins which were dated back to middle of the fifth century BCE

[a] **Wt :** Weight (g)

[b] **Dia :** Diameter (cm)

Table 4.2 Data obtained from Greek coins which were dated back to reign of Alexander the Great (323 – 336 BCE)

[a] **Wt :** Weight (g)

[b] **Dia :** Diameter (cm)

4.1.1 Results of the Physical Examinations of the Coins

4.1.1.1 Physical Properties of the Greek Coins Which Were Dated Back to Middle of the Fifth Century BCE

Weights of six real coins were changing in the range 16.73 g - 17.16 g (average being 17.0133). Diameters of those coins were changing in the range 2.4 cm - 2.5 cm (average being 2.483) (Table 4.1). Six real coins can be collected in one group according to their weights and diameters (Table 4.1).

Weights of eight fake coins were changing in the range 12.39 g - 15.77 g (average being 14.57). Diameters of those coins were changing in the range 2.3 cm - 2.6 cm (average being 2.4) (Table 4.1). Eight fake coins can be collected in two different groups according to their weights. Weights of fake coins that were collected in the first group were changing in the range 12.39 g - 14.88 g (average being 14.2) (Table 4.1). Weights of fake coins that were collected in the second group were changing in the range 15.57 g - 15.77 g (average being 15.67) (Table 4.1). The difference in weight may come from difference in amount of Cu as Table 4.1 shown. Eight fake coins were collected in one group according to their diameters (Table 4.1).

Weights of fourteen coins (six real and eight fake coins) were changing in the range 12.39 g - 17.16 g (average being 15.61) (Table 4.1). Fourteen coins were collected in two different groups according to their weights (Table 4.1). Weights of the coins that were collected in the first group were changing in the range 15.57 g - 17.16 g (average being 16.67) (Table 4.1). Weights of the coins that were collected in the second group were changing in the range 12.39 g - 14.88 g (average being 14.2) (Table 4.1). The difference in weight may come from difference in percent of Ag as Table 4.1 shown. Ag values and also Ag average of the real coins were above 95 % (as fraction 0.95). Diameters of fourteen coins were changing in the range 2.3 cm - 2.6 cm (average being 2.43) (Table 4.1). Fourteen coins were collected in one group according to their diameters (Table 4.1). Therefore, there is no significant difference between diameters of real and fake coins so diameter is not used in statistical evaluation.

4.1.1.2 Physical Properties of the Greek Coins Which Were Dated Back to Reign of Alexander the Great (323 – 336 BCE)

Weights of sixteen real coins were changing in the range 14.14 g - 16.86 g (average being 16.0225). Diameters of those real coins were changing in the range 2.5 cm - 3.2 cm (average being 2.875) (Table 4.2). Sixteen real coins were collected in two different groups according to their weights and in one group according to their diameters. Weights of the coins that were collected in the first group were changing in the range 15.39 g to 16.86 (average being 16.14). Remaining one coin was collected in the second group and its weight was 14.14 g. The difference in weight may come from difference in Pb percentage as Table 4.2 shows. There is no significant difference between diameters of real coins.

Weights of ten fake coins were changing in the range 16.65 g to 17.04 g (average being 16.85). Diameters of fake coins were changing in the range 2.6 cm - 2.8 cm (average being 2.7) (Table 4.2). Ten fake coins were collected in one group according to their weights and diameters. There is no significant difference between weights and diameters of fake coins.

Weights of twenty six coins (sixteen real and ten fake) were changing in the range 14.14 g - 17.04 g (average being 16.34). Twenty six coins were collected in two different groups according to their weights. Weights of the twenty five coins that were collected in one group were changing in the range 15.39 g - 17.04 g (average being 16.42) (Table 4.2). Weight of remaining one coin that was collected in a second group is 14.14 g (Table 4.2). The difference in weigh may come from difference in Pb percentage as Table 4.2 shows. Diameters of those coins were changing in the range 2.5 cm to 3.2 cm (average being 2.69). Those coins were collected in one group according to their diameters (Table 4.2).

4.1.2 Results of the Chemical Examinations of the Coins

4.1.2.1 Chemical Examinations of the Greek Coins Which Were Dated Back to Middle of the Fifth Century BCE

XRF results showed that Ag (silver) is the major (first) element, changing in the range 88.55 % - 98.13 % (average being 93.92 %) (Table 4.2). Cu (copper) is the second element, changing in the range 0.63 % - 10.31 % (average being 4.23 %) (Table 4.1). Fe (iron) is the third element, changing in the range 0.005 % - 1.52 % (average being 0.64 %) (Table 4.1). Pb (lead) is the fourth element, changing in the range 0.021 % - 2.36 % (average being 0.53 %) (Table 4.1).

Silver values of six real coins were changing in the range 95.55 % - 98.13 % (average being 96.975 %), copper values of those coins were changing in the 0.63 % - 1.44 % (average being 1.10), iron values were changing in the range 0.13 % - 0.54 % (average being 0.41) and their lead values were changing in the range 0.36 % - 2.36 % (average being 1.09) (Table 4.1).

Silver values of eight fake coins were changing in the range 88.55 % - 98.13 % (average being 91.63 %). Copper values of those coins were changing in the range 3.40 % - 10.31 % (average being 6.58 %). Iron values of those coins were changing in the range 0.28 % - 1.52 % (average being 0.88 %). Lead values of them were changing in the range 0.021 % - 0.37 (average being 0.11 %) (Table 4.1).

Eight fake coins were collected in two different groups according to their silver values (Table 4.1). One fake coin was collected in one group and its silver value was 88.55 % (Table 4.1). Silver values of fake coins that were collected in the second group were changing in the range 90.04 % - 94.45 % (average being 92.07 %) (Table 4.1). The difference in Ag percentage may come from difference in Cu percentage as Table 4.1 shows. Forgers implemented a decrease in Ag percent by increasing Cu percent in order to harden the coin and economic reasons because Cu is less expensive than Ag (Tripathy et al. 2009).

Eight fake coins were collected in three different groups according to their copper values (Table 4.1). Copper values of fake coins collected in first group were changing in the range 3.40 % - 3.76 % (average being 3.58 %) (Table 4.1). Copper values of those coins collected in second group were changing in the range 5.98 - 8.41 % (average being 7.03 %) (Table 4.1). One fake coin was collected in third group and its copper value was 10.31 % (Table 4.1). The difference in Cu percentage may come from difference in Ag percentage as Table 4.1 shows. Actually when Ag percentages were increased Cu percentages were decreased in the compositions of the coins. Ag is more expensive than Cu. Preferring Ag in production indicates that the fineness of the coin will be higher even it will be a fake coin. Higher fineness of the coin makes detection of the fake coin more difficult.

Eight fake coins were collected in one group according to their iron values (Table 4.1). Iron values of fake coins collected in one group were changing in the range 0.28 % - 1.52 % (average being 0.88 %) (Table 4.1).

Eight fake coins were collected in two different groups according to their lead values (Table 4.1). Lead values of fake coins collected in first group were changing in the range 0.021 % - 0.057 % (average being 0.04 %) (Table 4.1). Lead values of fake coins collected in second group were changing in the range 0.15 % - 0.37 % (average being 0.22) (Table 4.1).

Fourteen coins (six real and eight fake coins) were collected in three different groups according to their silver values (Table 4.1). Silver values of the first group were changing in the range 95.55 % - 98.13 % (average being 96.975 %) (Table 4.1). Silver values of the second group were changing in the range 90.04 % - 94.45 % (average being 92.07 %) (Table 4.1). A coin in the third group has silver value of 88.55 % (Table 4.1). The third group coin seems to be fake. The difference in Ag percentage may come from difference in Cu percentage as Table 4.1 shows.

Fourteen coins were collected in three different groups according to their copper values (Table 4.1). Copper values of the coins collected in first group were changing in the range 0.63 % - 3.76 % (average being 1.72 %) (Table 4.1). Copper values of the coins collected in the second group were changing in the range 5.98 % - 8.41 % (average being 7.03 %) (Table 4.1). A coin was collected in the third group and its copper value was 10.31 % (Table 4.1). The difference in Cu percentage may come from difference in Fe percentage as Table 4.1 shows.

Fourteen coins were collected in two different groups according to their iron values (Table 4.1). Iron values of the coins that were collected in one group were changing in the range 0.13 % - 1.52 % (average being 0.69 %) (Table 4.1). A coin was collected in the second group and its iron value was 0.0050 % (Table 4.1). The difference in Fe percentage may come from difference in Pb percentage as Table 4.1 shows.

Fourteen coins were collected in two different groups according to their lead values (Table 4.1). Lead values of the coins collected in one group were changing in the range 0.15 % - 2.36 % (average being 0.58 %) (Table 4.1). Lead values of the coins in second group were changing in the range 0.057 % - 0.021 % (average being 0.04 %) (Tablo 4.1). The difference in Pb percentage may come from difference in Pb percentage as Table 4.1 shows.

There is a high and negative correlation (-97.3) between silver and copper values (Table 3.5).

4.1.2.2 Chemical Examinations of the Greek Coins Which Were Dated Back to Reign of Alexander the Great (323 – 336 BCE)

XRF results showed that Ag (silver) is the major (first) element, changing in the range 95.44 % - 99.34 % (average being 98.19 %). Cu (copper) is the second element, changing in the range 0.0010 % - 3.29 % (average being 1.12 %). Pb (lead) is the third element, changing in the range 0.017 % - 0.93 % (average being 0.30 %). Fe (iron) is the fourth element, changing in the range 0.0010 % - 0.71 % (average being 0.14 %) (Table 4.2).

Silver values of sixteen real coins were changing in the range 98.33 % - 99.34 % (average being 98.97 %). Copper values of those coins were changing in the range 0.0010 % - 1.12 % (average being 0.38 %). Lead values of those coins were changing in the range 0.11% - 0.93 % (average being 0.47 %) and iron values of them were changing in the range 0.0010 % - 0.14 % (average being 0.04 %) (Table 4.2).

Silver values of ten fake coins were changing in the range 95.44 % - 97.74 % (average being 96.93 %). Their copper values were changing in the range 1.75 % - 3.29 % (average being 2.31 %). Lead values of those coins were changing in the range 0.053 % - 0.017 % (average being 0.03 %) and their iron values were changing in the range 0.078 % - 0.71 % (average being 0.30 %) (Table 4.2).

Twenty six coins (sixteen real and ten fake coins) were collected in one group according to their silver values (Table 4.2). Silver values of coins collected in one group were changing in the range 95.44 % - 99.34 % (average being 98.19 %) (Table 4.2).

Twenty six coins were collected in five diffferent groups according to their copper values (Table 4.2). Eleven coins were collected in one group and their copper values were changing in the range 1.12 % - 3.29 % (average being 2.21 %). Five coins were collected in a second group and their copper values were changing in the range 0.50 % - 0.79 % (average being 0.68 %). Eight coins were collected in the third group and their copper values were changing in the range 0.12 % - 0.32 % (average being 0.1875 %). One coin was collected in the fourth group and its copper value was 0.090 %. This coin has almost the highest Ag value. It contains 99.30 % Ag. Remaining one coin was collected in fifth group and its copper value was 0.0010 %. This coin has the highest Ag value (99.34 %) (Table 4.2).

Twenty six coins were collected in four different groups according to their lead values (Table 4.2). Seven coins were collected in the first group and their lead values were changing in the range 0.50 % - 0.93 % (average being 0.67 %). Nine coins were collected in a second group and their lead values were changing in the range 0.11 % - 0.49 % (average being 0.31 %). One coin was collected in the third group and its lead value was 0.053 %. Other nine coins were collected in the fourth group and their lead values were changing in the range 0.017 % - 0.050 % (average being 0.03 %) (Table 4.2). The difference in Pb percentage may come from difference in Fe percentage as Table 4.2 shows.

Twenty six coins were collected in four different groups according to their iron values (Table 4.2). Two coins were collected in the first group and their iron values were changing in the range 0.67 % - 0.71 % (average being 0.69 %). Ten coins were collected in a second group and their iron values were changing in the range 0.10 % - 0.45 % (average being 0.19 %). Seven coins were collected in third group and their iron values were changing in the range 0.051 % - 0.079 (average being 0.06 %). Remaining seven coins were collected in fourth group and iron value of each coin was 0.0010 % (Table 4.2). The difference in Fe percentage may come from difference in Pb percentage as Table 4.2 shows.

There is a high and negative correlation (- 93.1) between silver and copper values (Table 3.6).

4.2 Results of the Statistical Analyses

In the statistical evaluation the steps given below were followed;

Firstly, dendrograms were constructed. In the construction of dendrograms amounts of elements were used. In general, physical parameters (weights and diameters of the coins) were not used because weights and diameters of the coins can be imitated easily. Elemental compositions of the coins provide compositional data. For clustering and constructing the dendrograms the statistical software R 2.14.0 was used. R 2.14.0 was found to be more convenient than SPSS to investigate materials that have compositional data (see Section 3.3 in page 28). Compositional data values were turned into fractions because of the necessity of the program. In constructing dendrograms, main elements of the coins were used. The main elements are Ag, Cu, Fe and Pb for investigated coins (Table 4.1 - 4.2). Clustering of the coins were carried out in two different ways for each pair of elements; former one is based on the distance between the element ratios and the latter one is based on the distance between the individual elements. For instance; considering grouping the coins based on Ag and Cu elements, coins are grouped based on their Ag / Cu ratios and also based on Ag and Cu values individually and simultaneously. The first method takes the account for compositional data whereas the second one ignores the compositional data.

Accordingly, pairs for first group of Greek coins (dated back to middle of the fifth century BCE) were Ag and Cu (*r* = -0.973), Ag and Fe (*r* = -0.44), Ag and Pb (*r* = 0.426), Cu and Fe (*r* = 0.322), Cu and Pb (*r* = 0.533) and lastly Pb and Fe (r = -0.415). The pairs for second group of Greek coins (dated back to reign of Alexander the Great (323 – 336 BCE)) were also constructed from same elements and their *r* values were given as follow; Ag and Cu (*r* = -0.931), Ag and Fe (*r* = -0.71), Ag and Pb (*r* = 0.628), Cu and Fe (*r* =0.56), Cu and Pb (*r* = -0.787) and lastly Pb and Fe (*r* = -0.518).

The correlation rule was not really applied to some pairs such as Ag and Pb (*r* = 0.426) and Cu and Fe (*r* = 0.322) and yet they are included in the analyses as pairs since they are the major components.

To read the groups in the dendograms:

This is explained with an example. For instance; if fake coins are separated into two different groups, the groups from left to right of the dendogram are referred as first and second group respectively. Similar referencing is used for the real coins as well.

In this section, the percentages of the elements are presented in decimals.

4.2.1 Greek Coins Which Were Dated Back to Middle of the Fifth Century BCE

4.2.1.1 RESULTS OF CLUSTER ANALYSIS

Ag / Cu Ratio

As seen in Fig 4.1 Ag / Cu ratio completely differentiated fake coins from the real ones; six real coins (1 - 6) were collected in two different groups. Eight fake coins (7 - 14) were collected in three different groups.

The real coins (2, 5 and 6) were collected in the first group. Silver values were changing in the range 0.9619 - 0.9737 (average being 0.9688). Copper values were changing in the range 0.137 - 0.144 (average being 0.0139).

Other real coins (1, 3 and 4) were collected in the second group. Silver values were changing in the range 0.9555 - 0.9813 (average being 0.9706). Copper values were changing in the range 0.0063 - 0.0093 (average being 0.0082).

The fake coins (13 and 14) were collected in the first group. Silver values were changing in the range 0.9313 - 0.9445 (average being 0.9379). Copper values were changing in the range 0.034 - 0.0376 (average being 0.0358).

Other fake coins (7, 9 and 11) were collected in the second group. Silver values were changing in the range 0.9144 - 0.9309 (average being 0.9219). Copper values were changing in the range 0.0598 - 0.0683 (average being 0.0633).

