AUTHENTICITY OF ROMAN IMPERIAL AGE SILVER COINS USING NON-DESTRUCTIVE ARCHAEOMETRIC TECHNIQUES

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

BY

MAHMUT AYDIN

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

FEBRUARY 2013

Approval of the thesis:

AUTHENTICITY OF ROMAN IMPERIAL AGE SILVER COINS USING NON-DESTRUCTIVE ARCHAEOMETRIC TECHNIQUES

submitted by **MAHMUT AYDIN** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Department of Archaeometry, Middle East Technical University by,**

Prof. Dr. Canan ÖZGEN
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Ümit ATALAY
Head of Department, **Archaeometry** _______________

Prof. Dr. O. Yavuz ATAMAN
Supervisor, **Chemistry Department, METU** _______________

Dr. Abdullah ZARARSIZ
Co-supervisor, **Turkish Atomic Energy Authority** _______________

Examining Committee Members:

Prof. Dr. Ali KALKANLI
Metallurgical and Material Engineering Dept., METU _______________

Prof. Dr. O.Yavuz ATAMAN
Chemistry Department, METU _______________

Prof. Dr. Orhan ATAKOL
Chemistry Department, Ankara University _______________

Assoc. Prof. Dr. Jan Krzysztof BERTRAM
Settlement Archaeology Department, METU _______________

Assist. Prof Dr. Zeynep KALAYLIOĞLU
Statistics Department, METU _______________

Date: **11.02.2013**

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: MAHMUT AYDIN

Signature:

ABSTRACT

AUTHENTICITY OF ROMAN IMPERIAL AGE SILVER COINS USING NON-DESTRUCTIVE ARCHAEOMETRIC TECHNIQUES

Aydın, Mahmut
Ph.D., Department of Archaeometry
Supervisor: Prof. Dr. O. Yavuz Ataman
Co-Supervisor: Dr. Abdullah Zararsız

February 2013, 201 pages

Imitation of archeological artifacts or replacing the authentic ones with fake replicates is a universal problem; it is particularly important in Turkey for historical metal objects. Traditionally used visual inspection methods alone are not sufficient for the solution of contemporary problems. In this study, chemical characterization has been used to determine the differences between the authentic and fake objects. The non-destructive analyses were carried out by Portable X-ray Fluorescence Spectrometry (P-XRF). Silver Roman Coins (27 B.C. to 244 A.D.) were the objects handled in this research. In particular the concentrations of Zr, Pt, Pb and Bi were used for differentiation; it has been observed that the concentrations have different trends in the authentic and fake silver coins. In authentic coins the average Pb concentration was found to be 0.77%, while this value was 0.055% for the fake ones. Bi could be determined in 86% of the authentic coins while it could not be detected in any fake coin. It has been generally observed that the silver and copper concentrations could not be utilized in authenticity tests. Another approach was the use of Line Scanning Electron Microscopy-Energy Dispersive X-Ray Fluorescence Spectrometry (LSEM-EDX). Using LSEM-EDX technique, it was observed that the concentration changes near the interface between the matrix and the copper-rich locations exhibits difference behaviors for the authentic and fake objects. This difference is originated by the fact that a newly formed copper amalgam contains copper-rich phases while with extended time concentration changes at interfaces become more gradual or not detectable. Pearson correlation was used in order to elucidate the relations between the element concentrations determined by P-XRF. In order to see whether the authentic and silver fake coins can form separate groups, dendograms have been constructed utilizing SPSS 16.0 software and Euclidian Square Distance method. It has been observed that the authentic and fake coins can be successfully grouped when the proper statistical choices are used. It has been observed that these groups have significant differences using t-test. The selected and used technology is proposed for use by museums and entities keeping archaeological collections in order to prevent forgeries.

Keywords: Authenticity of Coin, Counterfeit Coin, Portable X-Ray Fluorescence Spectrometry (P-XRF), Scanning Electron Microscopy (SEM)

ÖZ

ARKEOMETRİK YÖNTEMLERLE ROMA İMPARATORLUK DÖNEMİ GÜMÜŞ SİKKELERİNDE OTANTİKLİK SAPTANMASI

Aydın, Mahmut
Doktora, Arkeometri Bölümü
Tez Yöneticisi: Prof. Dr. O.Yavuz Ataman
Ortak Tez Yöneticisi: Dr. Abdullah Zararsız

Şubat 2013, 201 sayfa

Arkeolojik buluntularda gerçek (otantik) olanların taklit edilmesi veya gerçek eserlerle sahte kopyalarının değiştirilmesi evrensel bir sorundur; Türkiye'deki tarihi metal eserlerde özellikle önemlidir. Gerçek ve sahte eserlerin farkını anlamak için geleneksel olarak görsel inceleme metotları kullanılmaktadır; ancak yalnız bu yöntemlerin kullanılması çağımızın ihtiyaçlarına cevap vermekten uzak kalmıştır. Bu çalışmada gerçek ve sahte eserler arasındaki farkı belirlemek için kimyasal karakterizasyon kullanıldı. Tahribatsız analizler, taşınabilir X –Işınları Floresans Spektrometri (P-XRF) ile yapıldı. Çalışmada, Roma İmparatorluk Dönemine (M.Ö. 27-M.S. 244) ait seçilmiş gümüş sikkeler incelendi. Farklılaştırma için özellikle Zr, Pt, Pb ve Bi derişimleri incelendi; derişimlerin orijinal ve sahte gümüş sikkelerde farklılıklar gösterdiği saptandı. Otantik sikkelerde ortalama %0.77 Pb bulunurken sahtelerde bu değerin %0.055 olduğu görüldü. Bi orijinallerin %86'sında tayin edildi ancak sahtelerin hiç birinde gözlenemedi. Gümüş ve bakır derişimlerinin otantiklik saptamalarında çoğunlukla yararlı olamadığı görülmüştür. Kullanılan diğer bir yaklaşım ise Çizgide Tarayan Elektron Mikroskopi-Enerji Dağılımlı X Işınları Floresans Spektrometri (LSEM-EDX) tekniği idi. LSEM tekniği kullanarak, gerçek ve sahte sikkelerde bakırca zengin noktalarla ana matriks ara yüzeyindeki derişim değişmelerinin sahte ve gerçek sikkelerde oldukça farklı özellikler gösterdiği saptandı. Bu farkın nedeni, yakın geçmişte oluşturulmuş bakır içeren alaşımlarda bulunan bakırca zengin noktaların kolayca bulunması, ancak aradan geçen zaman içinde ana matriks ile ara yüzeyde derişim değişikliklerinin daha az, hatta gözlenemez hale gelmesidir. P-XRF ile bulunan derişim değerlerinden elementlerin birbiriyle ilişkilerini anlamak için Pearson Korelasyonu kullanarak korelasyonlar bulundu. Sahte ve orijinal sikkelerin gerçekten farklı gruplardan oluşup oluşmadığını anlamak için SPSS 16.0 programı ve Euclidian Square Distance methodu kullanılarak dendrogramlar çizildi. Sahte ve orijinallerin doğru elementler ve doğru methodlar kullanılarak ayrı gruplara başarıyla bölünebildiği görüldü. Gruplamanın anlamlı olduğu yine SPSS 16.0 kullanılarak yapılan t-test ile saptanmıştır. Seçilen ve kullanılan yöntemlerin, müzelerde ve koleksiyon oluşturan kurumlarda sahteciliğe karşı önleyici olarak kullanılması önerilmektedir.

Anahtar Kelimeler: Sikkelerin Otantikliği, Sahte Sikke, Taşınabilir X-Işını Floresans Spektrometri (P-XRF), Taramalı Elektron Mikroskopi (SEM)

To the memory of my father
who wanted to see today

ACKNOWLEDGEMENTS

I express my deepest gratitude to my supervisor Prof. Dr. O. Yavuz ATAMAN, co-supervisor Dr. Abdullah ZARARSIZ, Prof. Dr Ali KALKANLI and Assoc. Prof. Dr. Jan Krzysztof BERTRAM for their valuable guidance, contributions, helps and patience.

I would like to thank Prof. Dr. Şahinde DEMİRCİ for her very valuable help and encouragements.

I would like to thank Prof. Dr. Aymelek ÖZER and Prof Dr. Şahinde DEMİRCİ for their valuable contributions to establish Department of Archaeometry and to give extraordinary effort to increase the awareness about archaeometry.

I am thankful to Assist. Prof. Dr. Zeynep Işıl KALAYLIOĞLU who guided me for statistical applications. I am also thankful to İçten TANSEL who helped me in the execution of statistical computations.

I would like to thank Assist. Prof. Dr. Ali Akın AKYOL who encouraged me to select this important subject.

I would like to thank Cengiz TAN who helped in Line Scanning Electron Microscopy-EDX analyses.

I would like to thank the Museum of Anatolian Civilizations (MAC). My special thanks go to Melih ARSLAN and Ülkü DEVECİOĞLU who shared with me their valuable knowledge and experience in numismatics.

I would like to thank Sabiha PAZARCI (Director of Uşak Museum) who was providing to me the most of fake samples used in this thesis.

I thank Jale VELİBEYOĞLU and Prof. Dr. Numan TUNA who encouraged and gave me support in METU. They are the reasons of this success.