Another fake coins (8, 10 and 12) were collected in the third group. Silver values were changing in the range 0.8855 - 0.903 (average being 0.8963). Copper values were changing in the range 0.0777 - 0.1031 (average being 0.0883).

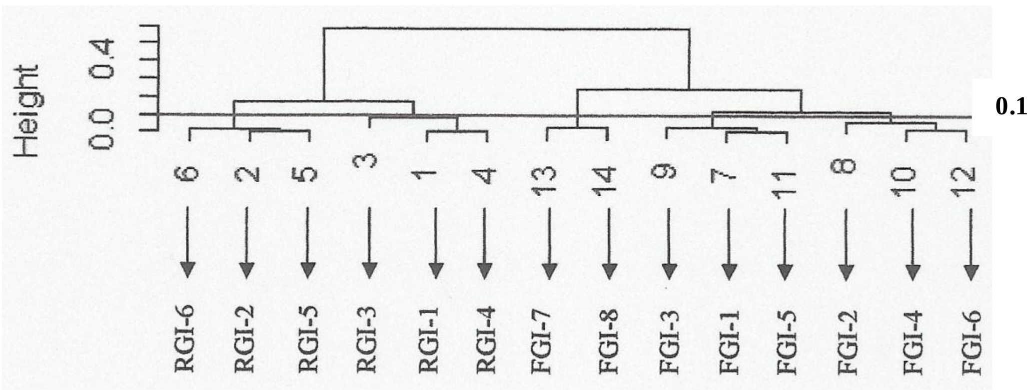


Figure 4.1 Grouping of real & fake coins by log ratio distance using Ag / Cu ratio and 0.1 height

To recapitulate the results;

1. Ag / Cu ratio was able to completely differentiate fake coins from the real ones (Figure 4.1).
2. Six real coins (1 – 6) were collected in two different groups. Ag / Cu ratio of the real coins (2, 5 and 6) that were collected in the first group was 69.4113 whereas Ag / Cu ratio of the other real coins (1,3 and 4) that were collected in the second group was 122.2828. Those two ratios imply that there is a quality

difference in the production of real coins. Real coins that are collected in the second group should be higher in quality than those in the first group.

3. Eight fake coins (7 – 14) were collected in three different groups. Ag / Cu ratio of the fake coins (13 and 14) that were collected in the first group was 26.2740. Ag / Cu ratio of the other fake coins (7, 9 and 11) that were collected in the second group was 14.6005. Ag / Cu ratio of the other fake coins (8, 10 and 12) that were collected in the third group was 10.3047. Those three ratios imply that there is a quality difference in the production of fake coins as in real ones. Fake coins collected in the first group should be higher in quality than those in the second and third groups. Fake coins collected in the second group are higher in quality than those in the third group.
4. Ag percentages of the some coins may be replaced by Cu. Decrease in Ag is preferred from especially many economic reasons such as debasements, wars,…etc. Ag is more expensive than Cu so using Ag in production also increases the costs. In order to decrease the costs forgers implemented a decrease in Ag percentages especially by increasing Cu percentages of the coins (Tripathy et al. 2009).

Ag and Cu Values

As seen in Figure 4.2 Ag and Cu values, completely differentiated fake coins from the real ones; six real coins (1 - 6) were collected in one group. Eight fake coins (7 - 14) were collected in three different groups.

The real coins (1 - 6) were collected in the first group have silver values changing in the range 0.9555 - 0.9813 (average being 0.9697). Copper values were changing in the range 0.0063 - 0.0144 (average being 0.0110).

The fake coins (8, 10 and 12) were collected in the first group. Silver values were changing in the range 0.8855 - 0.903 (average being 0.8963). Copper values were changing in the range 0.0777 - 0.1031 (average being 0.0883).

Other fake coins (13 and 14) were collected in the second group. Silver values were changing in the range 0.9313 - 0.9445 (average being 0.9379). Copper values were changing in the range 0.034 - 0.0376 (average being 0.0358).

Remaining fake coins (7, 9 and 11) were collected in the third group. Silver values were changing in the range 0.9144 - 0.9309 (average being 0.9219). Copper values were changing in the range 0.0598 - 0.0683 (average being 0.0633).

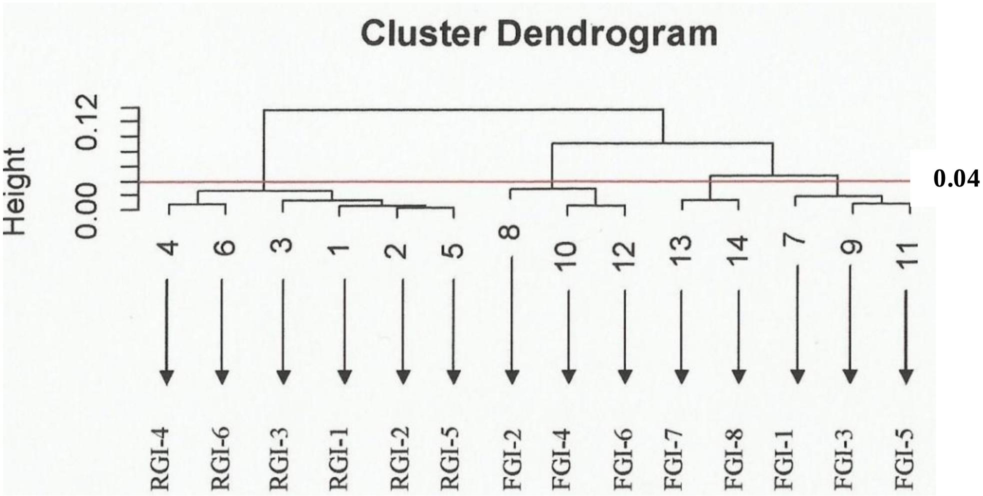


Figure 4.2 Grouping of real & fake coins by euclidean distance using Ag and Cu values and 0.04 height

To recapitulate the results;

1. Ag and Cu values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. Real coins were collected in two groups by using ratios of the elements (Ag / Cu). However, real coins were collected in one group by using individual values of the elements (Ag and Cu). As a result element ratios can be tought as more sensitive than individual values of the elements.
3. Fake coins were collected in three groups for both element ratios and individual elements. At this point, every two constructions denominated the same success.

Ag / Pb Ratio

As seen in Figure 4.3 Ag / Pb ratio did not completely differentiate fake coins from the real ones; six real coins (1 – 6) were collected in two different groups and eight fake coins (7 – 14) were collected in three different groups.

The fake coins (7, 10, 11, 13 and 14) were collected in one group. Silver values were changing in the range 0.9004 - 0.9445 (average being 0.9255). Lead values were changing in the range 0.00057 - 0.00021 (average being 0.0004).

Other fake coins (8 and 12) were collected in the second group. Silver values were changing in the range 0.8855 - 0.903 (average being 0.8942). Lead values were changing in the range 0.0015 - 0.0016 (average being 0.0015).

The real coins (4 and 6) were collected in the first group. Silver values were changing in the range 0.9555 - 0.9619 (average being 0.9587). Lead values were changing in the range 0.0217 - 0.0236 (average being 0.0226).

Remaining coins (1 - 3, 5 and 9) were collected in a different group. Four of them were real coins (1 - 3 and 5) and one of them was a fake coin (9). Silver values of those real coins were 0.9751, 0.971, 0.9813 and 0.9737. Lead values of those real coins were 0.0063, 0.0054, 0.0036 and 0.0048. Silver value of fake coin was 0.9144 and lead value of the coin was 0.0037.

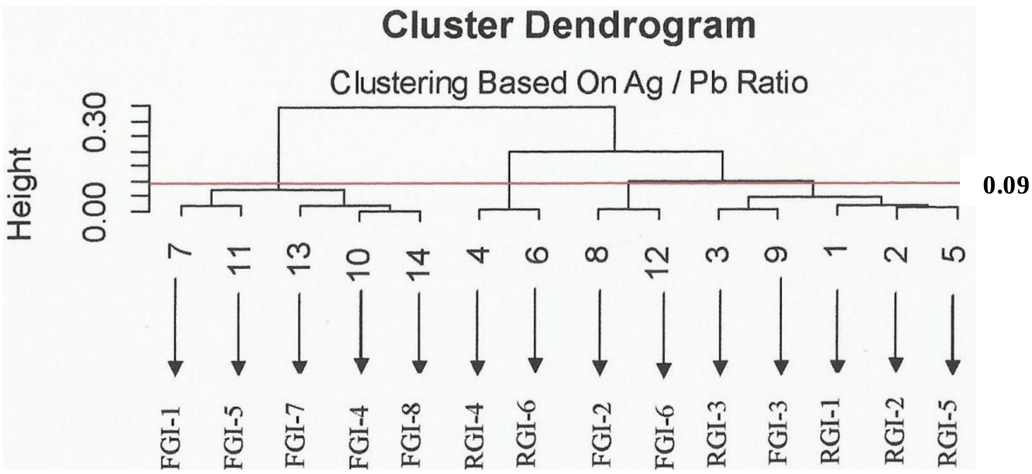


Figure 4.3 Grouping of real & fake coins by log ratio distance using Ag / Pb ratio and 0.09 height

To recapitulate the results;

1. Ag / Pb ratio was not able to completely differentiate fake coins from the real ones.
2. Two real coins (4 and 6) were collected in one group. Ag / Pb ratio of those real coins collected in this group was 42.4072.
3. Seven fake coins (7, 8 and 10 - 14) were collected in two different groups. Ag / Pb ratio of the fake coins (7, 10, 11, 13 and 14) that were collected in the first group was 2659.491 whereas Ag / Pb ratio of the other fake coins (8 and 12) collected in the second group was 577.7188. Those two ratios imply that there is a quality difference in production of fake coins. Fake coins collected in the first group are higher in quality than those in the second group.
4. Most of the real coins (1 - 3 and 5) were collected in this group except two real coins (4 and 6). Average Ag percentages of these two groups are close to each other. Real coins can be collected in two different groups due to having different Pb percentages.

Ag and Pb Values

As seen in Figure 4.4 Ag and Pb values completely differentiated fake coins from the real ones; six real coins (1 – 6) were collected in two different groups and eight fake coins (7 – 14) were collected in three different groups.

The real coins (4 and 6) were collected in the first group. Silver values were changing in the range 0.9555 - 0.9619 (average being 0.9587). Lead values were changing in the range 0.0217 - 0.0236 (average being 0.0226).

Other real coins (1, 2, 3 and 5) were collected in the second group. Silver values were changing in the range 0.971 - 0.9813 (average being 0.9752). Lead values were changing in the range 0.0036 - 0.0063 (average being 0.0050).

The fake coins (8, 10 and 12) were collected in the first group. Silver values were changing in the range 0.8855 - 0.903 (average being 0.8963). Lead values were changing in the range 0.00055 - 0.0016 (average being 0.0012).

Other fake coins (9 and 11) were collected in the second group. Silver values were changing in the range 0.9144 - 0.9205 (average being 0.9174). Lead values were changing in the range 0.00026 - 0.0037 (average being 0.0019).

Another fake coins (7, 13 and 14) were collected in the third group. Silver values were changing in the range 0.9309 - 0.9445 (Avr: 0.9355). Lead values were changing in the range 0.0039 - 0.0059 (average being 0.0004).

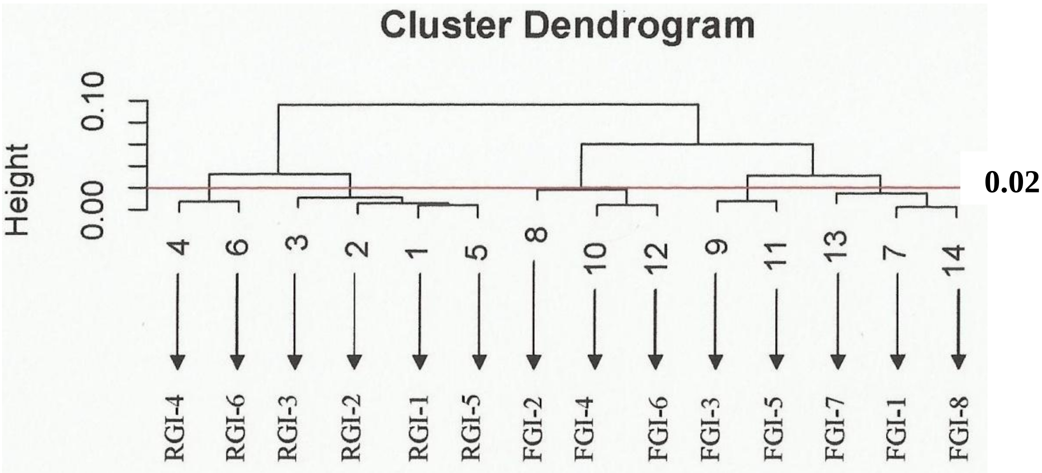


Figure 4.4 Grouping of real & fake coins by euclidean distance using Ag and Pb values and 0.02 height

To recapitulate the results;

1. Ag and Pb values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. Real coins were collected in two different groups using both ratios of the elements (Ag / Pb) and individual values of the elements (Ag and Pb). However, individual values of the elements (Ag and Pb) was more successful than Ag /Pb ratio for real coins.
3. Fake coins were collected in three different groups both ratios of the elements (Ag / Pb) and individual values of the elements (Ag and Pb). However, at this point individual values of Ag and Pb and euclidean distance was more successful than the other.

Ag / Fe Ratio

As seen in Figure 4.5 Ag / Fe ratio did not completely differentiate fake coins from the real ones; six real coins (1 – 6) were collected in three different groups and eight fake coins (7 - 14) were collected in three different groups.

The real coin numbered 6 fell into a different group (collected in the first group) than the rest of the real coins. Silver value of this real coin was 0.9619 and its iron value was 0.0013.

The fake coins (10, 11, 13 and 14) were collected in the first group. Silver values were changing in the range 0.9004 - 0.9445 (average being 0.9241). Iron values were changing in the range 0.0109 - 0.0152 (average being 0.0130).

Other fake coins (7 and 12) and one real coin (3) were collected in the second group. Silver values of those two fake coins were 0.9309, 0.903 and their iron values were 0.0028 and 0.0036. Silver value of one real coin was 0.9813 and its iron value as fraction was 0.0037.

Remaining real and fake coins (1, 2, 4, 5, 8 and 9) were collected in the third group. Two of them were fake (8 and 9) and four of them were real coins (1, 2, 4 and 5). Silver values of those fake coins were 0.8855, 0.9144 and their iron values were 0.0042 and 0.0080. Silver values of four real coins were 0.9751, 0.971, 0.9555, 0.9737 and their iron values were 0.0050, 0.0049, 0.0054 and 0.0046.

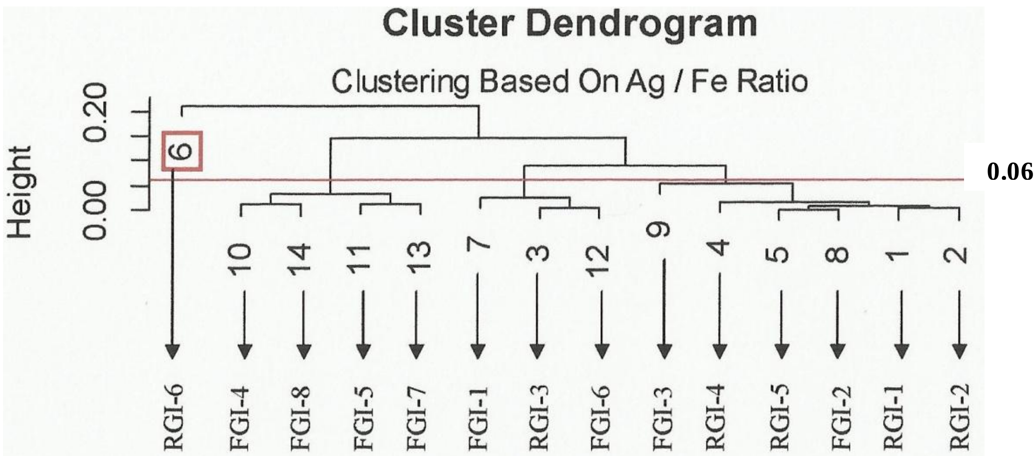


Figure 4.5 Grouping of real & fake coins by log ratio distance using Ag / Fe ratio and 0.06 height

To recapitulate the results;

1. Ag / Fe ratio was not able to completely differentiate fake coins from the real ones.
2. The fake coins (10, 11, 13 and 14) were collected in one group separate from the real coins whereas fake coins (7 and 12) were grouped with a real coin numbered 3 and other fake coins (8 and 9) were grouped with the real coins (1, 2, 4 and 5). The average Ag / Fe ratio of the former was 72.1210 whereas it was 291.64 and 162.56 for the latters. Also, the average Ag / Fe ratio of the real coin numbered 3 was 265.21. The average Ag / Fe ratio of the real coins numbered 1, 2, 4 and 5 was 195.44. Based on Table 4.1, Ag (std. dev. = 1.94) values are more variable than Fe values (std. dev. = 0.49). This explains the difference in Ag / Fe ratio over the fake coins.
3. When Ag / Fe ratio was taken into account, coin 6 seems to be separated out from the other real coins (Figure 4.5). However, this coin seemed quite similar to the other real coins when Ag and Fe values were considered independently (Figure 4.6).

Ag and Fe Values

As seen in Figure 4.6 Ag and Fe values completely diffferentiated fake coins from the real ones; six real coins (1 – 6) were collected in two different groups and eight fake coins were collected in three different groups.

The real coins (4 and 6) were collected in the first group. Silver values were changing in the range 0.9555 - 0.9619 (average being 0.958). Iron values were changing in the range 0.0013 - 0.0054 (average being 0.003).

Other real coins (1 - 3 and 5) were collected in the second group. Silver values were changing in the range 0.971 - 0.9813 (average being 0.975). Iron values were changing in the range 0.0013 - 0.005 (average being 0.002).

The fake coins (8, 10 and 12) were collected in the first group. Silver values were changing in the range 0.8855 - 0.903 (average being 0.896). Iron values were changing in the range 0.0036 - 0.0152 (average being 0.007).

Other fake coins (9 and 11) were collected in the second group. Silver values were changing in the range 0.9144 - 0.9205 (average being 0.917). Iron values were changing in the range 0.008 - 0.0121 (average being 0.010).

Remaining fake coins (7, 13 and 14) were collected in the third group. Silver values were changing in the range 0.9309 - 0.9445 (average being 0.935). Iron were changing in the range 0.0109 - 0.0028 (average being 0.009).

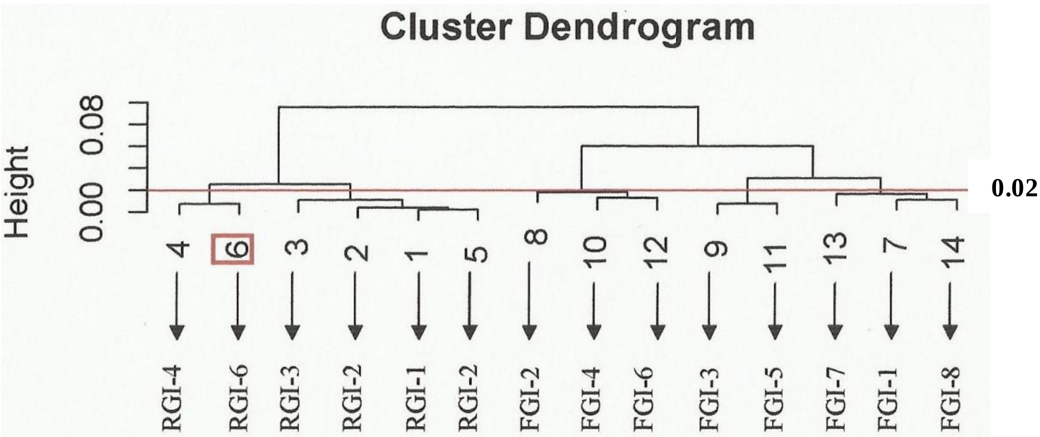


Figure 4.6 Grouping of real & fake coins by euclidean distance using Ag and Fe values and 0.02 height

To recapitulate the results;

1. Ag and Fe values, when used simultaneously, were able to differentiate fake coins from the real ones.
2. Real and fake coins were differentiated from each other more successfully by using individual values of their Ag and Fe elements because when Ag / Fe ratio was taken into account fake coins was not fully differentiated from the real ones.
3. Real coins were collected in three different groups by using ratios of the elements (Ag / Fe). Those coins were collected in two different groups by using individual values of the elements. Individual values of the elements (Ag and Fe) was more successful than Ag / Fe ratio for real coins.
4. Fake coins were collected in three different groups by using ratios of the elements (Ag / Fe). Fake coins were collected in two different groups by using individual values of the elements (Ag and Fe). At this point, individual

values of Ag and Fe were more successful than the other in differentiating coins.

Cu /Pb Ratio

As seen in Figure 4.7 Cu / Pb ratio completely differentiated fake coins from the real ones; six real coins (1 - 6) were collected in two different groups and eight fake coins (7 - 14) were collected in three different groups.

The real coins (4 and 6) were collected in the first group. Copper values were changing in the range 0.0093 - 0.0144 (average being 0.0118). Lead values were changing in the range 0.0217 - 0.0236 (average being 0.0226).

Other real coins (1, 2, 3 and 5) were collected in the second group. Copper values were changing in the range 0.063 - 0.0138 (average being 0.0107). Lead values were changing in the range 0.0036 - 0.0063 (average being 0.0050).

The fake coins (7, 10 and 11) were collected in the first group. Copper values were changing in the range 0.0598 - 0.0777 (average being 0.0665). Lead values were changing in the range 0.00021 - 0.00055 (average being 0.0003).

Other fake coins (8, 9, 12, 13 and 14) were collected in the second group. Copper values were changing in the range 0.034 - 0.1031 (average being 0.0654). Lead values were changing in the range 0.00057 - 0.0037 (average being 0.0015).

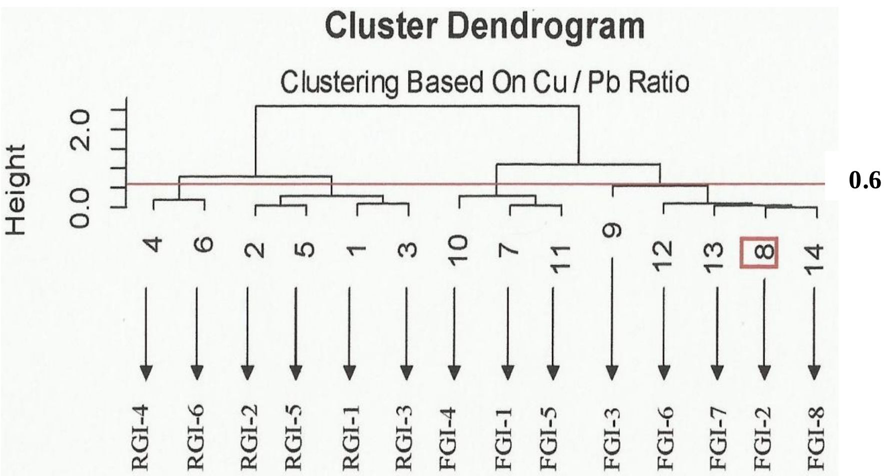


Figure 4.7 Grouping of real & fake coins by log ratio distance using Cu / Pb ratio and 0.6 height

To recapitulate the results;

1. Cu / Pb ratio was able to completely differentiate fake coins from the real ones.
2. Six real coins (1 - 6) were collected in two different groups. Cu / Pb ratio of the real coins (4 and 6) that were collected in the first group was 0.5288 whereas Cu / Pb ratio of the remaining real coins (1 - 3 and 5) that were collected in the second group was 2.1470. Those two ratios imply that there is a quality difference in production of real coins. Real coins that are collected in the first group are lower in quality than those in the second group.
3. Eight fake coins (7 – 14) were also collected in two different groups. Cu / Pb ratio of fake coins (7, 10 and 11) that were collected in the first group was 221.4987 whereas Cu / Pb ratio of the remaining fake coins (8, 9, 12 - 14) was 55.7683. Those two ratios imply that there is a quality difference in production of fake coins. Fake coins collected in the first group are higher in quality than those in the second group.

Cu and Pb Values

As seen in Figure 4.8 Cu and Pb values completely differentiated fake coins from the real ones; six real coins (1 – 6) were collected in one group and seven fake coins (7 and 9 – 14) were collected in two different groups.

The fake coins (13 and 14) were collected in the first group. Copper values were changing in the range 0.034 - 0.0376 (average being 0.0358). Lead values were changing in the range 0.00046 - 0.00057 (average being 0.0005).

The fake coin numbered 8 fell into a different group than the rest of the fake coins. Copper value of this fake coin was 0.1031 and its lead value was 0.0016.

Other fake coins (7 and 9 - 12) were collected in the second group. Copper values were changing in the range 0.0598 - 0.0841 (average being 0.0703). Lead values were changing in the range 0.00055 - 0.0037 (average being 0.0012).

The real coins (1 - 6) were collected in one group. Copper values were changing in the range 0.0063 - 0.0144 (average being 0.0110). Lead values were changing in the range 0.0036 - 0.0236 (average being 0.0109).

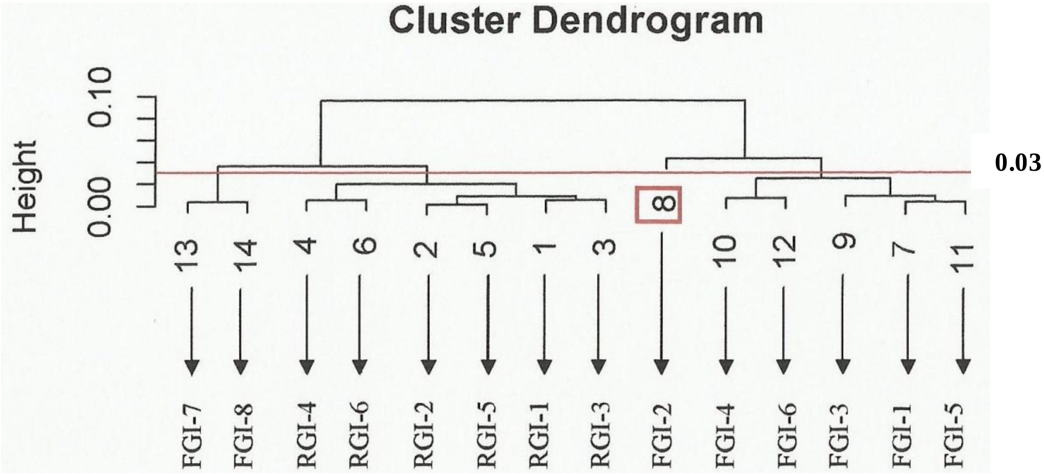


Figure 4.8 Grouping of real & fake coins by euclidean distance using Cu and Pb values and 0.03 height

To recapitulate the results;

1. Cu and Pb values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. When Cu / Pb ratio was taken into account, coin 8 seems to be quite similar to the other fake coins (Figure 4.7). However, this coin separated out from the other fake coins when Cu and Pb values were considered independently (Figure 4.8).
3. Individual values of Cu and Pb were able to differentiate fake coins from the real ones more successfully.
4. Real coins were collected in two different groups in terms of Cu / Pb ratio. However, real coins were collected in one group in terms of individual Cu and Pb values.
5. Fake coins were collected in two different groups when ratio between the elements (Cu / Pb) was used. At this point, individual elements of the coins were more successful than the other in differentiating coins from the each other.

Cu / Fe Ratio

Cu / Fe ratio did not completely differentiate fake coins from the real ones; six real coins (1 – 6) were collected in three different groups and eight fake coins (7 – 14) were collected in four different groups.

The real coins (1, 3 and 4) were collected in the first group. Copper values were changing in the range 0.0063 - 0.0093 (average being 0.0082). Iron values were changing in the range 0.0037 - 0.0054 (average being 0.0047).

The fake coins (7, 8 and 12) were collected in the first group. Copper values were changing in the range 0.0598 - 0.1031 (average being 0.0823). Iron values were changing in the range 0.0028 - 0.0042 (average being 0.0035).

Other fake coins (10 and 11) were collected in the second group. Copper values were changing in the range 0.062 - 0.0777 (average being 0.0698). Iron values were changing in the range 0.0121 - 0.0152 (average being 0.0136).

Two coins were collected in one group. One of those coins was a real (6) and the other was a fake coin (9). Copper value of the real coin (6) was 0.0144 and its iron value was 0.0013. Copper value of the fake coin (9) was 0.0683 and its iron value as was 0.008.

Some coins (2, 5, 13 and 14) were collected in one group. Two of them were real (2 and 5) and remaining two (13 and 14) were fake coins. Copper values of those real coins (2 and 5) were 0.0138 and 0.0137. Iron values of those real coins (2 and 5) were 0.0049 and 0.0046. On the other hand, copper values of those fake coins (13 and 14) were 0.034 and 0.0376. Iron values of those two fake coins (13 and 14) were 0.0109 and 0.014.

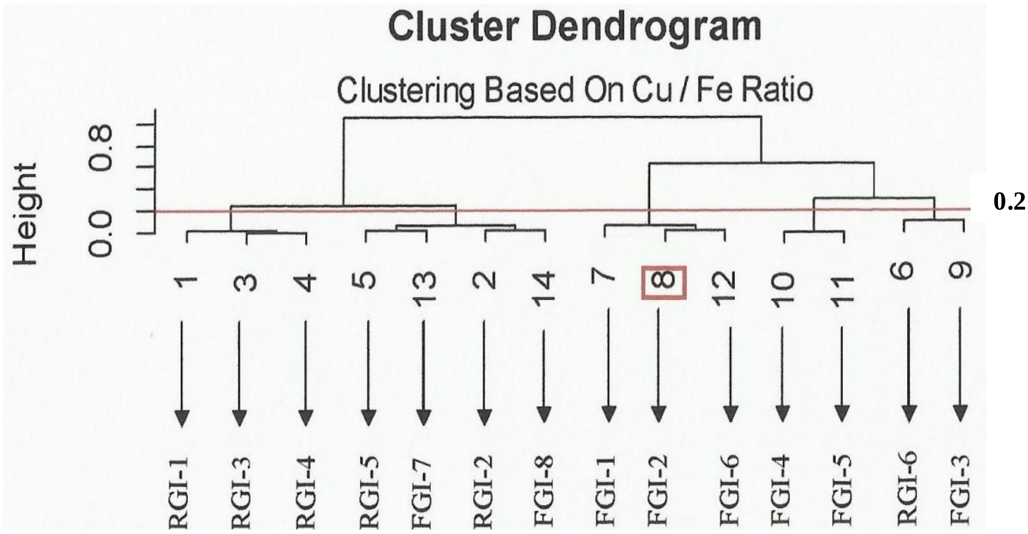


Figure 4.9 Grouping of real & fake coins by log ratio distance using Cu / Fe ratio and 0.2 height

To recapitulate the results;

1. Cu / Fe ratio was not able to completely differentiate fake coins from the real ones.
2. The real coins (1, 3 and 4) were collected in one group separate from the fake coins whereas real coins (2 and 5) were grouped with the fake coins (13 and 14). The average Cu / Fe ratio of the real coins in the former group was 1.7416 whereas it was 2.8973 in the latter group. Also, the average Cu / Fe ratio of the fake coins (13 and 14) were 2.9025. Based on Table 4.1, Cu (std. dev. = 0.33) values are more variable than Fe values (std. dev. = 0.15). This explains the difference of Cu / Fe ratio over the real coins.
3. Five fake coins (7, 8 and 10 - 12) were collected in two different groups. Cu / Fe ratio of the fake coins (7, 8 and 12) that were collected in the first group was 23.0886 whereas Cu / Fe ratio of the remaining fake coins (10 and 11) that were collected in the second group was 5.1179. Those two ratios imply that there is a quality difference in production of fake coins. Fake coins collected in the first group are higher in quality than those in the second group.
4. Although average of Fe fractions of fake coins was close to each other (0.0035 for the first group and 0.0136 for the second group), their average of

Cu fractions was different from each other (0.0247 for the first group and 0.0698 for the second group).