I thank to my wife, my twins who let me study after they slept, their valuable support, patience and encouragements throughout this study process.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

ABBREVATIONS

A: Authentic
AAS: Atomic absorption spectrometer
A.D.: Anno Domini (After Christ Born)
ARant: Antoninianus (Bronze coin plated with silver)
B.C.: Before Christ Born
CRM: Certified Reference Material
D: Diameter
EDX: Energy Dispersive X-ray
F: Fake
ICP-OES: Inductively coupled plasma optical emission spectrometry
ICP-MS: Inductively coupled plasma mass spectrometry
Inv: Inventory
LC: Little Corrosion
LSEM-EDX: Line Scan Electron Microscopy coupled with energy dispersive X-ray
MAC: The Museum of Anatolian Civilizations
MC: Much corrosion
NAA: Neutron activation analysis
ND: Not detected
Obv: Obverse
O PH: Obverse with pin hole
O WPH: Obverse without pin hole
PIXE: Proton induced X-ray emission spectrometry
P-XRF: Portable X-ray florescence spectrometer
Rev: Reverse
R PH: Reverse with pin hole
R WPH: Reverse without pin hole
RSD: Relative standard deviation
SEM: Scan electron microscopy
TAEK: Turkish Atomic Energy Agency Authority
TMC: Too much corrosion
TMP: Too much patina
XRD: X-ray diffraction spectrometry
XRF: X-Ray Florescence
W: Weight
WC: With corrosion

CHAPTER 1

INTRODUCTION

Coins are important objects of the cultural heritage. They are usually of high artistic and cultural value. In addition, the iconography and/or writing on the coins help to determine the date of minting of coins. They may directly show the production city or country and even the exact year of production.

It is obvious that commercial activities between people require some materials to be used. Those materials should be sustainable, readily available and if possible be valuable. It is clear that coins have been one of the most significant tools of valuable materials throughout history up today. The value of the coin is related to its production materials. Coins are produced from precious and noble metals, like gold, silver and some valuable amalgams. As the value of the coin increases in time, production of fake (counterfeit) coins started and put into circulation (Tansel 2012).

The crime of counterfeit currency is one of the most serious problems in the world (Suzuki 2007). This is valid not only for present time but also for ancient times. The Mediterranean Middle East have been traditionally the main centre of ancient coins counterfeiting but, in the last few years, most of the fakes, found in the international numismatic market, has been proved to come from Bulgaria, Yugoslavia and Sicily (Mezzasalma et al. 2009). It is clear that experts of museums must improve their knowledge about forging technology to be able to cope with the growing amount of fake coin works. In Turkey like in the most of the other countries museums buy coins from individuals. Therefore authenticity is an important subject to be taken into account to protect museums from counterfeit objects which have low artistic value and to save our financial resources.

It is known on inspection that too many fake coins have been bought by museum's experts within the last decade in the museums of Turkey. Of course this is not happening only during the last decades; this must have been continuing for a long time and its extend is not exactly known.

There are two sources for coin entrance to the museum. One is related with archaeological excavations; the second source is the individuals who try to sell the coins they have. The second source is the main subject of the counterfeit. Therefore the coins from the second source are taken into consideration firstly.

In the Museum of Anatolian Civilizations (MAC) the coins of Lydian, Greek, Roman, Byzantium and Islamic period (including Seljuk, Ottoman and others) were collected in a certain section called coin section.

The highest abundance of fake coins happen to belong to Roman Imperial Period. In addition these coins were not studied in any way as far as we know. Therefore in this thesis Roman Imperial Coins were selected for examination. In the study, the samples were handled together without any distinction whether it is fake or real. Documentation of the samples was prepared according to their emperor, source of acquiring and by taking their photographs. For each sample, all possible analytical methods including P-XRF and SEM-EDX were applied to obtain chemical compositions. In addition some physical properties including weight and diameter were measured to be used in final discussion of the result.

Other aim of thesis was statistical evaluation of the experimental results. Statistical treatment will help to distinct fake coins from real ones. For this purpose various statistical methods were applied and cluster analysis was found to be the proper method.

This thesis beside this firs introductory chapter, background information on forgery is given in the second chapter. Chapter 3 contains archaeometric techniques used; Chapter 4 includes materials and methods. The discussion and results has been explained in Chapter 5. The conclusions of the result have been collected in Chapter 6.

CHAPTER 2

BACKGROUND INFORMATION ON FORGERY

In this chapter background information on forgery was explained.

The Italian Renaissance saw a wide spread revival of interest in the classical world, Greek and Roman. Desire for Greek and Roman artifacts fed market not only for items of antiquity, but for contemporary creations based on ancient themes. Almost as quickly as this desire emerged, forgeries of antiquities and coins were produced to feed the market. As early as 1555 AD the Italian Numismatist Enea Vico included a section on the issue of forgeries in his book named *"Discorsi sopra le Medaglie degli Antichi".* The warnings of Vico read much like the warnings one might hear today about re-engraving or tooling cast, modern die struck specimens etc. (Sayles 2000).

As the world became increasingly scientific in the 17th and 18th centuries, the nature of forgeries changed. The rise of specialization during this period presented to forgers of the day an irresistible challenge. For the first time in the long history of making fakes, a conscious effort was made to produce items specifically for collectors' consumptions (Sayles 2000).

In the post renaissance, the challenge between forger and collector was really begun. For this period an important article was published by Jeffrey Spier and Jonathan Kagan. The publication was related with famous forgery of ancient coins in eighteenth century Rome (Speir and Kagan 2000).

Forgers of the 19^{th} century may not have had access to all of the technological aids that exist today. But anyhow they produced remarkable works. Even today, we are just discovering fakes that were made a century ago (Sayles 2000).

The most notable change in the nature of forgeries during the 20th century was the use of advanced technology to make precision copies of coins.

It is generally accepted that there is a clear distinction between contemporary counterfeit of ancient coins and ancient imitations. The former are generally thought as coins that were produced by individuals for aim of profit. The latter served as the official currency of political assets and were produced in emulation of another state's coinage for purposes of politics and trade. In this context, coinage of Athens, Romanian and Byzantium ancient coins were imitated by various cultures such as Celtics, Arabic, Mesopotamian Cultures and Balkans Countries (Sayles 2000).

In principle, a traditional optical analysis, in other word by visual inspection, the expert may identify a fake coin. After the first easy controls concerning the weight and the style of the pieces, the numismatist will look for and will examine all the details present on their surfaces. In fact, the technique adopted for the production of a fake generally leaves a number of characteristic macroscopic and microscopic traces which can be considered as the fingerprints of that particular technique (Mezzasalma et al. 2009). Macroscopic traces as the edges' abrasion (used to remove metal residuals) (Figure 2.1), the sharpness of lettering and that one of the fine details, the relative position of one face of the coin with respect to the other, the artificially (chemically) patinas induced to simulate the natural ageing are all examples of such fingerprints (Mezzasalma et al. 2009).

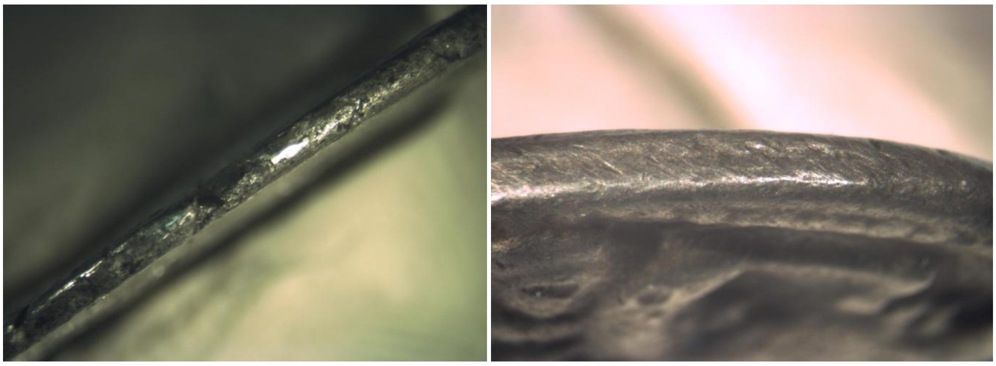


Figure 2.1: Edge of an authentic coin (Left), edge of a fake coin grinded by forger (Right), Note the edge abrasion of fake coin (Aydın and Zoroğlu 2012).

In a study done by Hida and co workers (Hida et al. 2000) a number of counterfeit coins that looked like the real coins because of their iconography, letters, feeling to the touch and the weight were examined. Most people were fooled and believed that counterfeit coins were real ones. The special money counting machines however, discovered that they were not real coins. In the study counterfeit coins were analyzed by XRD and XRF methods after measuring their diameter, thickness and weight. The results obtained were subjected to multivariate analysis such as cluster analyses and principal component analyses to classify those (Hida et al. 2000). In the study 288 samples were analyzed 277 of them were fake and the remaining were real coins. The result of all analyses showed that real coins accumulate in a separate group beside counterfeit (Hida et al. 2000).

There are essentially two main classes of fake coins. The first one is utilized to deceive non numismatic people by means of rough imitations of authentic pieces. The second class is built up by all those counterfeits that are of such a good quality to be sometime believed authentic also from experts. The second class is obviously the most dangerous one and it is the problem we are dealing with (Mezzasalma et al. 2009). The difference between these two classes should depend upon the production techniques used. Learning to recognize how coins were produced is very important in learning to judge authenticity (Sayles 2000). Therefore here, it is necessary to summarize the techniques used in forgery.

2.1 Techniques Used in Forgery

Learning to recognize how coins were produced is very important in learning to judge authenticity (Sayles 2000). Therefore here, it is necessary to summarize the techniques used in forgery.

The basic techniques are; Cast Forgeries and the die – struck forgeries. These will discuss below.

2.1.1 Cast Forgeries

Casting is one of the oldest methods known to produce an accurate copy of most coins. The greatest advantage the casting process has to offer is the totally faithful duplication of original coin **(**http://books.google.com.tr/books false, fakes, forgery).

Cast forgeries can be subdivided into four groups; Sand Mold Casting, Re-usable metal molds, lost wax casting and plastic mold casting.

2.1.1.1 Sand Mold Casting

Sand mold castings are probably the least dangerous of cast forgeries, as the fakes made this way are generally in poor quality. This kind of model casting is given in Figure 2.2. Sand and clay mold casting fakes are inexpensive and easy to make, and are generally intended for the tourist market not to deceive experienced museums experts or collectors.

Figure 2.2: An example of sand casting, note the unclear figures and traces of sand mold.

Casting Procedure: A box is constructed in halves that fit together easily. The halves are filled with fine sand and mixed with binding agent moist clay that holds the sand grains together while remaining soft. The coin to be copied is immersed into the sand on each half, and a channel is cut from the edge of the coin to the edge of the box (this is known as the feeding channel) so that when the two halves of the box are fitted together a mold is created. Molten metal is poured into the feeding channel to fill the mold. The result is a copy of the original coin with a metal "feeding" attached which is then cut off to leave just the coin (http://www.calgarycoin.com/reference/fakes/cast.htm).

2.1.1.2 Re-usable Metal Molds

Many common reproductions made for giftware are made in two-piece re-usable metal molds. The process is the same as used to make home-cast toy lead soldiers with an impression of the two sides of the coin on iron or aluminum molds that fit together easily so that molten metal can be poured in through a feeding channel. This kind of model casting is given in Figure 2.3 (http://www.calgarycoin.com/reference/fakes/cast.htm).

Figure 2.3 Re-usable metal molds for Corinthian coin fakes (http://www.calgarycoin.com/reference/fakes/cast.htm).

The advantage of this method over sand casting is that the molds are re-usable, and hundreds or even thousands of coins can be cast very quickly with just one set of molds, no sand grains to leave impressions on the surface, so the metal tends to have a smoother and natural look. However, it shares some problems in that there will be a feeding channel that has to be removed, a mold line will normally be visible around the edge and may need to be removed, and since it is even more difficult to get a fit between the parts of the mold, significant amounts of metal may squeeze out between them leaving "flashings" of extra metal on the mold lines (see Figure 2.3 left, bottom) (http://www.calgarycoin.com).

An additional problem is that metal molds are normally used cold but conduct heat quickly. This can cause molten metals with high melting points to solidify before fully filling the molds, resulting in an incomplete casting. This makes casting in silver, gold or bronze somewhat unsuitable for this method, so metals like tin, lead or zinc with low melting points are normally used and must be plated with another metal to have any chance of deceiving (http://www.calgarycoin.com).

2.1.1.3 Lost Wax Casting

Lost wax casting has two-step molding process. There are a few ways to make the first mold, but the most common is to paint a genuine ancient coin with a rubber which captures details very accurately. The rubber is vulcanized and then cut in such a way as to allow the coin to be removed but the cuts will fit back together very closely. A small feeding channel is cut, into which hot wax is injected to create very accurate wax copies of the original coin. The wax copy can be removed through the same cut the original coin was. This rubber mold can be used to make large numbers of identical wax copies of the original coin (Figure 2.4) (http://www.calgarycoin.com/reference/fakes/cast.htm).

Figure 2.4: Fake coin made with lost/flying wax cast fake (http://www.calgarycoin.com/reference/fakes/cast.htm).

The wax copies are then fitted with a fine wax spew an inch or so long, placed in a short metal tube with the spew sticking out. A substance similar to plaster of Paris, known as "investment", is poured into encase the wax with the feeding channel projecting out. When the investment hardens and dries, the tube is placed upside down in a hot kiln until the wax melts and burns out (hence the name lost-wax) leaving a cavity the exact shape of the coin, and the channel left by the wax spew provides a channel leading down from the surface of the mold.

While the mold is still hot from the kiln, molten metal is poured down the feeding channel to fill the cavity, creating a fairly accurate copy of the original coin. There are ways using steam, or just centrifugal force by spinning the mold, to force the metal more compactly into the mold, resulting in better details on the finished coin. As soon as the metal solidifies, and while the mold is still hot, it is thrown into cold water causing the investment to break up, and the coin just falls out. The feeding channel is then cut from the coin and the coin is basically finished (Figure 2.4) (http://www.calgarycoin.com/reference/fakes/cast.htm).

Lost wax castings can be much more dangerous to collectors, but require correspondingly more sophisticated equipment to make. This is a method commonly used by jewelers to make gold and silver jewelry so the equipment is readily available. Fakes made by this method are normally aimed at deceiving, although some are intended only for the jewelry market (http://www.calgarycoin.com/reference/fakes/cast.htm).

Fakes made by this method can be of much higher quality than sand casts for several reasons:

a) While a casting seam will normally be present on the wax copies, it is easily removed from the wax without a significant trace, although this is not always done. No casting seam is created in the final "investment" process, so fakes made by lost wax casting often show no visible casting traces.

b) The feeding channels are much thinner than on sand casts, so removing them and "worrying" the area to remove any sign of them is much easier, although often one can figure out where the feeding channel was.

c) While casting quality varies, if good quality equipment with pressure or force to compact the metal into the mold is used, coins made by this method can have very good surfaces and capture very fine details.

2.1.1.4 Plastic Mold Casting

Another relatively new molding technique is plastic mold casting. It involves making impressions of coins in special plastics that can survive the heat of pouring in molten metal. The resulting castings are amazingly good and very successful and thus dangerous fakes. They capture the details of genuine coin as well as lost-wax castings, with fewer stages for something to go wrong and since there is only one hot metal process they do not have the same degree of weight loss as lost-wax castings. However, they still have the problem of needing a casting feeding channel removed and will normally show traces of that feeding channel removal is normally larger than on lost-wax coins. But more importantly they still cannot capture the microscopic details that make die-struck coins look and feel like die-struck coins (http://www.calgarycoin.com/reference/fakes/cast.htm).

Figure 2.5: Plastic mold casting coin (http://www.calgarycoin.com/reference/fakes/cast.htm).

There are some fairly good diagnostics that allow these types of fakes to be detected. At this time one of the things we have noticed with them is that they tend to have a soft muted appearance that resembles coins that have been over-cleaned in acids. For the most part they are forging silver coins with this method, and it is suggested that until you get a good handle on what the fakes actually look like, it is best to avoid any coin that has a soft, slightly acid-washed or over-cleaned look to it (Figure 2.5) (http://www.calgarycoin.com/reference/fakes/cast.htm).

2.2 Electro-Types Forgery

The electrotyping process was invented sometime around 1850; almost immediately after electrical batteries good enough to manage the process were invented. It was at first an industrial process, and the first copies of coins were probably made this way some time in the mid 1850's. They can vary in quality, and the best ones would be very realistic fakes, except for one flaw all electrotypes have in common and is fairly easy to spot.

The process is rather simple, at least in theory. One side of a genuine ancient coin is impressed into a soft substance that captures the details of the coin. Normally fine clay is used, but almost any substance that will take the impression can be used. The impression is dusted with a very fine conductive powder (usually graphite), and then metal (usually copper) is electroplated onto the surface, forming a thin metal film that can have a remarkably accurate image of the original coin (http://www.calgarycoin.com/reference/fakes/electro.htm).

Figure 2.6: Coin produced in Electro –Types forgery (http://www.calgarycoin.com/reference/fakes/electro.htm).

The flaw with this process is each side of the coin must be copied separately as its own hollow metal shell, as illustrated by the electrotype of the obverse of a British medieval Cnut penny shown in Figure 2.6, and with the obverse and reverse halves shown in Figure 2.7.

To turn these two halved into a convincing fake, the edges have to be trimmed and the two halves joined. While for thin coins it may be possible to connect the two shells directly, thicker coins require the shells to be filled to give them strength and weight, prior to joining. Generally the shells are filled with lead, but even clay could be used. The choice of filling will significantly affect the weight of the finished fake (Figure 2.7) (http://www.calgarycoin.com/reference/fakes/electro.htm).