Cu and Fe Values

As seen in Figure 4.10 Cu and Fe values completely differentiated fake coins from the real ones; six real coins (1 – 6) were collected in one group and eight fake coins (7 and 9 – 14) were collected in three different groups.

The fake coins (13 and 14) were collected in first group. Copper values were changing in the range 0.034 - 0.0376 (average being 0.0358). Iron values were changing in the range 0.0109 - 0.014 (average being 0.0124).

The fake coin numbered 8 fell into a different group than the rest of the fake coins. Copper value of this fake coin (8) was 0.1031 and its iron value was 0.0042.

Other fake coins (7, 9 and 11) were collected in the second group. Copper values were changing in the range 0.0598 - 0.0683 (average being 0.063). Iron values were changing in the range 0.0028 - 0.0121 (average being 0.0076).

Another fake coins (10 and 12) were collected in the third group. Copper values were changing in the range 0.0777 - 0.0841 (average being 0.0809). Iron values were changing in the range 0.0036 - 0.0152 (average being 0.0094).

The real coins (1 - 6) were collected in one group. Copper values were changing in the range 0.0063 - 0.0144 (average being 0.0110). Iron values were changing in the range 0.0013 to 0.0054 (average being 0.0041).

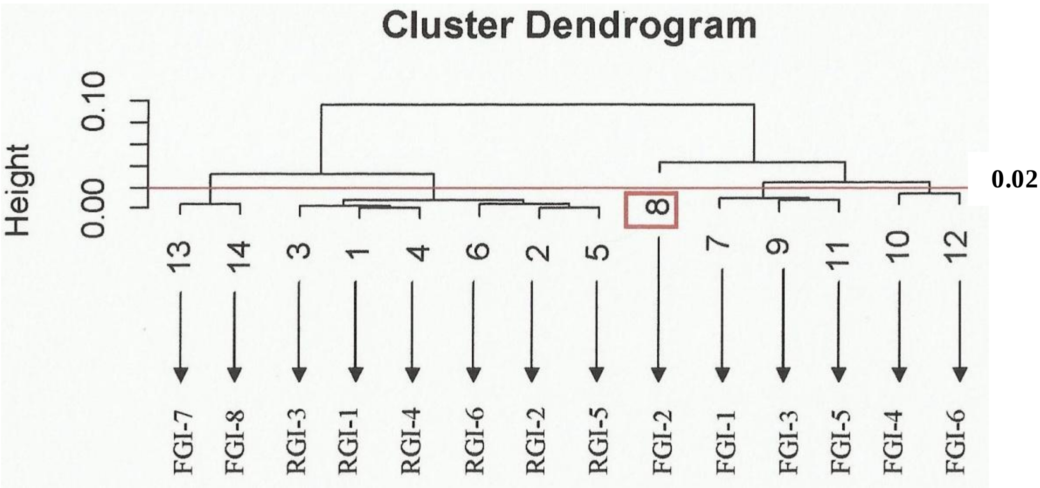


Figure 4.10 Grouping of real & fake coins by euclidean distance using Cu and Fe values and 0.02 height

To recapitulate the results;

1. Cu and Fe values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. When Cu / Fe ratio was taken into account, coin 8 seems to be quite similar to the other fake coins (Figure 4.9). However, this coin separated out from the other fake coins when Cu and Fe values were considered (Figure 4.10).
3. Although a fake coin was seperated out, Cu and Fe values differentiated fake coins from the real ones more successfully.
4. Real coins were collected in three different groups in terms of Cu / Fe ratio. However, real coins were collected in one group in terms of individual Cu and Fe values.
5. Fake coins were collected in four different groups in terms of Cu / Fe ratio. However, fake coins were collected in three different groups in terms of individual Cu and Fe values.
6. Although using Cu / Fe ratio seemed more efficient, actually individual Cu and Fe values differentiated fake coins from the real ones more successfully.

Pb / Fe Ratio

As seen in Figure 4.11 Pb / Fe ratio completely differentiated fake coins from the real ones; six real coins (1 – 6) were collected in three different groups and eight fake coins (7 - 14) were collected in again three different groups.

The fake coin (7) was collected in first group. Lead value of this fake coin was 0.00021 and its iron value was 0.0028.

The fake coins (10, 11, 13 and 14) were collected in the second group. Lead values were changing in the range 0.00026 - 0.00057 (average being 0.00046). Iron values were changing in the range 0.0109 - 0.0152 (average being 0.0130).

Other fake coins (8, 9 and 12) were collected in the third group. Lead values were changing in the range 0.0015 - 0.0037 (average being 0.0022). Iron values were changing in the range 0.0036 - 0.008 (average being 0.0052).

The real coins (1 - 3 and 5) were collected in the first group. Lead values were changing in the range 0.0036 - 0.0063 (average being 0.0050). Iron values were changing in the range 0.0037 - 0.005 (average being 0.0045).

Other real coin (4) was collected in the second group. Lead value of this real coin was 0.0236 and its iron value was 0.0054.

Another real coin (6) was collected in the third group. Lead value of this real coin was 0.00217 and its iron value was 0.0013.

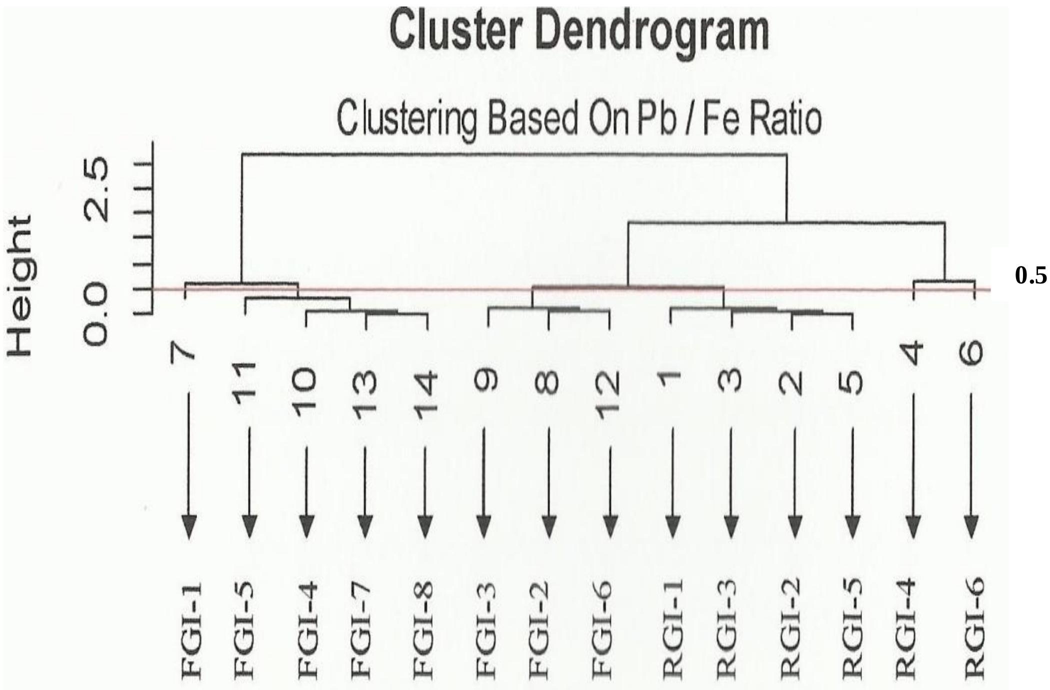


Figure 4.11 Grouping of real & fake coins by log ratio distance by Pb / Fe ratio and 0.5 height

To recapitulate the results;

1. Pb / Fe ratio was able to completely differentiate fake coins from the real ones.
2. The real coins (1 - 3 and 5) were collected in one group seperate from fake coins. The average Pb / Fe ratio was 1.0946.
3. Seven fake coins (8 - 14) were collected in three different groups. Pb / Fe ratio of the fake coins (10, 11, 13 and 14) that were collected in the first group was 0.0351 whereas Pb / Fe ratio of the remaining fake coins (8, 9 and 12) that were collected in the second group was 0.4200. Those two ratios imply that there is a quality difference in production of fake coins. Fake coins collected in the second group are higher in quality than those in the first group.

Pb and Fe Values

As seen in Figure 4.12 Pb and Fe values did not completely differentiate fake coins from the real ones; six real coins (1 – 6) were collected in two different groups. Eight fake coins (7 – 14) were collected in three different groups.

The real coins (4 and 6) were collected in the first group. Lead values were changing in the range 0.0217 - 0.0236 (average being 0.0226). Iron values were changing in the range 0.0013 - 0.0054 (average being 0.0033).

The fake coins (10, 11, 13 and 14) were collected in the first group. Lead values were changing in the range 0.00026 - 0.00057 (average being 0.00046). Iron values were changing in the range 0.0109 - 0.0152 (average being 0.0130).

Other fake coins (7, 8 and 12) were collected in the second group. Lead values were changing in the range 0.00021 - 0.0016 (average being 0.0011). Iron values were changing in the range 0.0028 - 0.0042 (average being 0.0035).

Some coins were collected in one group. Four of them were real (1 - 3 and 5) and one of them was a fake coin (9). Lead values of real coins (1 - 3 and 5) were 0.0063, 0.0054, 0.0036 and 0.0048. Iron values of real coins (1 - 3 and 5) were 0.005, 0.0049, 0.0037 and 0.0046. Lead value of fake coin (9) was 0.0037 and its iron value was 0.008.

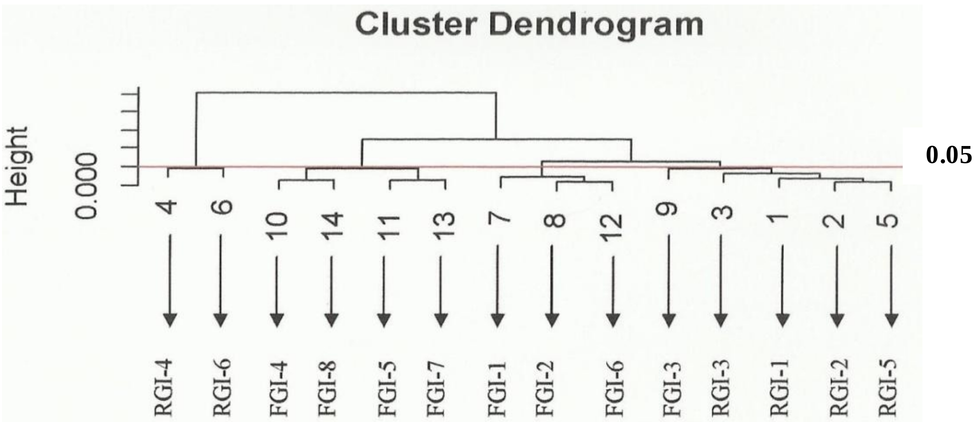


Figure 4.12 Grouping of real & fake coins by euclidean distance by Pb and Fe values and 0.05 height

To recapitulate the results;

1. Pb and Fe values, when used simultaneously, were not able to completely differentiate fake coins from the real ones.
2. Real coins were collected in three different groups in terms of both ratio and individual value.
3. Fake coins were collected in two different groups in terms of Pb / Fe ratio. However, fake coins were collected in three different groups in terms of individual Cu and Fe values.
4. Pb / Fe ratio differentiated fake coins from the real ones more successfully than the other.

4.1.1.2 RESULTS OF t-test

In this section, statistical significance of the differences between the groups of fake and real coins were investigated for the element ratios that were able to differentiate fake coins from the real ones. In the following tables, results for only three element ratios are given as they are the ones that were able to differentiate fake coins of the from the real ones.

In Table 4.3, descriptive statistics are given. In the second column of the table, type of the coins are given. Two types of coins were used in this study. Real coins were labeled with 0 whereas fake coins were labeled with 1 in SPSS 16.0. The column N is the number of investigated real and fake coins. Element ratios are transferred into log scale, that is instead of e.g. Ag/Cu, log(Ag/Cu) are used. The Mean column contains the averages whereas Standard deviation is the square root of the variance where variance is the mean of the squares of variations from the aritmetic mean and computed using the following formula.

$$[(2.03-1.95)^2+(1.84-1.95)^2+(2.19-1.95)^2+(2.01-1.95)^2+(1.85-1.95)^2+(1.82-1.95)^2]/5$$

The column Std. Error contains the standard errors and is calculated by dividing the standard deviation of the coins by the square root of number of investigated real or fake coins as in the formula given by $0.1449 / \sqrt{6}$.

Table 4.3 Descriptive statistics for Greek Coins Which Were Dated Back to Middle of the Fifth Century BCE

Descriptive Statistics

	Type	N	Mean	Std. Deviation	Std. Error
Ag / Cu	0	6	1.9598	±.1449	.0591
	1	8	1.1690	±.1747	.0617
Cu / Pb	0	6	.1128	±.3388	.1383
	1	8	1.9792	±.3109	.1099

In Table 4.4, results of the t-test are given. There are two different types of two sample t tests one of which is used when the variances of the two groups are equal, and the other one is used when the variances are different. Levene's test is used to test the equality of the group variances. The p value greater than 0.05 implies equality of variances. Accordingly, the group variances are equal for all the element ratios considered here. Two sample t-test statistic are computed for both cases where variances are assumed equal and unequal. Since, group variances are found to be equal, only the highlighted t-test results are used.

In this table, Mean Difference column contains the difference between the mean of fake coins and the real coins for the corresponding element ratio whereas the column labeled Std. Error Difference contains the standard error of this difference. The columns labeled Lower and Upper give the 95% confidence interval for the difference between the means.

Table 4.4 Results of independent samples t test for Greek coins which were dated back to middle of the fifth century BCE

In Table 4.4, obtained results from independent samples t-test for Greek coins which were dated back to middle of the fifth century BCE were presented. The p-values (0.000) are much smaller than significance level (0.05) in this table. This implies that there is a statistically significant difference between real and fake coins in terms of their Ag / Cu and Cu / Pb ratios.

The statistical power of the two sample t-test is found to be above 95% for testing the equality of group means where group sizes are 6 and 8 at the significance level of 5% (SAS 9.2). This means that even if there is a one unit difference between the element ratio averages of the population of fake and population of real coins, the test is able to discover it 95% of the time based on the sampled data.

4.2.2 Greek Coins Which Were Dated Back to Reign of Alexander the Great (323 – 336 BCE)

4.2.2.1 RESULTS OF CLUSTER ANALYSIS

Ag / Cu Ratio

As seen in Figure 4.13 Ag / Cu ratio completely differentiated fake coins from the real ones; sixteen real coins (1 - 16) were collected in two different groups and ten fake coins (17 – 26) were collected in one group.

Real coin numbered 6 fell into a different group (first group) than the rest of the real coins. Silver value of this real coin was 0.9934 and its copper value was not detected by the spectrometer and completed later by minimum detection limit of the element (0.001 for Cu). Copper value was 0.00001.

The real coins (2, 4, 7, 8, 12, 14 - 16) were collected in the second group. Silver values were changing in the range 0.985 - 0.9933 (average being 0.9901). Copper values were changing in the range 0.0009 - 0.0032 (average being 0.0015).

Remaining real coins (1, 3, 5, 9 - 11 and 13) were collected in the third group. Silver values were changing in the range 0.9833 - 0.992 (average being 0.9888). Copper values were changing in the range 0.005 - 0.0112 (average being 0.0069).

The fake coins (17 - 26) were collected in one group. Silver values were changing in the range 0.9544 - 0.9774 (average being 0.9693). Copper values were changing in the range 0.02 - 0.0329 (average being 0.0231).

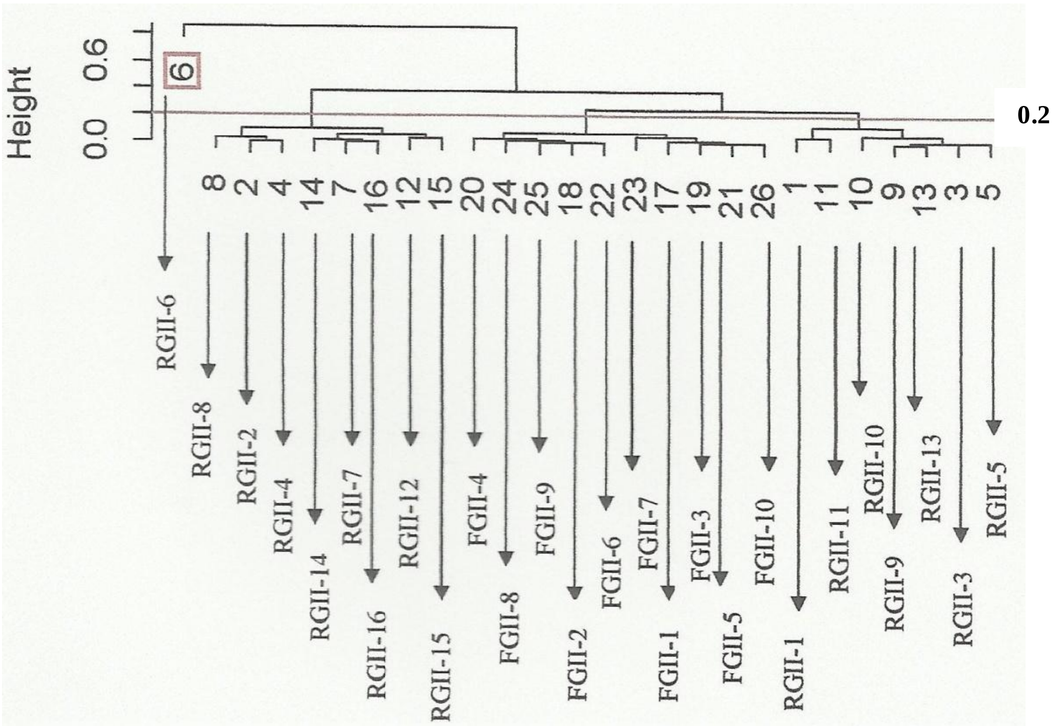


Figure 4.13 Grouping of real & fake coins by log ratio distance
using Ag / Cu ratio and 0.2 height

To recapitulate the results;

1. Ag / Cu ratio was able to completely differentiate fake coins from the real ones.
2. Fifteen real coins (1 – 5 and 7 - 16) were collected in two different groups. Ag / Cu ratio of the real coins (2, 4, 7, 8, 12, 14 and 16) that were collected in the first group was 683.4498 whereas Ag / Cu ratio of the remaining real coins (1, 3, 5, 9 - 11 and 13) that were collected in the second group was 163.4298. Those two ratios imply that there is a quality difference in production of real coins. Real coins that are collected in the first group are higher in quality than those in the second group.
3. Ten fake coins (17 - 26) were collected in one group. Ag / Cu ratio of them was 43.1410.

Ag and Cu Values

As seen in Figure 4.14 Ag and Cu values completely differentiated fake coins from the real ones; sixteen real coins (1 – 16) were collected in two different groups and ten fake coins (17 - 26) were collected in three different groups.

The real coins (9 and 10) were collected in the first group. Silver values were changing in the range 0.9833 - 0.9862 (average being 0.9847). Copper values were changing in the range 0.0075 - 0.0112 (average being 0.0093).

Other real coins (1 – 8 and 11 - 16) were collected in the second group. Silver values were changing in the range 0.985 - 0.9934 (average being 0.9904). Copper values were changing in the range 0.00001 - 0.0079 (average being 0.0030).

The fake coins (18 – 22, 24 and 25) were collected in the second group. Silver values were changing in the range 0.97 - 0.9774 (average being 0.9736). Copper values were changing in the range 0.0175 - 0.0245 (average being 0.0210).

Other one fake coin (26) was collected in the third group. Silver value of this one coin was 0.9544 and its copper value was 0.0239.

The other fake coins (17 and 23) were collected in the fourth group. Silver values were changing in the range 0.9609 - 0.9632 (average being 0.9620). Copper values were changing in the range 0.0278 - 0.0329 (average being 0.0303).

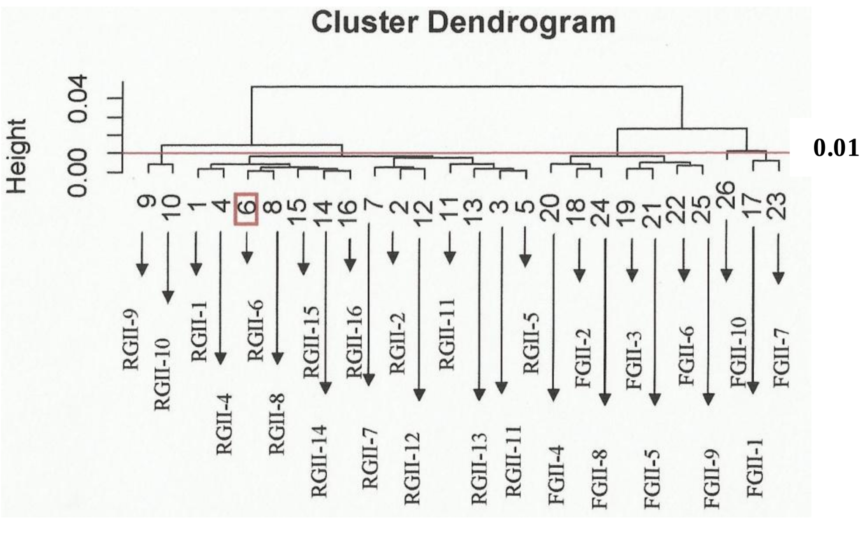


Figure 4.14 Grouping of real & fake coins by euclidean distance using Ag and Cu values and 0.01 height

To recapitulate the results;

1. Ag and Cu values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. When Ag / Cu ratio was taken into account, coin 6 separated out from the other real coins (Figure 4.13). However, this coin seems to be quite similar to the other real coins when Ag and Cu values were considered (Figure 4.14).
3. Real coins were collected in three different groups in terms of Ag / Cu ratio. However, real coins were collected in two group in terms of individual Ag and Cu values.
4. Fake coins were collected in one group in terms of Ag / Cu ratio. However, fake coins were collected in three different groups in terms of individual Ag and Cu values.
5. Although using individual Ag and Cu values seemed more efficient, actually Ag / Cu ratio even seperated out a real coin numbered 6 due to its significant position (Cu of this coin was not detected.) differentiated fake coins from the real ones more successfully than individual values of the coins.

Ag / Pb Ratio

As seen in Figure 4.15 Ag / Pb ratio completely differentiated fake coins from the real ones; sixteen real coins (1 – 16) were collected in three different groups. Ten fake coins (17 – 26) were collected in two different groups.

The fake coins (17 - 20 and 23) were collected in first group. Silver values were changing in the range 0.9609 - 09774 (average being 0.9694). Lead values were changing in the range 0.00045 - 0.0005 (average being 0.0004).

Other fake coins (21, 22 and 24 - 26) were colled in the second group. Silver values were changing in the range 0.9544 - 0.977 (average being 0.9692). Lead values were changing in the range 0.00017 - 0.00029 (average being 0.0002).

The real coins (1, 2, 4, 7, 9, 12, 14 and 16) were collected in the first group. Silver values were changing in the range 0.985 - 0.9933 (average being 0.9894). Lead values were changing in the range 0.0046 - 0.0093 (average being 0.0063).

Other real coins (11 and 13) were collected in the second group. Silver values were changing in the range 0.9889 - 0.992 (average being 0.9904). Lead values were changing in the range 0.0011 - 0.0016 (average being 0.0013).

Another real coins (3, 5, 6, 8 and 10) were collected in the third group. Silver values were changing in the range 0.9833 - 0.9934 (average being 0.9900). Lead values were changing in the range 0.0023 - 0.0038 (average being 0.0032).

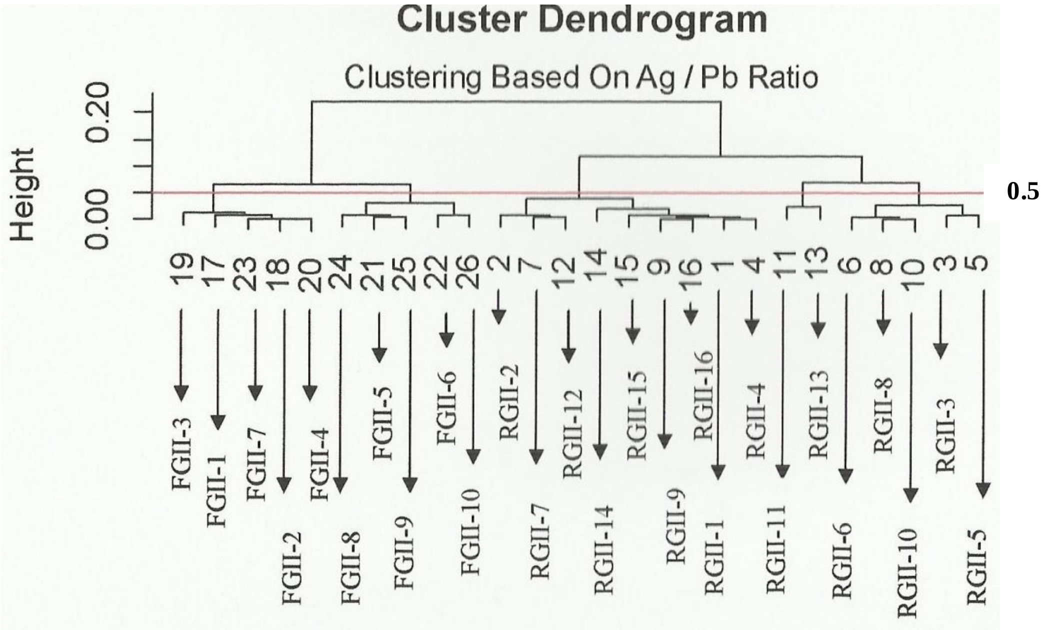


Figure 4.15 Grouping of real & fake coins by log ratio distance using Ag / Pb ratio and 0.5 height

To recapitulate the results;

1. Ag / Pb ratio was able to completely differentiate fake coins from the real ones.
2. Both average of Ag fractions of fake coins and Pb fractions of them had same closeness (0.0002).
3. Sixteen real coins (1 - 16) were collected in three different groups. Ag / Pb ratio of the real coins (1, 2, 4, 7, 9, 12 and 14 - 16) that were collected in the first group was 166.8708. Ag / Pb ratio of the other real coins (11 and 13) that were collected in the second group was 759.9403. Ag / Pb ratio of the remaining real coins (3, 5, 6, 8 and 10) that were collected in the third group was 321.4926. Those three ratios imply that there is a quality difference in

production of real coins. Real coins collected in the second group are higher in quality than those in the first and third groups whereas real coins collected in the third group are higher in quality than those in the first group.

4. Ten fake coins (17 - 26) were collected in two different groups. Ag / Pb ratio of the fake coins (17 - 20 and 23) that were collected in the first group was 1976.278 whereas Ag / Pb ratio of the remaining fake coins (21, 22 and 24 - 26) that were collected in the second group was 4685.841. Those two ratios imply that there is a quality difference in production of fake coins. Fake coins collected in the second group are higher in quality than those in the first group.

Ag and Pb Values

As seen in Figure 4.16 Ag and Pb values completely differentiated fake coins from the real ones. Sixteen real coins (1 – 16) were collected in two different groups. Ten fake coins (17 – 26) were also collected in two different groups.

The real coins (1, 3, 4 – 6, 8, 11 and 13 - 16) were collected in the first group. Silver values were changing in the range 0.9889 - 0.9934 (average being 0.9915). Lead values were changing in the range 0.0011 - 0.0063 (average being 0.0037).

Other real coins (2, 7, 9, 10 and 12) were collected in the second group. Silver values were changing in the range 0.9833 - 0.9877 (average being 0.9859). Lead values were changing in the range 0.0038 - 0.0093 (average being 0.0069).

Seven fake coins (18 – 21, 24 and 25) were collected in the first group. Silver values were changing in the range 0.97 - 0.9774 (average being 0.9736). Lead values were changing in the range 0.00017 - 0.00050 (average being 0.0003).

Other fake coins (17, 23 and 26) were collected in the second group. Silver values were changing in the range 0.9544 - 0.9632 (average being 0.95). Lead values were changing in the range 0.00025 - 0.00053 (average being 0.0004).

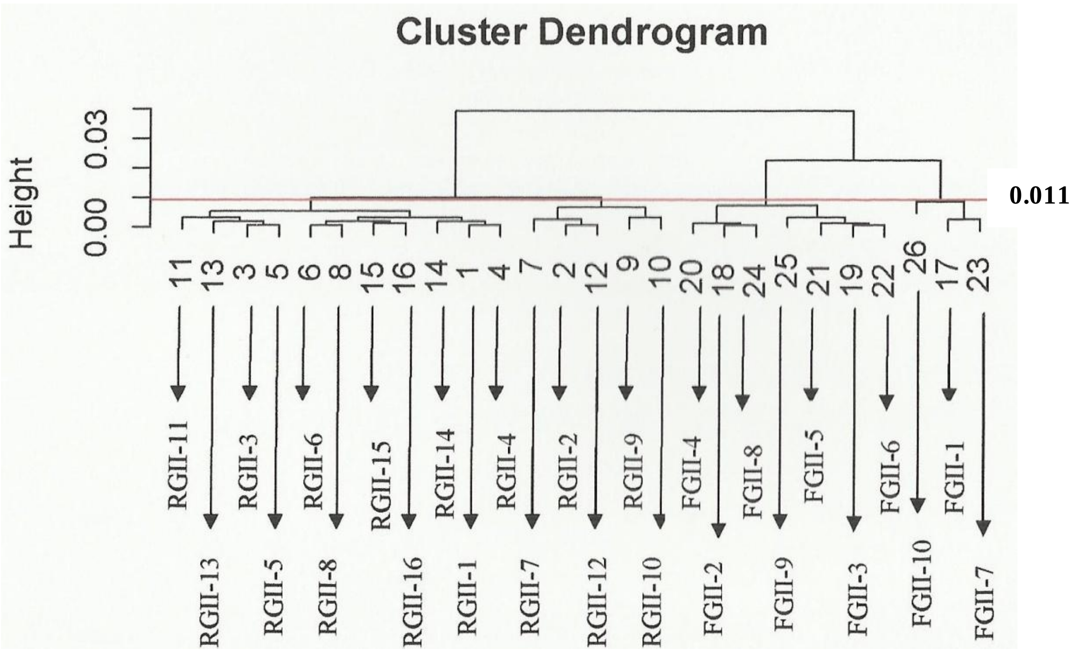


Figure 4.16 Grouping of real & fake coins by euclidean distance using Ag and Pb values and 0.011 height

To recapitulate the results;

1. Ag and Pb values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. Real coins were collected in two different groups in terms of both Ag / Pb ratio and individual Ag and Pb values.
3. Fake coins were collected in three different groups in terms of Ag / Pb ratio. However, fake coins were collected in two different groups in terms of individual Ag and Pb values.
4. Although using individual Ag and Pb values seemed more efficient, actually Ag / Pb ratio differentiated fake coins from the real ones more successfully than individual values of the coins.