This presents the forger with three problems:

Figure 2.7: Joined shells trace of Electro types forgery (http://www.calgarycoin.com/reference/fakes/electro.htm).

a) The two halves have to be joined with a fairly strong binding agent, which usually means soldering. This joint is going to be very difficult to fit perfectly, and virtually always one can see evidence of it on the coin's edge. The example above shows the edge of the Julia Soaemias illustrated, and while more poorly joined than most, it illustrates the problem; even on good joints, traces of the line will almost always be visible (Figure 2.7).
b) Having to fill the halves makes controlling weight difficult, so electrotypes will seldom be of correct weight.

c) Electrotyping normally involves electroplating of copper, so to create fake gold or silver coins means having to then plate the finished copper fake with gold or silver, which seldom gives a convincing look.

Figure 2.8: Detail from a fake coin produced in electro type forgery (http://www.calgarycoin.com/reference/fakes/electro.htm).

The quality of electrotypes can vary considerably, with the limiting factor being how accurately the clay captured the image as the coin was impressed. As with casting, air bubbles can become trapped between the coin and the clay, resulting in depressions in the clay that show up as rounded lumps on the coin. Within the circled area, the small very round bump just under her nose is almost certainly the result of such a trapped air bubble (Figure 2.8). Another problem can occur as the coin is pulled from the clay, as bits of clay may pull away with it leaving ragged depressions in the clay, which show up as irregular bumps on the coin. The slightly irregular bump to the lower right of the nose may have been caused by this (Figure 2.8). In spite of these potential problems, if done very carefully electrotypes can capture amazingly accurate images of the original coins.

Electrotyping is no longer commonly used to make copies of ancient coins. Forgers seldom use it anymore because of the difficulty in hiding the lines on the edges, but a few museums still make them for study purposes (for which they can be very useful). Because of the problems electrotypes have caused in the past, all responsible people making such copies for study purposes will provide them only as two parts, without joining. This prevents any possible confusion with originals. However, many thousands of electrotypes were made fully joined in the late 19th and early 20th century, and they show up fairly often. One should take the time to learn how to recognize them, and be on the watch for them (http://www.calgarycoin.com/reference/fakes/electro.htm).

2.3 Die-struck Forgeries

The only way to reproduce a coin exactly is carried out by striking it from a set of dies. Only die striking is capable of duplicating every characteristic, essence, and subtle nuance of the essential fabric of an original die-struck coin.

Until the end of 18^{th} century or so, all dies for real coins were usually cut by hands using of simple tools resulting in a great many die varieties for any single coin types. Since that time dies have normally been produced by processes involving the use of sophisticated three-dimensional producing methods have been used.

There are two practical ways for forgers to create dies for struck aim; cutting by hands and mechanical cutting. The first is really only suitable for producing ancient or medieval types of coins. The other three which work well with modern coinage, have been devised refined using all sort of trick and short cut until the processes have become simple and foolproof (Figure 2.9) **(**http://books.google.com.tr/books false, fakes, forgery).

Figure 2.9: A fake coin produced in die struck technique
(http://www.calgarycoin.com/reference/fakes/struck.htm).

2.3.1 Hand Cut Dies

First forgeries (actually counterfeit) made by hand-cut dies in exactly same fashion as the originals. The designs on these earliest dies were simple, varied considerably and were often rather crudely done in time artistic quality of official dies improved and the challenge of creating convincing false dies increase correspondingly (Figure 2.10) (http://www.calgarycoin.com/reference/fakes/struck.htm).

Figure 2.10: A fake coin produced in hand cut die technique
(http://www.calgarycoin.com/reference/fakes/struck.htm).

False hand-cut dies can produce some of the most dangerous fake, if only it was cut by a very talented technical engraver. Most of the engravers attempting to cut dies are artists and so are doomed to failure because of the nature of artistic training and the artistic mind (http://www.calgarycoin.com/reference/fakes/struck.htm).

2.3.2 Mechanically Cut Dies

In this method there are machines which trace the surfaces of genuine coin and guide another machine in cutting a negative image of that coin into a new die.

The advantage of these machines is that they eliminate the artistic interpretive process that art forgers hand cutting dies. They allow them to almost perfectly capture the image and style of the original coin, but there are several problems they cannot overcome: These are as follows
a) Genuine ancient coins are not perfect copies of the ancient dies they were struck from.
b) The ancient tools used to cut ancient dies leave microscopic details on genuine ancient coins that cannot be duplicated by a modern copying machine. This is a major obstacle for such forgers.
c) The machines that trace the original coin can only do so in a set pattern with a set spacing. There is no way this can capture all the really fine details that hand cutting creates, and this minor loss of detail

creates a die that results in a coin that has a slightly "soft" look over all (Figure 2.11) (http://www.calgarycoin.com/reference/fakes/struck.htm).

Figure 2.11: A fake coin produced from mechanically cut die (http://www.calgarycoin.com/reference/fakes/struck.htm).

CHAPTER 3

ARCHAEOMETRICAL TECHNIQUES USED IN METAL ARTIFACTS

In the archaeometrical investigation of archaeological findings including artifacts two types of chemical analyses are used. These are destructive chemical analyses and non-destructive chemical analyses.

3.1 Destructive Chemical Analysis Techniques

In these techniques sample to be studied is dissolved in a convenient solvent and analyzed. The most commonly used destructive techniques are atomic absorption spectrometry (AAS), inductively coupled plasma optical emission spectrometry (ICPOES) and inductively coupled plasma mass spectrometry (ICPMS).

3.1.1. Atomic Absorption Spectrometry (AAS)

AAS is a spectroanalytical technique for the qualitative and quantitative determination of chemical elements employing the absorption of light by free atoms in the gaseous state. In analytical chemistry the technique is used for determining the concentration of a particular element (the analyte) in a sample to be analyzed. AAS can be used to determine over 70 different elements in solution or directly in solid samples (http://en.wikipedia.org/wiki/Atomic_absorption_spectroscopy 23/12/2010).

A typical AAS have sample region, light source, monocromoter and detector (Figure 3.1)

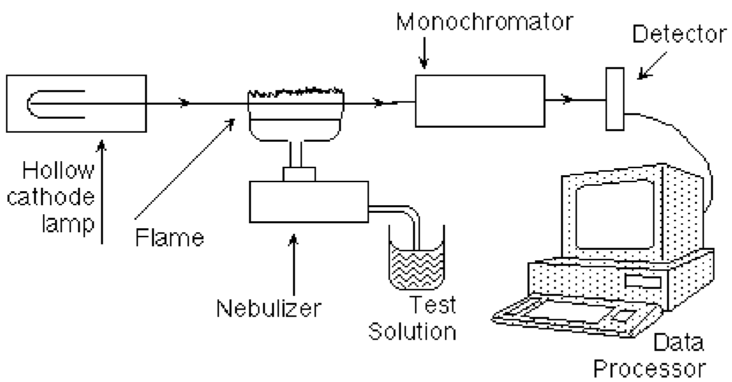


Figure 3.1: An atomic absorption spectrometer.
(http://www.chemistry.nmsu.edu/Instrumentation/AAS_schematic.gif. 23/12/2010).

3.1.2. Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)

ICP-OES is an analytical technique used for the detection of trace metals. It is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample (http://en.wikipedia .org/wiki /Inductively_coupled_plasma_ atomic_emission_spectroscopy 23/12/2010).

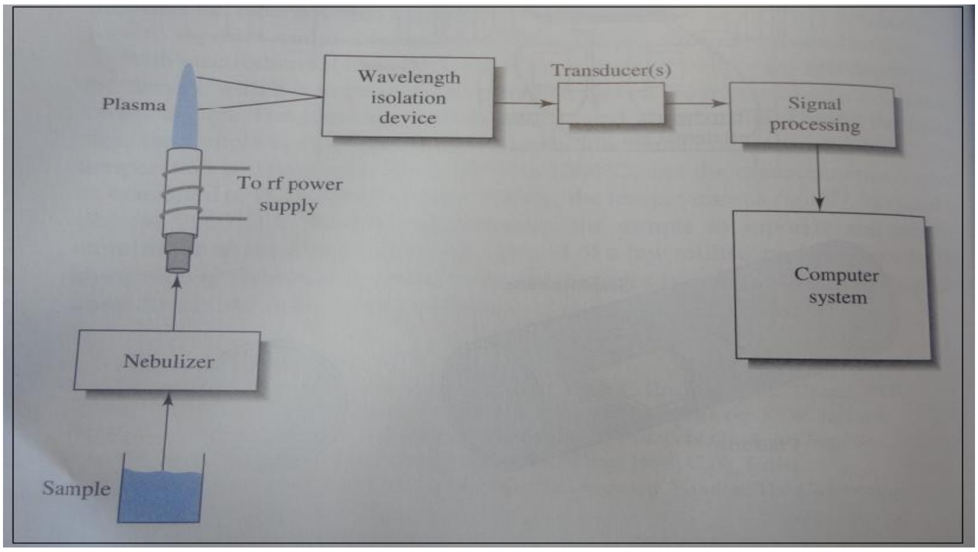


Figure 3.2: Blog diagram of ICP Mass spectrometer (Skoog et al. 2002).