Ag / Fe Ratio

As seen in Figure 4.17 Ag / Fe ratio did not completely differentiate fake coins from the real ones.

The real coins (1 – 3, 5, 6, 14 and 15) were collected in the first group. Silver values were changing in the range 0.9875 - 0.9934 (average being 0.9910). Iron values of those real coins did not detected by the spectrometer and later replaced by using minimum detection limit of the element.

The fake coins (20, 22, 25 and 26) were collected in the first group. Silver values were changing in the range 0.9544 - 0.9759 (average being 0.9685). Iron values were changing in the range 0.0041 - 0.0071 (average being 0.0056).

Some coins (4, 7, 9, 12, 13, 16 and 24) were collected in one group. Six of them were real (4, 7, 9, 12, 13 and 16) coins and one of them (24) was a fake coin. Silver values of those real coins (4, 7, 9, 12, 13 and 16) were 0.9903, 0.985, 0.9862, 0.9877, 0.9889 and 0.9925 and their iron values were 0.00065, 0.00079, 0.00051, 0.00067, 0.00065 and 0.00056. Silver value of this one fake coin (24) was 0.977 and its iron value was 0.00078.

Some other coins (8, 10, 11, 17, 18, 19, 21 and 23) were collected in other one group. Three of them were real (8, 10 and 11) and five of them (17, 18, 19, 21 and 23) were fake coins. Silver values of three real coins (8, 10 and 11) were 0.993, 0.9833 and 0.992 and their iron values were 0.0011, 0.0014 and 0.0011. Silver values of five fake coins (17 – 19, 21 and 23) were 0.9632, 0.9774, 0.97, 0.9711 and 0.9609 and their iron values were 0.0017, 0.001, 0.0015, 0.0001 and 0.0019.

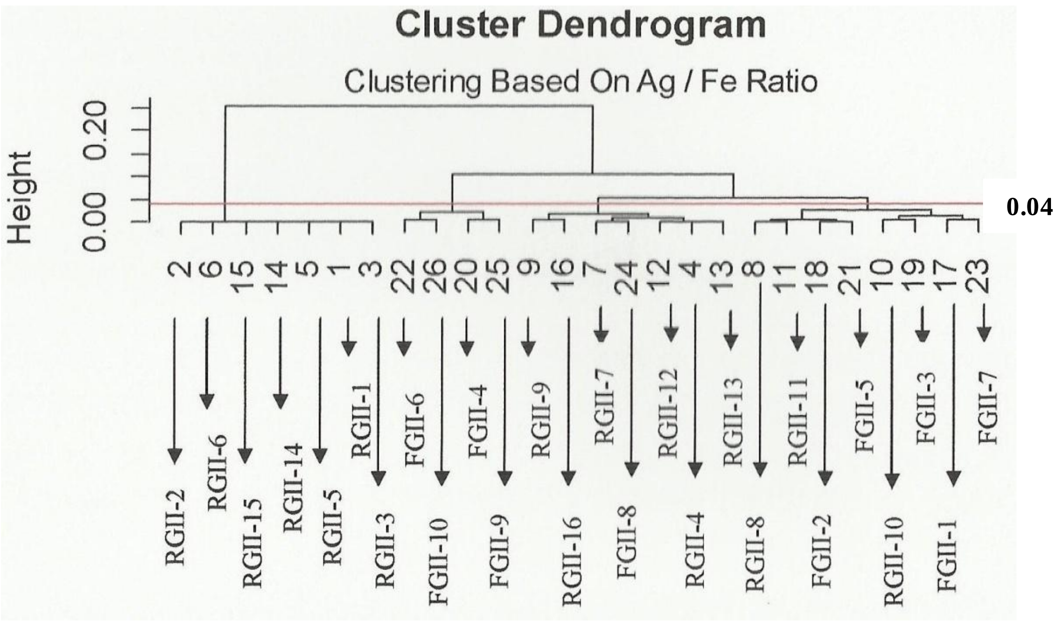


Figure 4.17 Grouping of real & fake coins by log ratio distance using Ag / Fe ratio and 0.04 height

To recapitulate the results;

1. Ag / Fe ratio was not able to completely differentiate fake coins from the real ones.
2. Seven real coins (1 – 3, 5, 6, 14 and 15) were collected in one group. Ag / Fe ratio of them was 99104.29.
3. Four fake coins (20, 22, 25 and 26) were also collected in one group. Ag / Fe ratio of them was183.4003.

Ag and Fe Values

As seen in Figure 4.18 Ag and Fe values completely differentiated fake coins from the real ones. Sixteen real coins (1 – 16) were collected in two different groups. Ten fake coins (17 – 26) were collected in four different groups.

The real coins (1, 3, 4 – 6, 8, 11, 14 and 16) were collected in the first group. Silver values were changing in the range 0.9901 - 0.9934 (average being 0.9917). Iron values were changing in the range 0.00001 - 0.0011 (average being 0.0002).

Other real coins (2, 7, 9, 10, 12 and 13) were collected in the second group. Silver values were changing in the range 0.9833 - 0.9889 (average being 0.9864). Iron values were changing in the range 0.00001 - 0.0014 (average being 0.0006).

The fake coins (18, 20, 24 and 25) were collected in the first group. Silver values were changing in the range 0.9735 - 0.9774 (average being 0.9759). Iron values were changing in the range 0.00078 - 0.0045 (average being 0.0025).

Other fake coins (19, 21 and 22) were collected in the second group. Silver values were changing in the range 0.97 - 0.9711 (average being 0.9704). Iron values were changing in the range 0.001 - 0.0067 (average being 0.0030).

Another one fake coin (26) was collected in the third group. Silver value of this one fake coin was 0.9544 and its iron value was 0.0071.

The other fake coins (17 and 23) were collected in the fourth group. Silver values were changing in the range 0.9609 - 0.9632 (average being 0.9620). Iron values were changing in the range 0.0017 - 0.0019 (average being 0.0018).

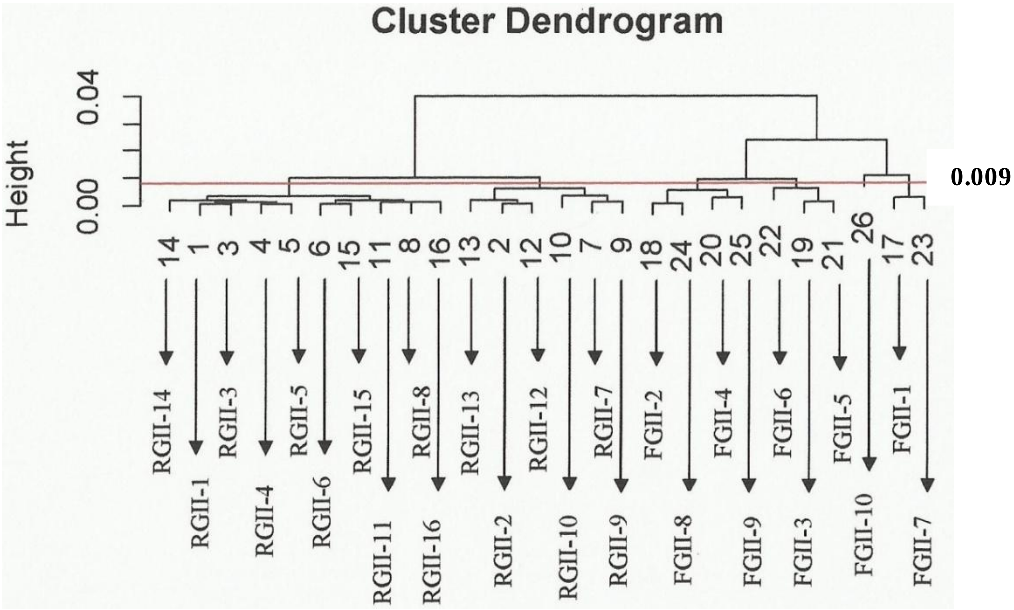


Figure 4.18 Grouping of real & fake coins by euclidean distance using Ag and Fe values and 0.009 height

To recapitulate the results;

1. Ag and Fe values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. Real coins were collected in three different groups in terms of Ag / Fe ratio. However, real coins were collected in two different groups in terms of individual Ag and Fe values.
3. Fake coins were collected in three different groups in terms of Ag / Fe ratio. However, fake coins were collected in four different groups in terms of individual Ag and Fe values.
4. Although using Ag / Fe ratio seemed more efficient, actually individual Ag and Fe values differentiated fake coins from the real ones more successfully than individual values of the coins.

Cu / Pb Ratio

As seen in Figure 4.19 coins were collected into three different groups. Cu / Pb ratio was completely differentiated fake coins from the real ones; sixteen real coins (1 – 16) were collected in three different groups and ten fake coins (17 - 26) were collected in one group.

Real coin numbered 6 fell into a different group than the rest of the real coins. Copper value of this one real coin was 0.00001 and its lead value was 0.0036.

The real coins (3, 5, 9, 10, 11 and 13) were collected in the second group. Copper values were changing in the range 0.005 - 0.0112 (average being 0.0075). Lead values were changing in the range 0.0011 - 0.0051 (average being 0.0027).

Other real coins (1, 2, 4, 7, 8, 12, 14 and 16) were collected in the third group. Copper values were changing in the range 0.0009 - 0.0032 (average being 0.0017). Lead values were changing in the range 0.0038 - 0.0093 (average being 0.0061).

The fake coins (17 - 26) were collected in the first group. Copper values were changing in the range 0.0175 - 0.0329 (average being 0.0231). Lead values were changing in the range 0.00017 - 0.00053 (average being 0.0003).

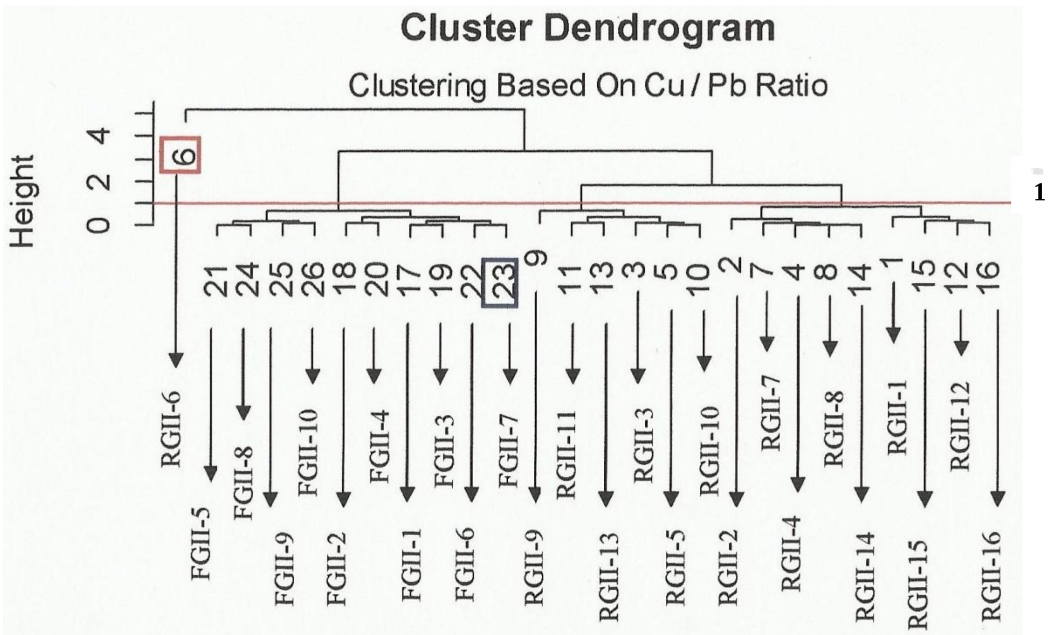


Figure 4.19 Grouping of real & fake coins by log ratio distance using Cu / Pb ratio and 1 height

To recapitulate the results;

1. Cu / Pb ratio was able to completely differentiate fake coins from the real ones.
2. Fifteen real coins (1 – 5 and 7 - 16) were collected in two different groups. Cu / Pb ratio of the real coins (3, 5, 9 - 11 and 13) that were collected in the first group was 3.2471 whereas Cu / Pb ratio of the remaining real coins (1, 2, 4, 7, 8, 12, 14 - 16) that were collected in the second group was 0.3069. Those two ratios imply that there is a quality difference in production of real coins. Real coins that are collected in the first group are higher in quality than those in the second group.
3. Ten fake coins (17 - 26) were collected in one group. Cu / Pb ratio of them was 78.1333.

Cu and Pb Values

As seen in Figure 4.20 Cu and Pb values were completely differentiated fake coins from the real ones; sixteen real coins (1 – 16) were collected in four different groups and ten fake coins (17 - 26) were collected in three different groups.

The real coins (2, 7 and 12) were collected in the first group. Copper values were changing in the range 0.0012 - 0.0025 (average being 0.0018). Lead values were changing in the range 0.0081 - 0.0093 (average being 0.0086).

Other real coins (1, 4, 6, 8, 14 and 16) were collected in the second group. Copper values were changing in the range 0.00001 - 0.0032 (average being 0.0015). Lead values were changing in the range 0.0036 0.0063 (average being 0.0047).

Another real coins (3, 5, 11 and 13) were collected in the third group. Copper values were changing in the range 0.005 - 0.0079 (average being 0.0066). Lead values were changing in the range 0.0011 - 0.0026 (average being 0.0019).

The other real coins (9 and 10) were collected in the fourth group. Copper values were changing in the range 0.0075 - 0.0112 (average being 0.0093). Lead values were changing in the range 0.0038 - 0.0051 (average being 0.0044).

The fake coins (18, 20, 22, 24 and 25) were collected in the first group. Copper values were changing in the range 0.0175 - 0.0216 (average being 0.0198). Lead values were changing in the range 0.00017 - 0.00050 (average being 0.0003).

The other fake coin numbered 23 fell into a different (second) group than the rest of the fake coins. Copper value of this one fake coin was 0.0329 and its lead value was 0.00048.

Another fake coins (17, 19, 21 and 26) were collected in the third group. Copper values were changing in the range 0.0237 - 0.0278 (average being 0.0249). Lead values were changing in the range 0.00018 - 0.00053 (average being 0.0003).

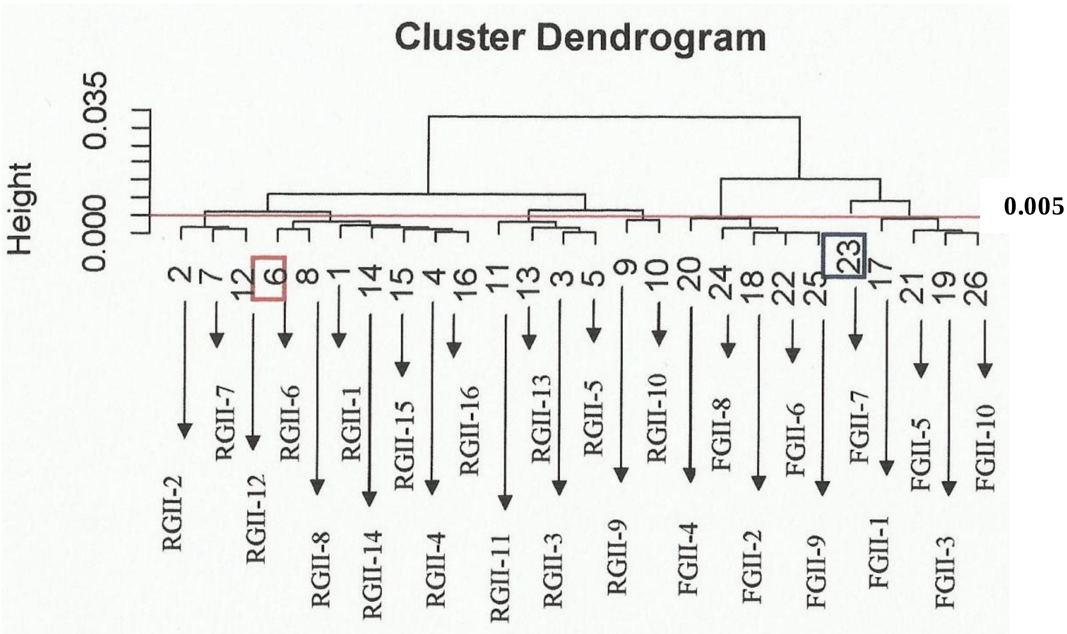


Figure 4.20 Grouping of real & fake coins by euclidean distance using Cu and Pb values and 0.005 height

To recapitulate the results;

1. Cu and Pb values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. When Cu / Pb ratio was taken into account, coin 6 separated out from the other real coins (Figure 4.19) However, this coin seems to be quite similar to the other real coins when Cu and Pb values were considered (Figure 4.20).

3. When Cu / Pb ratio was taken into account, coin 23 was not separated out from the other fake coins (Figure 4.19) However, this coin seems to be quite similar to the other fake coins when Cu and Pb values were considered (Figure 4.20).
4. Real coins were collected in three different groups in terms of Cu / Pb ratio. However, real coins were collected in four different groups in terms of individual Cu and Pb values.
5. Fake coins were collected in one group in terms of Cu / Pb ratio. However, fake coins were collected in three different groups in terms of individual Cu and Pb values.
6. Although using individual Cu and Pb values seemed more efficient, actually Cu / Pb ratio differentiated fake coins from the real ones more successfully than individual values of the coins.

Cu / Fe Ratio

As seen in Figure 4.21 Cu / Fe ratio did not completely differentiate fake coins from the real ones; sixteen real coins (1 – 16) were collected in five different groups and ten fake coins (17 - 26) were collected in two different groups.

The real coins (3 and 5) were colleced in the first group. Copper values were changing in the range 0.0066 - 0.007 (average being 0.0068). Iron values were not detected by the spectrometer and completed by using minimum detection limit of the element.

Other real coins (1, 2, 14 and 15) were collected in the second group. Copper values were changing in the range 0.0012 - 0.0032 (average being 0.0019). Iron values were not detected by the spectrometer and completed by using minimum detection limit of the element.

Another real coins (6 and 8) were collected in the third group. Copper values were changing in the range 0.00001 - 0.0009 (average being 0.0004). Iron values were changing in the range 0.00001 - 0.0011 (average being 0.0005).

Some coins (9, 10, 13, 17 – 19, 21, 23 and 24) were collected in one group. Three of them were real (9, 10 and 13) and six of them were fake coins (17 – 19, 21, 23 and 24). Copper values of those real coins were 0.0075, 0.0112, 0.0079 and their iron values were 0.00051, 0.0014 and 0.00065. Copper values of those fake coins were 0.0278, 0.0201, 0.0237, 0.0245, 0.0329, 0.0216 and their iron values were 0.0017, 0.001, 0.0015, 0.001, 0.0019 and 0.00078.

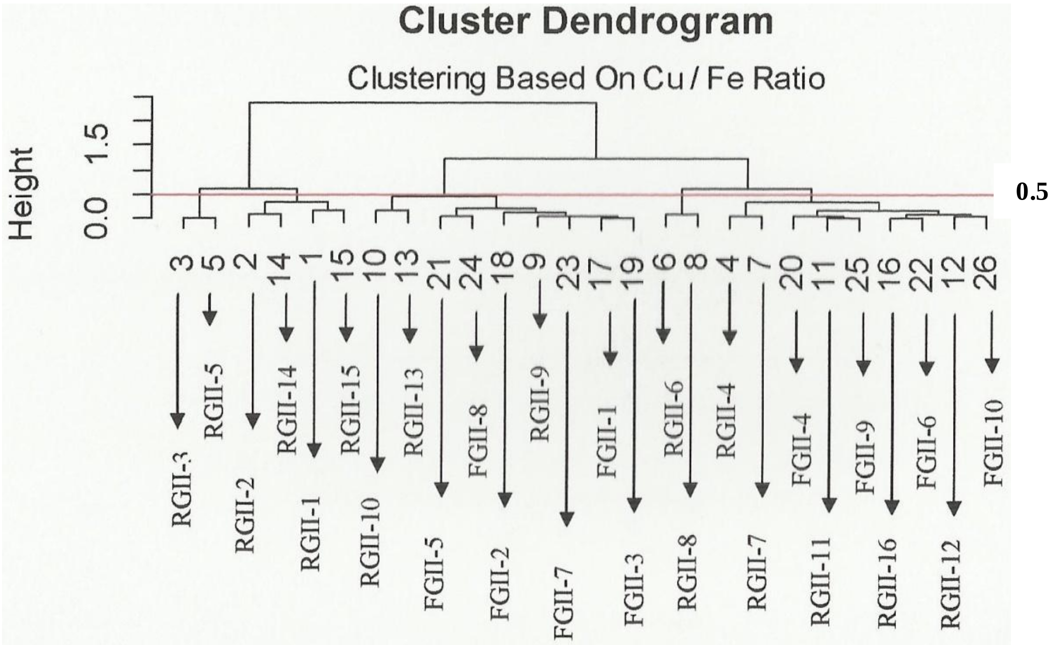


Figure 4.21 Grouping of real & fake coins by log ratio distance using Cu / Fe ratio and 0.5 height

To recapitulate the results;

1. Cu / Fe ratio was not able to completely differentiate fake coins from the real ones.
2. Eight real coins (1 – 3, 5, 6, 8, 14 and 15) were collected in three different groups. Cu / Fe ratio of the real coins (3 and 5) that were collected in the first group was 680. Cu / Fe ratio of the real coins (1, 2, 14 and 15) that were collected in the second group was 197.5. Cu / Fe ratio of the remaining real coins (6 and 8) that were collected in the third group was 0.9090. Those three ratios imply that there is a quality difference in production of real coins. Real coins that were collected in the first group are higher in quality than those in

the second and third groups whereas real coins that were collected in the second group are higher in quality than those in the third group.

Cu and Fe Values

As seen in Figure 4.22 Cu and Fe values completely differentiated fake coins from the real ones; sixteen real coins (1 – 16) were collected in two different groups. Ten fake coins (17 – 26) were collected in three different groups.

The real coins (3, 5, 9, 10 and 13) were collected in the first group. Copper values were changing in the range 0.0066 - 0.0112 (average being 0.0080). Iron values were changing in the range 0.00065 - 0.0014 (average being 0.0005).

Other real coins (1, 2, 4, 6 – 8, 11, 12, 14 and 16 were collected in the second group. Copper values were changing in the range 0.00001 - 0.0032 (average being 0.0019). Iron values were changing in the range 0.00079 - 0.0011 (average being 0.0004).

The fake coins (18, 20, 22, 24 and 25) were collected in the first group. Copper values were changing in the range 0.0175 - 0.0216 (average being 0.0198). Iron values were changing in the range 0.00078 - 0.0067 (average being 0.0034).

Other one fake coin (23) was collected in the second group. Copper value of this coin was 0.0329 and its iron value was 0.0019.

Another fake coins (17, 19, 21 and 26) were collected in the third group. Copper values were changing in the range 0.0237 - 0.0278 (average being 0.0249). Iron values were changing in the range 0.0017 - 0.0071 (average being 0.0028).

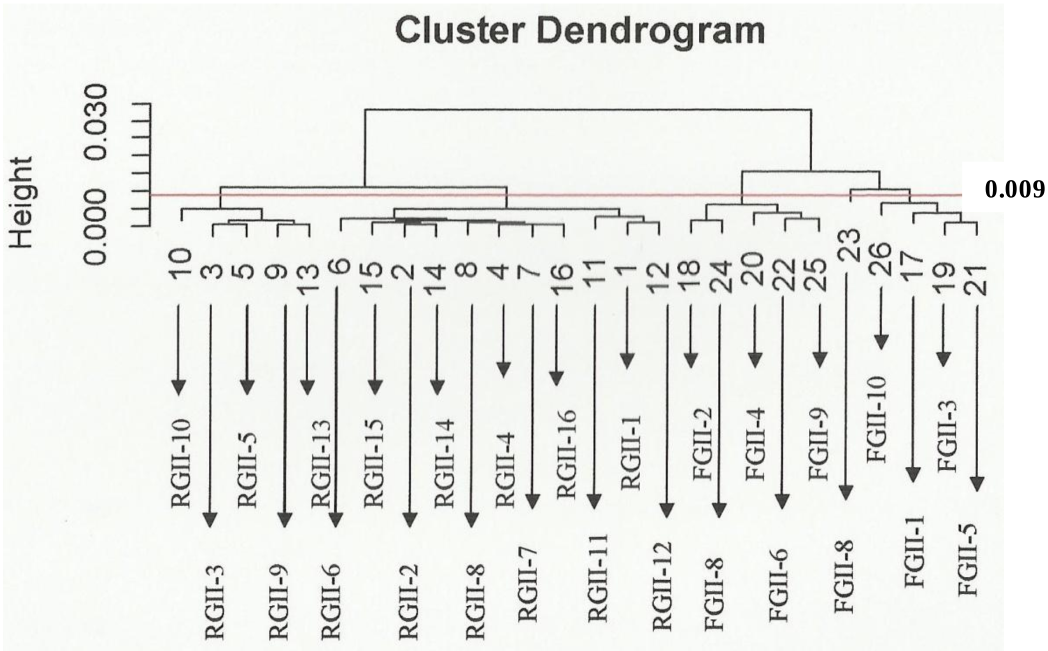


Figure 4.22 Grouping of real & fake coins by euclidean distance using Cu and Fe values and 0.009 height

To recapitulate the results;

1. Cu and Fe values, when used simultaneously, were able to completely differentiate fake coins from the real ones.
2. Real coins were collected in five different groups in terms of Cu / Fe ratio. However, real coins were collected in two different groups in terms of individual Cu and Fe values.
3. Fake coins were collected in two different groups in terms of Cu / Fe ratio. However, fake coins were collected in three different groups in terms of individual Cu and Fe values.
4. Although using Cu / Fe seemed more efficient, actually individual Cu and Fe values differentiated fake coins from the real ones more successfully than the other.

Pb / Fe Ratio

As seen in Figure 4.23 Pb / Fe ratio did not completely diferentiate fake coins from the real ones; sixteen real coins (1 – 16) were collected in three different groups. Ten fake coins (17 – 26) were collected in two different groups.

The real coins (1, 2, 3, 5, 6, 14 and 15) were collected in the first group. Lead values were changing in the range 0.0023 - 0.0093 (average being 0.0048). Iron values were not detected by the spectrometer and completed by using minimum detection limit of the element.

Other real coins (4, 7 – 10, 12, 13 and 16) were collected in the second group. Lead values were changing in the range 0.0016 - 0.0085 (average being 0.0051). Iron values were changing in the range 0.00079 - 0.0014 (average being 0.0007).

Some coins (11 and 17 - 19) were collected in one group. One of them was a real coin (11) and remaining three of them were fake coins (17 - 19). Lead value of one real coin was 0.0011 and its iron value was 0.0011. Lead values of three fake coins were 0.00053, 0.0005, 0.00045 and their iron values were 0.0017, 0.001 and 0.0015.

The fake coins (20 - 26) were collected in the first group. Lead values were changing in the range 0.00017 - 0.00050 (average being 0.0002). Iron values were changing in the range 0.00078 - 0.0071 (average being 0.0037).

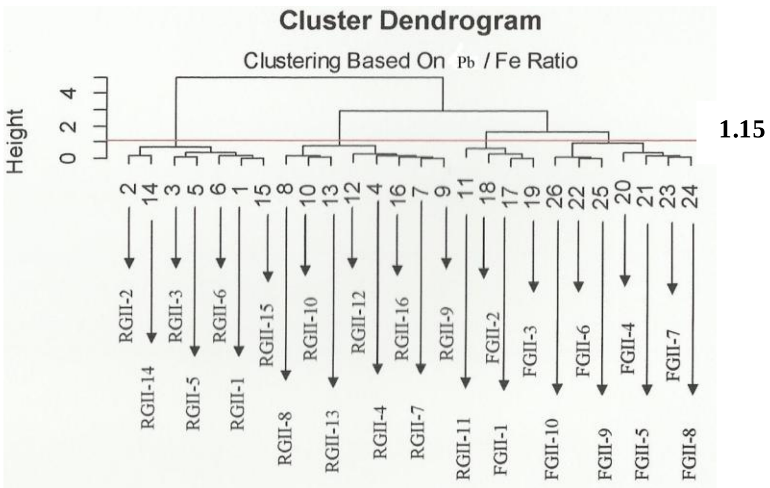


Figure 4.23 Grouping of real & fake coins by log ratio distance using Pb / Fe ratio and 1.15 height

To recapitulate the results;

1. Pb / Fe ratio was not able to completely differentiate fake coins from the real ones.
2. Sixteen real coins (1 - 16) were collected in two different groups. Pb / Fe ratio of the real coins (1 – 3, 5, 6, 14 and 15) that were collected in first group was 480 whereas Pb / Fe ratio of the remaining real coins (4, 7 – 10, 12, 13 and 16) that were collected in the second group was 7.3185. Those two ratios imply that there is a quality difference in production of real coins. Real coins that are collected in the first group are higher in quality than those in the second group.
3. Fake coins (20 - 26) were collected in one group. Pb / Fe ratio of them was 0.1276.

Pb and Fe Values

As seen in Figure 4.24 Pb and Fe values did not completely differentiate fake coins from the real ones. Sixteen real coins (1 - 16) were collected in three different groups. Ten fake coins (17 - 26) were collected in two different groups.

The real coins (2, 7 and 12) were collected in the first group. Lead values were changing in the range 0.0081 - 0.0093 (average being 0.0086). Iron values were changing in the range 0.00001 - 0.00079 (average being 0.0004).

Other real coins (1, 4, 9, 14 and 16) were collected in the second group. Lead values were changing in the range 0.0046 - 0.0063 (average being 0.0051). Iron values were changing in the range 0.00001 0.00065 (average being 0.0002).

Another fake coins (20, 22, 25 and 26) were collected in the third group. Lead values were changing in the range 0.00019 - 0.0005 (average being 0.0003). Iron values were changing in the range 0.0041 - 0.0071 (average being 0.0056).

Some coins (11, 13, 17 – 19, 21, 23 and 24) were collected in one group. Two of them were real coins (11 and 13). Lead values of those coins were 0.0011, 0.0016 and their iron values were 0.0011 and 0.00065. Six of them were fake coins (17 – 19, 21, 23 and 24). Lead values of those coins were 0.00053, 0.0005, 0.00045, 0.00018.

0.00048, 0.00017 and their iron values were 0.0017, 0.001, 0.0015, 0.001, 0.0019 and 0.00078.