3.1.3. Inductively Coupled Plasma Mass Spectrometry (ICPMS)

ICPMS is a type of mass spectrometry that is highly sensitive and capable of the determination of a range of metals and several non-metals at concentrations below one part in 10^{12} (part per trillion). It is based on coupling together inductively coupled plasma as a method of producing ions with a mass spectrometer as a method of separating and detecting the ions. ICP-MS is also capable of monitoring isotopic speciation for the ions of choice (http://en.wikipedia.org/wiki/Inductively coupled_plasma_ mass_spectrometry 23/12/2010).

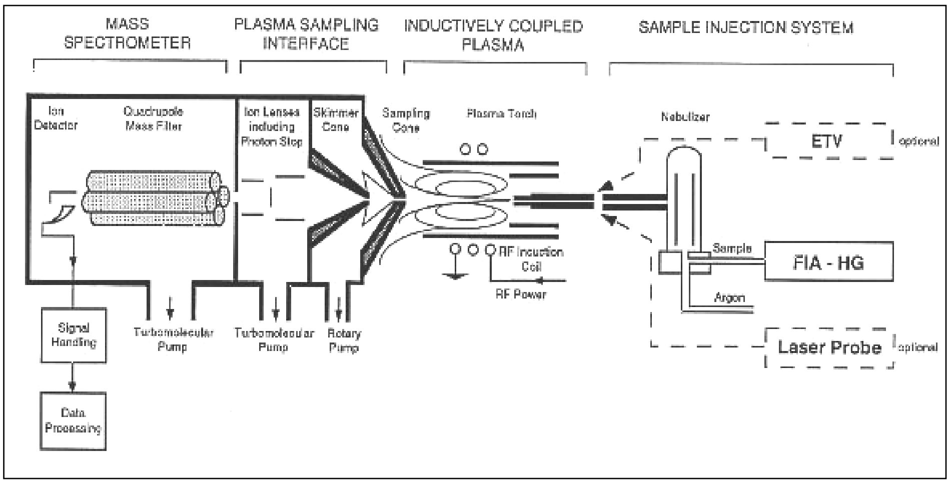


Figure 3.3: Schematic drawing of the ICP-MS system with integrated components: sample injection system, inductively coupled plasma, plasma sampling interface, mass analyzer, detector and computer (www.gso.uri.edu/icpms/ICPMS-80-75.gif 23/12/2010).

3.2 Non-Destructive Chemical Analysis Techniques

In these techniques sample to be analyzed is not dissolved in a solvent and generally no sample preparation is required before analyses. These techniques are more convenient in the study of authenticity of metal coins other archaeological artifacts. The important non-destructive techniques are X-ray fluorescence spectrometry (XRF), proton-induced X-ray emission (PIXE) and X-ray diffraction (XRD).

Authenticity of a coin refers as a way of determining whether it is real or not. It is based on the inspection and analyzes of the sample in detail. Visual inspection is a subjective method, since two experts may propose different proposal on the authenticity of the same item. In order to evaluate a coin of interest objectively non-destructive diagnostic scientific techniques must be employed (Rojas et al. 2003).

The development of non-destructive physical methods of analysis has opened new windows for the study of archaeological objects. The data obtained by the application of these methods can help the archaeologists to answer specific questions concerning dating, technology, provenance and authenticity of the objects like coins (Civici et al. 2007).

Even if a destructive analytical approach allows to obtain accurate and detailed quantitative information about the composition and structure of the alloy including ancient coins under investigation, the use of non-destructive techniques is preferable when a large number of artifacts must be analyzed or when the analysis deals with objects that must be preserved for their great historical and artistic value. This is the case in the study of ancient coins present in The Museum of Anatolian Civilizations (Rizzo et al. 2010).

PIXE is based on the characterization of the thin surface and XRF is characterization of near surface layers of the coins. However the new technique of DPAA (deep proton activation analysis) is used to determine the composition of the interior of alloy, minimizing the surface contribution (Rizzo et al. 2010).

3.2.1 X-Ray Fluorescence Analysis (XRF)

The history of X-ray fluorescence dates back to the accidental discovery of X-rays in 1895 by the German physicist Wilhelm Conrad Roentgen. Roentgen's discovery of X-rays and their possible use in analytical chemistry went unnoticed until 1913. In 1913, H.G.J. Mosley showed the relationship between atomic number (Z) and the reciprocal of the wavelength ($1/\lambda$) for each spectral series of emission lines for each element.

Moseley was also responsible for the construction of the early X-ray spectrometer. His design centered on a cold cathode tube where the air within the tube provided the electrons. The major problem experienced laid in the inefficiency of using electrons to create x-rays; nearly 99% of the energy was lost as heat.

In the same year, the Bragg brothers built their first X-ray analytical device. Their device was based around a pinhole and slit collimator. Like Mosley's instrument, the Braggs ran into difficulty in maintaining efficiency. Progress in XRF spectroscopy continued in 1922 when Hadding investigated using XRF spectrometry to analyze mineral samples. Three years later, Coster and Nishina put forward the idea of replacing electrons with x-ray photons to excite secondary x-ray radiation resulting in the generation of an X-ray spectrum. (http://www.karlloren.com 10/12/2010).

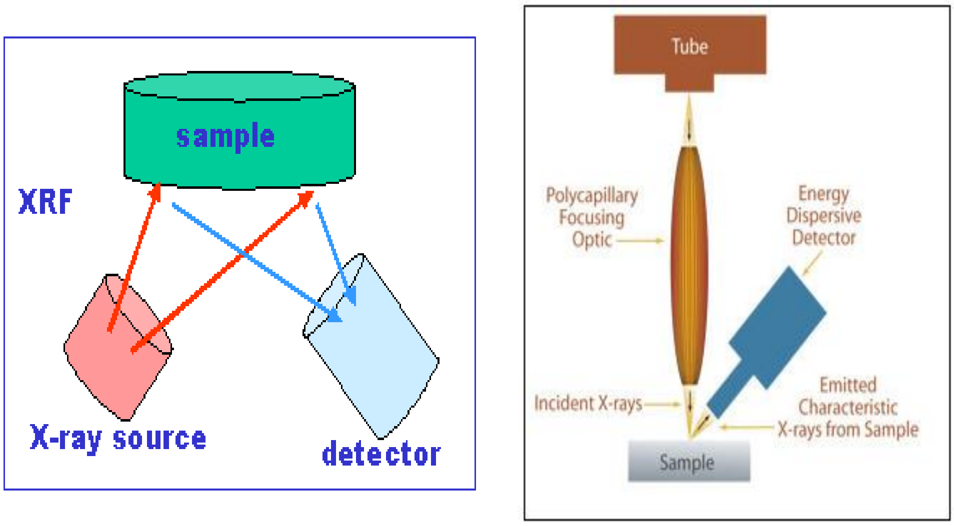


Figure 3.4: The basic component of XRF Spectrometer**.**

In XRF spectrometry, the material being examined is irradiated with X-rays, and as a result the atoms of each element emit a characteristic radiation of a particular wavelength. The emitted radiations are then separated by a diffraction crystal and can be detected and measured either by a photographic plate or by a Geiger counter. The technique is very similar to that of emission spectrometry. In XRF spectrometry there is no need to remove a sample from the sample holder, the results obtained will be an analysis of the surface only (Hodges 1981) (Figure 3.4).

There are two types of XRF Spectrometer, one is energy dispersive (EDXRF), the other is wavelength dispersive (WDXRF). The former is more common than the latter.

XRF spectrometry is a widely used technique for the analysis of archaeological artifacts, since it is relatively rapid, cheap, sensitive, and specific. The technique most commonly used involves the exposure of unprepared or minimally prepared surfaces to the X-ray radiation and method is non-destructive. However, major errors can be present in the results, if the surface of the area exposed to the beam of X-rays is insufficiently flat (Solmon 1970).

XRF analyses can detect elements having atomic number 15 even less with some particular detectors.

In the field of authenticity, the XRF spectroscopy is one of the main techniques to determine the elements including in the alloy of the object like coins whether it is fake or not.

An important improvement in the method was the possibility of using a portable X-ray spectrometer starting in 1964. In this way a large number of measurements can be collected for statistical processing, comparison, and characterization of differences in the same work (Moioli and Seccaroni 2000).

3.2.1.1. Advantages of Using Portable XRF Technique

The advantages can be summarized as follows

- There is no need for sample preparation
- Measurement is simple and rapid,
- Analytical results are taken immediately
- Analysis of many areas in a single object can be possible
- Simultaneous multi-element analysis can be possible
- Detection limits is low (50-10 ppm) high sensitivity (Beckhoff 2006).

This technique will be named as P-XRF in the text.

3.2.1.2 Weakness of Portable XRF Technique

XRF is a surface technique. On the other hand, the composition of an ancient alloy sample including coins may not be the representative of its original composition especially if analysis is limited to the artifact's surface as it is done in XRF.

It is known that the surface may be covered by an impurity layer called *patina* and/or some surface loss may have happened due to corrosion. Corrosion effect, especially in Cu-based alloys like bronze, silvered-bronze or brass, can be seen easily even by naked eye.

With XRF method enrichment effects cannot be detected. In the past and today in order to increase the worth of a coin, not the same valuable metal was used in the whole composition. Occasionally, in the core of the coin some invaluable metals are inserted and the valuable metal is plated on the surface. This heterogeneity may not be detected by XRF, a surface technique.