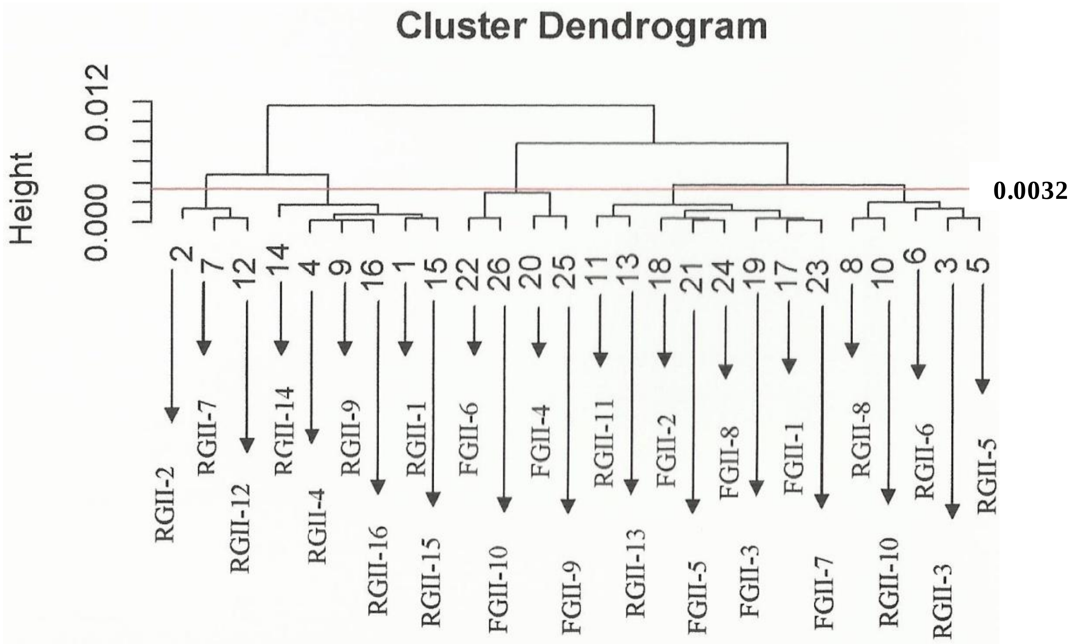


Figure 4.24 Grouping of real & fake coins by euclidean distance using Pb and Fe values and 0.00325 height

To recapitulate the results;

1. Pb and Fe values, when used simultaneously, were not able to completely differentiate fake coins from the real ones.
2. Real coins were collected in three different groups in terms of both for Pb / Fe ratio and individual Pb and Fe values.
3. Fake coins were collected in two different groups in terms of both for Pb / Fe ratio and individual Pb and Fe values.
4. Coins were separated into equal number of groups both by using ratio and individual values. More to the point, fake coins were not differentiated from the real coins. Real coins have higher amounts of Pb in their chemical contents than fake coins. However, fake coins have higher amounts of Fe in their chemical contents than real coins. Due to this difference coins might be collected in different groups.

4.1.2.2 RESULTS OF t-test

In the following tables, results for three element ratios are given as they are the three that were able to differentiate fake Greek coins of the reign of Alexander the Great (323 – 336 BCE) from the real Greek ones of the same period.

In Table 4.5, descriptive statistics are given. For details of the table, please refer to page 66. Standard deviation is computed using the following formula.

$[(-0.18 - -0.29)^2+(-0.88 - -0.29)^2+(0.40 - -0.29)^2+(-0.61 - -0.29)^2+(0.48 - -0.29)^2+(-2.55 - -0.29)^2+(-0.67 - -0.29)^2+(-0.62 - -0.29)^2+(0.16 - -0.29)^2+(0.46 - -0.29)^2+(0.65 - -0.29)^2+(-0.53 - -0.29)^2+(0.69 - -0.29)^2+(-0.62 - -0.29)^2+(-0.36 - -0.29)^2+(-0.60 - -0.29)^2]/15$

On the other hand, Std. Error is computed using following formula. $0.8112 / \sqrt{16}$

Table 4.5 Descriptive statistics for Greek coins which were dated back to Reign of Alexander the Great (323 – 336 BCE)

Descriptive Statistics

	Type	N	Mean	Std. Deviation	Std. Error
Ag / Cu	0	16	2,6694	±,7099	,1774
	1	10	1,6220	±,0824	,0260
Ag / Pb	0	16	2,3775	±,2576	,0644
	1	10	3,4740	±,2041	,0645
Cu / Pb	0	16	-,2998	±,8112	,2028
	1	10	1,7498	±,4435	,1402

Table 4.6 Results of independent samples t test for Greek coins which were dated back to Reign of Alexander the Great (323 – 336 BCE)

In Table 4.6, obtained results from independent samples t-test for Greek coins which were dated back to reign of Alexander the Great (323 - 336 BCE) were presented. For the groups based on Ag / Cu ratio, the hypothesis on the equality of the variances is rejected (p-value of the Levene's test is 0.041 and is less than 0.05). Therefore t-test results corresponding to the unequal variance assumption should be used.

The p-values are much smaller than significance level (0.05) in this table. This implied that there is a statistically significant difference between real and fake coins in terms of Ag / Cu, Ag / Pb and Cu / Pb ratios.

The statistical power of the two sample t test is found to be above 95% for testing the equality of group means where group sizes are 16 and 10 at the significance level of 5% (SAS 9.2). This means that even if there is a one unit difference between the element ratio averages of the population of fake and population of real coins, the test is able to discover it 95% of the time based on the sampled data.

CHAPTER 5

CONCLUSION

In this study, forty coins were investigated. Some of those coins were real (twenty two coins) and the remaining ones were fake (eighteen) coins. Those coins were obtained from coin section of Museum of Anatolian Civilizations (MAC) in Ankara.

In order to differentiate fake coins from the real ones weights and diameters of the samples were measured and chemical compositions of the coins were determined by using portable X – Ray Fluorescence (PXRF) spectrometer. The statistical program R 2.14.0 and statistical software package SPSS 16.0 were used for statistical analysis of the data. Cluster Analysis and two sample t-test were employed for the statistical evaluation of the data. Dendograms were constructed to visualize the statistical results obtained. In the light of the results obtained the following conclusions may be drawn;

As mentioned before (Chapter 3) the coins studied were of two different periods namely, middle of the fifth centrury BC(~450 BCE) and fourth century BC (323 – 336 BCE).

Greek coins dated back to middle of the fifth century BCE;

- Real and fake Greek coins resemble to each other according to their diameters. However, weights of the real coins did not resemble to weights of the fake coins.

- Average silver percentage in real Greek coins was 96.97. This average was 91.63 in fake coins. Fake coins are lower than real coins in terms of their silver values.
- Average copper percentage in real Greek coins was 1.10. This average was 6.58 in fake coins. Forgers implemented a decrease in silver values by increasing copper values.
- Based on the results of the statistical analysis, a kind of "Forgery Reference Chart" that can be used in differentiating fake coins from the real ones is developed (Table 5.1)

Table 5.1 Forgery Reference Chart for Greek coins which were dated back to middle of the fifth century BCE

VARIABLES	ABILITY TO DIFFERENTIATE
Ag / Cu	differentiated
Ag - Cu	differentiated
Ag / Pb	not differentiated
Ag - Pb	differentiated
Ag / Fe	not differentiated
Ag - Fe	not differentiated
Cu / Pb	differentiated
Cu - Pb	differentiated
Cu / Fe	not differentiated
Cu - Fe	differentiated
Pb / Fe	differentiated
Pb - Fe	not differentiated

This table can be used as a reference table when a new coin arrives to the museum. The researcher can select the proper element pair or ratio based on the table to identify the new arrival as fake or real. One should remember that since the data are compositional data, the ratios should always be taken into account in forgery analysis.

In selecting the proper element pair it should be taken into account the correlation should be both negative and as high as possible in present case Ag and Cu (first and second elements) can differentiate fake coins from the real ones both in terms of ratio and individual values (r = -0.973). Cu and Pb (second and fourth elements) can differentiate fake coins from the real ones both in terms of ratio and individual values (r = 0.533).

Ag and Pb (first and fourth elements) partly differentiate fake coins from the real ones. Ratio cannot differentiate fake coins from the real ones whereas individual values differentiated fake coins from the real ones (r = 0.426). Cu and Fe (second and third elements) partly differentiate fake coins from the real ones. Fake coins cannot be differentiated from the real ones in terms of ratio whereas individual values can differentiate fake coins from the real ones (r = 0.322). Pb and Fe (fourth and third elements) partly differentiate fake coins from the real ones. Ratio can differentiate fake coins from the real ones whereas individual values cannot differentiate fake coins from the real ones (r = -0.415).

Ag and Fe (first and third elements) cannot differentiate fake coins from the real ones both in terms of ratio and individual values (r = -0.44).

Greek coins which were dated back to reign of Alexander the Great (322 – 336 BCE)

- Real and fake Greek coins resemble to each other according to their weights and their diameters.
- Average silver percentage of real Greek coins was 98.97. This average was 96.93 in fake coins. Fake coins are lower than real coins in terms of their silver values.
- Average copper percentage of real coins was 0.38. This average was 2.31 in fake coins. Forgers implemented a decrease in silver values by increasing copper values as in the coins which were dated back to middle of the fifth century BCE.
- A kind of “Forgery Reference Chart” that can be used to differentiate fake coins from the real ones is developed (Table 5.2)

Table 5.2 Forgery Reference Chart for Greek coins which were dated back to reign of Alexander the Great (322 – 336 BCE)

VARIABLES	ABILITY TO DIFFERENTIATE
Ag / Cu	differentiated
Ag - Cu	differentiated
Ag / Pb	differentiated
Ag - Pb	differentiated
Ag / Fe	not differentiated
Ag - Fe	differentiated
Cu / Pb	differentiated
Cu - Pb	differentiated
Cu / Fe	not differentiated
Cu - Fe	differentiated
Pb / Fe	not differentiated
Pb - Fe	not differentiated

In this case, both negative and high correlation in selecting the proper element pair is used as in previous case. Ag and Cu (first and second elements) can differentiate fake coins from the real ones both in terms of ratio and individual values (r = -0.931). Ag and Pb (first and third elements) can differentiate fake coins from the real ones both in terms of ratio and individual values (r = 0.628). Cu and Pb (second and third elements) can differentiate fake coins from the real ones both in terms of ratio and individual values (r = -0.787).

Ag and Fe (first and fourth elements) partly differentiate fake coins from the real ones. Ratio cannot differentiate fake coins from the real ones whereas individual values can differentiate fake coins from the real ones (r = -0.71). Cu and Fe (second and fourth elements) partly differentiate fake coins from the real ones. Ratio cannot differentiate fake coins from the real ones whereas individual values can differentiate fake coins from the real ones (r =0.56).

Pb and Fe (third and fourth elements) cannot differentiate fake coins from the real ones both in terms of ratio and individual values (r = -0.518).

Further Study

A further study can be suggested as follows;

By using the same non-destructive method (PXRF) and statistical method (Clustering Analysis), Greek, Roman and Byzantine coins of various different periods will be planned to analyze.

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APPENDIX A

PETITION TO MAC

ANADOLU MEDENİYETLERİ MÜZESİ MÜDÜRLÜĞÜNE

Ortadoğu Teknik Üniversitesi Arkeometri Ana Bilim Dalında Yüksek Lisans öğrencisiyim.

Yüksek Lisans tezimde müzenizde orijinalleri bulunan 30 adet sahte sikkeye ve yaklaşık 100 orijinal sikkeye XRF analizi yaparak sonuçlar üzerinde istatistik çalışması yapmak istiyorum.

Bilgilerinize saygılarımla arz ederim 22.02.2011.

Çevre sokak Farabi Apartmanı
1/17 Çankaya /Ankara

İçten TANSEL
İçten

APPENDIX B

ACCEPTANCE OF THE PETITION

ANADOLU MEDENİYETLERİ MÜZESİ MÜDÜRLÜĞÜNE

ODTÜ Arkeometri Yüksek Lisans öğrencisi İçten TANSEL 22.02.2011 tarihinde verdiği dilekçede müzemizde bulunan sahte ve gerçek sikkeler üzerinde tez çalışması yapmak istediğini belirtmektedir.

İçten TANSEL'in tez çalışması için sikke bölümümüzde çalışma yapması tarafımızca uygun görülmektedir 02.03.2011.

Arkeolog
Ülkü DEVECİOĞLU

Arkeolog
Mahmut AYDIN

T.C.
ANKARA VALİLİĞİ
İL KÜLTÜR VE TURİZM MÜDÜRLÜĞÜ
ANADOLU MEDENİYETLERİ MÜZESİ MÜDÜRLÜĞÜ

Sayı : B.16.0.KVM.4.06.00.01.230.06- 338
Konu : Bilimsel Müze Araştırması

ANKARA

02 Mart 2011

Sayın İçten TANSEL
Çevre Sok. Farabi Apt. No:1/17 Çankaya/ANKARA

İLGİ: 22.02.2011 tarihli dilekçeniz.

Müzemiz Müdürlüğü bünyesinde bulunan sahte ve gerçek sikkeler üzerinde tez çalışması yapmak istediğinizi belirten, ilgi yazıda kayıtlı dilekçeniz incelenmiştir.

Söz konusu çalışma talebiniz, Müdürlüğümüzce uygun görülmektedir.

Bilgilerinizi ve gereğini rica ederim.

Melih ARSLAN
Müze Müdürü

Ek :Uzman raporu (1 adet)

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Sayı : B.16.0.KVM.4.06.00.01.230.06- 338
Konu : Bilimsel Müze Araştırmaları

ANKARA

02 Mart 2011

Sayın İçten TANSEL
Çevre Sok. Farabi Apt. No:1/17 Çankaya/ANKARA

İLGİ : a)10/08/1984 tarih ve 18485 Sayılı Resmi Gazete'de yayımlanan Kültür ve Tabiat Varlıklarıyla İlgili Olarak Yapılacak Araştırma, Sondaj ve Kazılar Hakkında Yönetmelik.
b)26/01/1984 tarih ve 18293 Sayılı Resmi Gazete'de yayımlanan Müzelerle Müzelere Bağlı Birimlerde ve Örenyerlerindeki Kültür Varlıklarını Film ve Fotoğraflarının Çekilmesi Mülaj Ve Kopyalarının Çıkarılması Hakkında Yönetmelik.
c)Bakanlığımız Kültür Varlıkları ve Müzeler Genel Müdürlüğü'nün 27/03/2001 tarih ve 2487 sayılı yazısı.
d)Bakanlığımız, Döner Sermaye İşletmesi Merkez Müdürlüğü'nün 20/04/2009 tarih ve B.16.1 DÖS.0.05.00.00/75250 sayılı yazısı.
e)Bakanlığımız Kültür Varlıkları ve Müzeler Genel Müdürlüğü'nün 06/05/2010 tarih ve 95218 sayılı yazısı eki.Bakanlık Makamının 06/05/2010 tarih ve 95217 sayılı onayı.
f)22.02.2011 tarihli başvurunuz.

Müzemiz Müdürlüğü bünyesinde bulunan"sahte ve gerçek sikkeler'' konusu ile ilgili olarak,

- Çalışmanın ilgi (a),(b), (c), (d) ve (e)'de kayıtlı yazı, genelge ve yönetmelikler kapsamında gerçekleştirilmesi,
- Çalışmanın başlayacağı tarihin Müze Müdürlüğü'ne 15 gün önceden bildirilmesi ve randevu alınarak çalışılması,
- Çalışılacak eserlerin kazı malzemesi olması durumunda, Kazı Başkanından yazılı izin alınması ve Müzeye ibraz edilmesi,
- Müze Müdürlüğü'nün belirleyeceği şartlara uyulması ve gerekli güvenlik önlemlerine riayet edilmesi,
- Müze Müdürlüğü'nce uygun görülen eserler üzerinde çalışılması ve teşhir düzeninin bozulmaması,

Koşullarıyla, 2011 yılında araştırma yapılması ve fotoğraf çekilmesi Müdürlüğümüzce uygun görülmektedir.

Çalışmanın tamamlanmasının ardından hazırlanacak araştırma metni, çizim, fotoğraf v.b. belgeyi içeren, mümkünse CD ortamına aktarılmış çalışma raporu ile ileride yayımlanması halinde kitap ve ayrı basımların Müze Müdürlüğü'ne gönderilmesi gerekmektedir.

Söz konusu çalışmanın tamamlanamaması ve 2012 yılında da araştırmaya devam edilmesinin istenmesi halinde, öngörülen çalışma tarihinden 3 ay önce olmak üzere, 31 Aralık 2011 tarihine kadar araştırmacının mensubu bulunduğu bilimsel kurum veya kuruluş vasıtasıyla talepte bulunulması hususunda bilgi ve gereğini rica ederim.

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APPENDIX C

PERSONAL COMMUNICATION LIST

<u>Devecioğlu, personal communication</u>

Ülkü DEVECİOĞLU – Archaeologist at MAC’s Coin Section

<u>Aydın, personal communication</u>

Mahmut Aydın – Archaeologist at MAC’s Coin Section