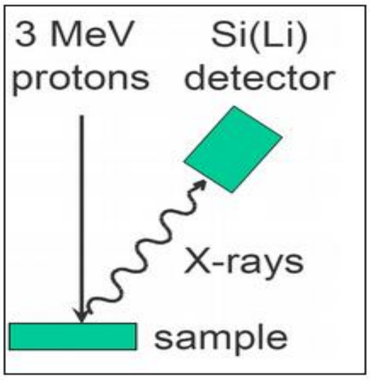
In all the analytical process it is necessary to use a Standard or Certified Reference Material (SRM or CRM). The composition of the CRM should be similar to the sample under study. This is unfortunately not always possible.

3.2.2 Proton-induced X-ray Emission Spectrometry (PIXE)

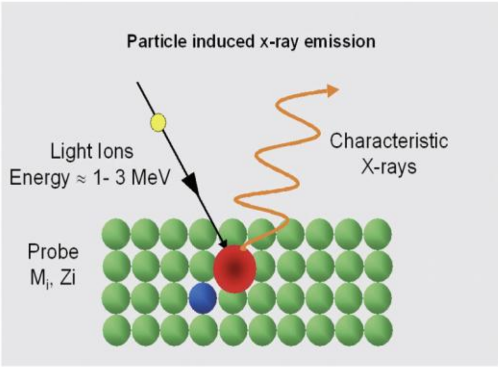
Proton-induced X-ray emission (PIXE) is a technique used in the determining the elemental content of a sample. When a material is exposed to an ion beam, atomic interactions occur that give off radiation of wavelengths in the X-ray part of the electromagnetic spectrum specific to an element. PIXE is a powerful and non-destructive elemental analysis technique now used routinely by geologists, archaeologists, art conservators and others to help answer questions of provenance, dating and authenticity.

The technique was first proposed in 1970 by Sven Johansson of Lund University, Sweden, and developed over the next few years with his colleagues Roland Akselsson and Thomas B Johansson.

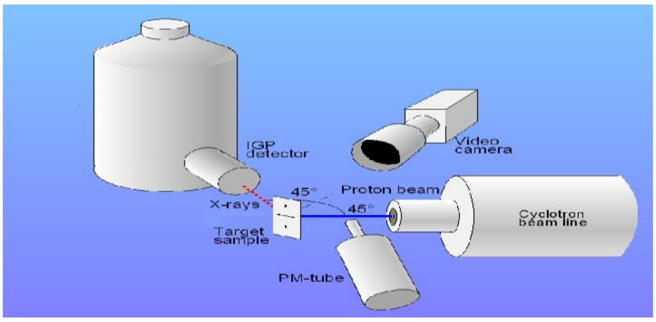
A recent extension of PIXE using tightly focused beams (down to 1 μm) gives the additional capability of microscopic analysis. This technique, called micro PIXE, can be used to determine the distribution of trace elements in a wide range of samples. A related technique, particle-induced gamma-ray emission (PIGE) can be used to detect some light elements (Figure 3.5) (http://en.wikipedia.org/wiki/Particle-induced X-ray emission 21/12/2010).



a)



b)



c)

Figure 3.5: a, b) Experimental principle of PIXE, c) schematic picture of PIXE (http://www.ams.ethz.ch/research/material/iba/pixe/pixe.png&imgrefurl=http://www.ams.ethz.ch/research/material/iba/pixe&usg 24.12.2010).

Quantum theory states that orbiting electrons of an atom must occupy discrete energy levels in order to be stable. Bombardment with ions of sufficient energy (usually MeV protons) produced by an ion accelerator, will cause inner shell ionization of atoms in a specimen. Outer shell electrons drop down to replace inner shell vacancies, however only certain transitions are allowed. X-rays of a characteristic energy of the element are emitted. An energy dispersive detector is used to record and measure these X-rays.

Only elements heavier than fluorine can be detected. The lower detection limit for a PIXE beam is given by the ability of the X-rays to pass through the window between the chamber and the X-ray detector. The upper limit is given by the ionization cross section, the probability of the K electron shell ionisation, this is maximal when the velocity of the proton matches the velocity of the electron (10% of the speed of light), therefore 3 MeV proton beams are optimal (http://en.wikipedia.org/wiki/Particle-induced_X-ray_emission 21/12/2010).

3.2.3 X-Ray Diffraction Analysis (XRD)

Each atom in a chrystal has the power of scattering an X-ray beam incident on it. The sum of he scattered waves in the chrystal result in the X-ray beam being diffracted from each chrystal plane. Every crystalline substance scatters X-rays in its own unique diffraction pattern, producing a finger print of its atomic and molecular structure (Figure 3.6). The intensity of each reflection forms the basic information required in crystal structure analyses. One important feature of X-ray diffraction is that those components are identified as specific compounds. Since different atoms have different numbers of electrons, their relative scattering varies. Thus the crystal structure determines the intensity and position of the diffracted beam. In the analyses of XRD traces Brag equation is used. Bragg equation describes the rule for X-ray diffraction. It is given as follow;

$AC+CB = 2d \sin\Theta$

When AC+CB (path difference) = $n.\lambda$ (n=1,2,3 .....) constructive interference occurs and diffracted light becomes more intensive.

Even when two crystals have identical lattices, the kinds of atoms of them may be different. Hence each crystal species diffract X-rays in a characteristically different way (Willard et al. 1981).

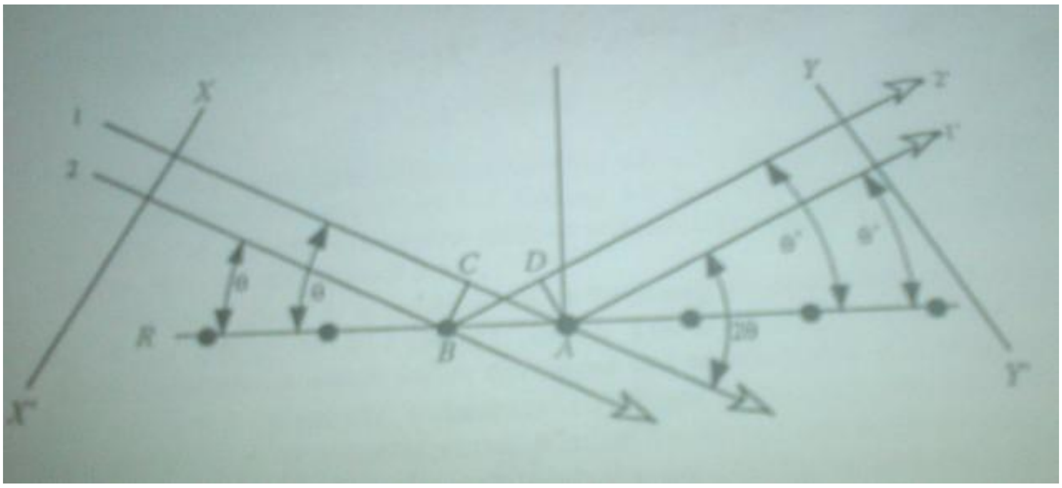


Figure 3.6: XRD Diffraction from a single row of atoms. 1 and 2 are incident rays; **1' and 2'** are diffracted rays (Moore et al. 1997).

3.2.4 Microscopy

Microscopy is the technical field of using microscopes to view objects and its details that cannot be seen with the naked eye. There are two well-known branches of microscopy; optical and electron microscopy.

The actual power or magnification of a compound optical microscope is the product of the powers of the ocular (eyepiece) and the objective lens. The maximum normal magnifications of the ocular and objective are 10X and 100X respectively, giving a final magnification of 1,000X.

Other important microscopes are ordinary microscopes, petrological microscopes and metallurgical microscopes. Petrological microscope works with polarized light. Its main task is to identify and characterize minerals. Metallurgical microscope uses reflected light to study chemical composition and the effect of technological process in metals.

The principle components of any microscope are threefold and arranged along the path of the light Firstly the specimen has to be illuminated. In stereo or ordinary microscope of low magnification (10x) illumination may come simply from the sun or a desk lamp (Figure 3.7 a).

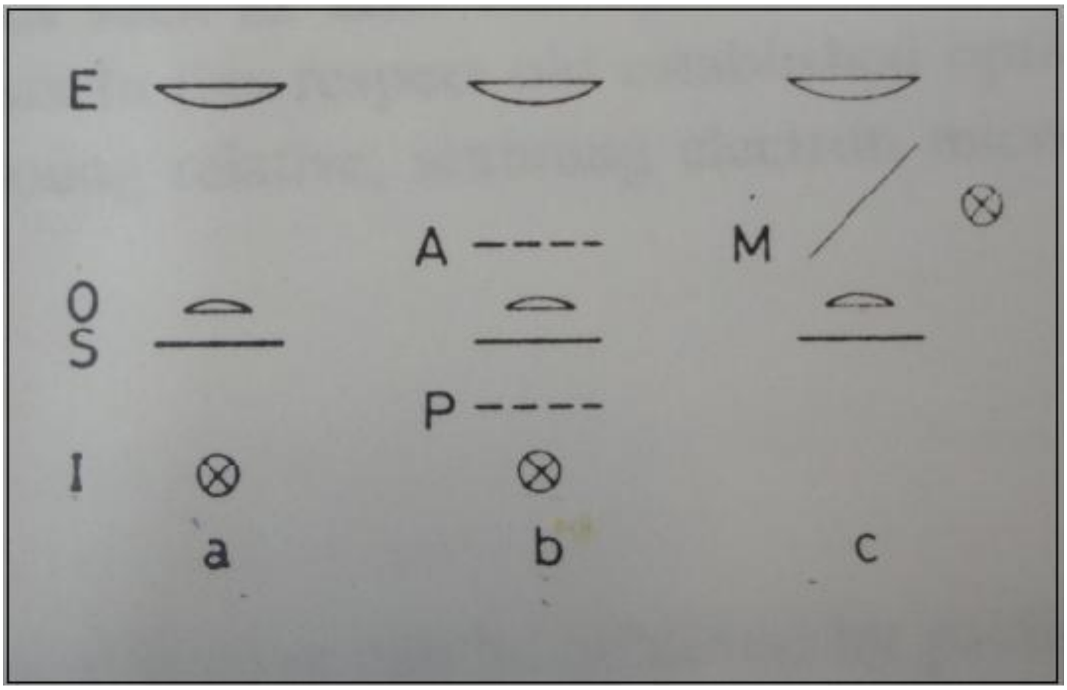


Figure 3.7: Schematic drawing of the main components of an ordinary microscope (a) a petrological microscope (b) a metallurgical microscope (c) the letter indicates: I illumination system, S stage for specimen, O objective lens system, E eyepiece lens system, A analyzer, P polarizer, M semitransparent mirror (Leute 1987).

The second component is the objective lens system immediately behind the sample. The task of objective is to generate a real image of specimen somewhere upward in microscope tube, magnified by a factor of 3 to 100. This image is viewed with eyepiece lens system acting as magnifying lens and contributes an additional factor of about 10 to total magnification.

In the petrologic microscope thin transparent sections, simply thin sections of the samples are inspected. The illuminations system contains a polarizer and inserted between objective lens and eyepiece there is an analyzer. In spite of difference of their names, this component may be identical; the former with the function to generate nearly polarized light the latter with the task to analyze the state of polarization (Leute 1987).

3.2.4.1 Electron Microscopy

Although every small elementary particle may play the role of a wave, electrons are particularly suited; they can be produced by a simple glowing wire (e.g. tungsten), their speed (and hence their wave-length) can be controlled by an accelerating voltage, and they can be steered easily enough by electric or magnetic field acting as lenses.

There are two types of electron microscopes; Transmission Electron Microscope (TEM) and Scanning Electron Microscope (SEM).

The convenient accelerating voltage of 50.000 volt leads to a wavelength of 0,0055 nm which is shorter than visible light by a factor of 100 000. Resolution value of below 0.2 nm have been reached in transmission electron microscope which is the length corresponding to the size of a small organic molecule, 4 nanometer is a routine resolution value in SEM (Figure 3.8).

As it is seen, electron microscope has a greater resolving power than a light-powered optical microscope, because it uses electrons that have wavelengths about 100,000 times shorter than visible light, and can achieve magnifications of up to 2,000,000 X, whereas light microscopes are limited to 1000X magnification.

TEM is constructed in complete analogy with an optical microscope with obvious exceptions, that glass lenses are replaced by focusing electric or magnetic fields, and that no direct visual observation is possible. Photographic film or a fluorescence screen takes place of the observers' eye (Leute 1987).

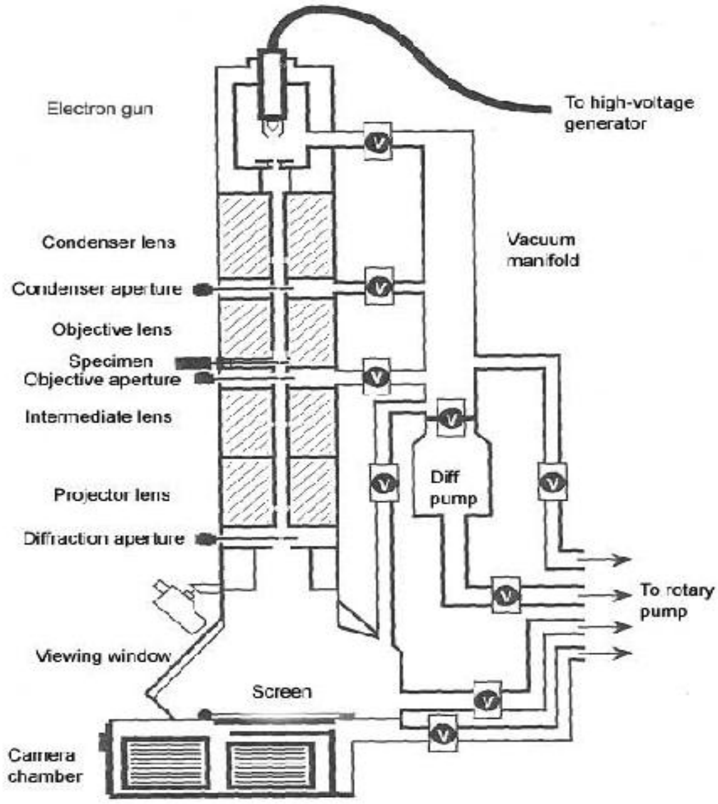


Figure 3.8: A Transmission Electron Microscope (www.mauricewilkinscentre.org/.../2. jpg 21/12/2010).

The application of TEM in archaeology and history of art is very limited. Even when operated at high accelerated voltages of 100 to 200 kV electrons can only penetrate very thin specimens of a few tenths of micrometers. SEM is used in archaeology and history of art studies. It is not similar to optical microscope (Figure 3.9). Here, a well focused beam of primary electrons accelerated typically 300 to 30 000 volts heats the sample on a spot of 10 to 1000 nm diameter. Secondary electrons then set free from a thin surface layer, having a low energy (below 50 EV) these secondary electrons can be easily kept to by the detector (Leute 1987).

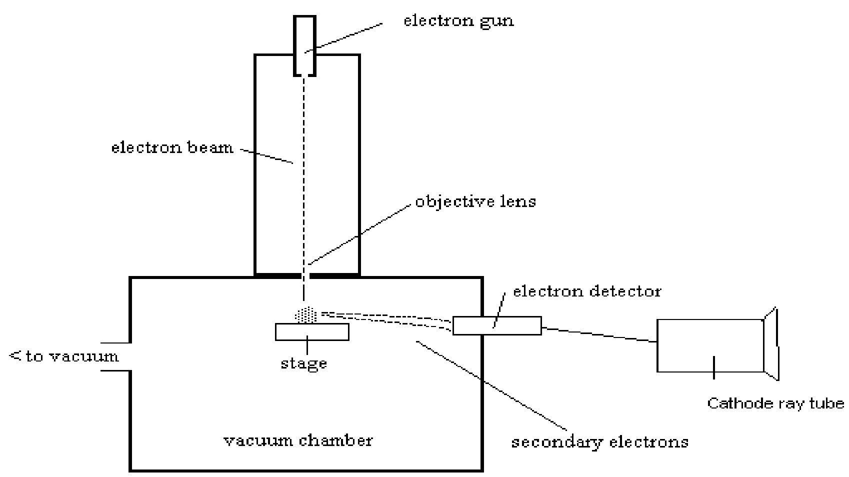


Figure 3.9: A Scanning Electron Microscope (www.gmu.edu/depts/SRIF/tutorial/sem/sem_xs.gif 21/12/2010).

3.3 Other Techniques

Other techniques used in archaeometrical investigations include Infrared (IR) and Raman spectroscopic methods. In authenticity studies of coins use of these methods are not so common.

3.3.1 Infrared Spectroscopy (IR spectroscopy)

It is a technique deals with the infrared region of the electromagnetic spectrum, that is the light with a longer wavelength and lower frequency than visible light. It covers a range of techniques, mostly based on absorption spectroscopy. As with all the spectroscopic techniques, it can be used to identify and study chemicals.

The infrared portion of the electromagnetic spectrum (07-350 μm) is usually divided into three regions; the near-, mid- and far- infrared, named for their relation to the visible spectrum. The higher energy near-IR, approximately 14000–4000 cm^{-1} (0.8–2.5 μm wavelength) can excite overtone or harmonic vibrations. The mid- infrared, approximately 4000–400 cm^{-1} (2.5–25 μm) may be used to study the fundamental vibrations and associated rotational-vibrational structure. The far- infrared, approximately 400–10 cm^{-1} (25–1000 μm), lying adjacent to the microwave region, has low energy and may be used for rotational spectroscopy (Figure 3.10). The names and classifications of these sub regions are conventions, and are only loosely based on the relative molecular or electromagnetic properties (http://webcache.googleusercontent.com/search?q=cache:1RJKLIt71ycJ:en.wikipedia.org/wiki/Infrared_spectroscopy+Infrared+Spectrometry 23/12/2010).

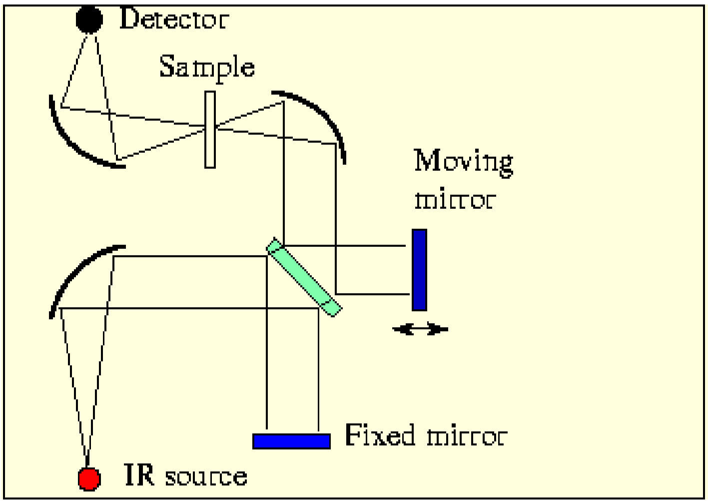


Figure 3.10: Schematic representation of a FTIR Spectrometer (solidstate.physics.sunysb.edu/.../node111.html 23/12/2010).

3.3.2 Raman Spectroscopy

It is a spectroscopic technique used to study vibrational, rotational modes in a system. It relies on inelastic scattering, or Raman scattering, of monochromatic light, usually from a laser in the visible, near infrared, or near ultraviolet range. The laser light interacts with molecular vibrations resulting in the energy of the laser photons being shifted up or down (Figure 3.11). The shift in energy gives information about the motions in the system (http://webcache.googleusercontent.com/search?q=cache:5vqoprN_wzwJ:en.wikipedia.org/wiki/Raman_spectroscopy+Raman+Spectrometry 23/12/2010).

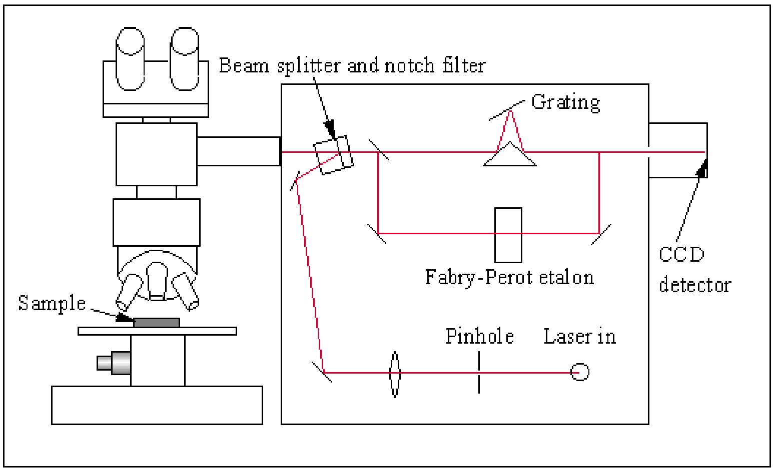


Figure 3.11: Schematic diagram of a Raman spectrometer (www.chm.bris.ac.uk/.../stuthesis/chapter2.htm 23/12/2010).

CHAPTER 4

MATERIALS AND METHODS

In this chapter the coins studied and the methods used in analyses were explained.

4.1 Selected coin samples

The coins studied were selected from silver coins present in MAC and Uşak Museum coin sections. The coins studied are of Roman Imperial Age between 27 B.C to 244 A.D. The age studied started with Emperor Augustus and ended with Emperor Gordian III. From archaeological records we know that Roman Impire faced with its richer life with Augustus and economic decline started with Septimius Severus. From the results of this study we will see the effect of economy to life of the people and metal value of the coin. Studied samples were of two types; unreliable (from individuals, by confiscation, donations and buying) and reliable coins (from archaeological excavations and hoards). The numbers, types, periods of the samples are shown in the Table 4.1. For the purpose of the comparison fake coins of Athena and Great Alexander, from Greek and Hellenistic age were also studied.

Table 4.1 List of analyzed coins from each emperor and the source of analyzed coins (Appendix B).

			Form of acquisition for analyzed samples	
Emperor Name	**Date**	**Number of Analyses made From Samples**	**Number of Analyses Made From Unreliable Samples**	**Number of Analyses Made From Reliable Samples**
Augustus	31 B.C. -14 A.D.	78	77	1
Tiberius	14-37 A.D.	5	5	0
Claudius	41-54 A.D.	23	23	0
Nero	54-68 A.D.	2	2	0

Table 4.1 CONTINUED				
			Form of acquisition for analyzed samples	
Emperor Name	**Date**	**Number of Analyses made From Samples**	**Number of Analyses Made From Unreliable Samples**	**Number of Analyses Made From Reliable Samples**
Galba	69 A.D.	2	2	0
Vitellius	69 A.D.	3	3	0
Vespasian	69-79 A.D.	30	23	7
Domitian	81-96 A.D.	18	3	15
Nerva	96-98 A.D.	7	7	0
Trajan	98-117 A.D.	29	22	7
Hadrian& Sabina	117-138 A.D.	18	5	13
Antoninus Pius & Faustina I (Senior)	138-161 A.D.	31	3	28
Marcus Aurelius	161-180 A.D.	28	15	13
Pertinax	193 A.D.	4	4	0
Pescennius Niger	193-195 A.D.	3	1	2
Septimus Severus	193-211 A.D.	18	14	4
Caracalla	198-217 A.D.	36	19	17
Geta	209-211 A.D.	28	10	18
Diadumenian –Son of Macrinus	217-218 A.D.	18	8	10
Elagabalus	218-222 A.D.	15	5	10
Severus Alexander	222-235 A.D	22	3	19
Maximinus I	235-238 A.D.	22	1	21
Gordian III	238-244 A.D.	21	2	19
Total		**461**	**257**	**204**

4.2 Instrumentation and Parameters

In the study two types of instruments were used for analyses namely P-XRF and SEM-EDX instruments

4.2.1 Portable X-Ray Florescence Spectrometer (P-XRF)

In order to analyze coins an Omega Portable X Ray Florescence Spectrometer of The Museum of Anatolian Civilizations (MAC) was used (Figure 3.6 and Figure 3.4).

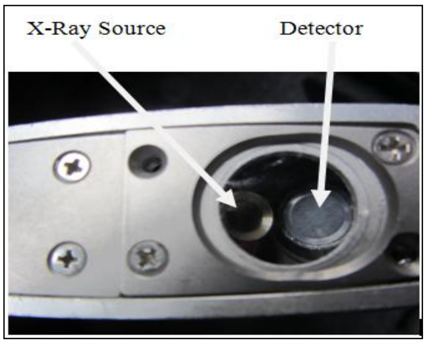


Figure 4.1: P-XRF Spectrometer used in the study

The P-XRF instrument used in this study was purchased in 2010 by The Ministry of Culture and Tourism for 30.000 €. Sample is placed on the sample holder of P-XRF of which diameter is 2 cm and measurements have been done in the analytical mode of the instrument by the selection of 30 second analysis time.

Table 4.2: Properties of the P-XRF used in the study

Detector	Ultra high resolution Silicon Drift Detector; <165eV Resolution
Excitation Source	X-ray tube – Ag anode 10 - 40 keV, 5 - 100 µA, up to 5 filter positions
Elements That Can be Detected in Analytical Mode	Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Zr, Nb, Mo, Rh, Pd, Ag, Sn, Sb, Hf, Ta, W, Re, Ir, Pt, Au, Pb, Bi Totally 26 elements can be in Analytical Mode.
Detection Limit	100-10 ppm
Duration of analysis for each sample	30 seconds

4.2.2 Scanning Electron Microscopy (SEM)

For SEM analysis, fake samples were taken from Uşak Museum and MAC where all the authentic samples were obtained from MAC and were originated from Juliopolis excavation. The samples were analyzed by using a scanning electron microscope equipped with energy dispersive X-Ray analysis system (Figure 4.2). The instrument was located in the Department of Metallurgical and Materials Engineering in METU. The instrument used is Jeol JSM 6400 SEM unit with EDX.

The JSM-6400 basic units consist of an electron optical column mounted on the main console, a control and display system, a power supply unit and a pump box. The main console incorporates a vacuum system and the control and display system incorporates the control panels, keyboard, and display system. The basic SEM is connected to an EDX unit, which allows a characteristic X-ray spectrum to be displayed (Ercanlı 2012).

Figure 4.2: JSM 6400 SEMEDX Instrument used in the study.

4.3 Procedures:

4.3.1 Sample Preparation

Steps of the study prior to analyses are as follow:

- Most of the coins under study were photographed using both sides.
- Preparation of sample record sheet, including inventory number, the place from where the coins come, name of the emperor who minted the coin, weight of coin, diameter of coin, condition of patina, prediction of metallic composition, and so on.
- An analytical balance was used to weight the coins; the sensitivity was 0.1 mg.

- A metal compass was used to measure the diameters of coin in mm.

Table 4. 3: List of Roman Coins In the Museum of Anatolian Civilizations including diameter and weight.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Emperor	Analyzed Side and Sampling Option	Denomination	Surface Condition
77-1-77	Bought	3.61	19	Augustus	Obverse	Denarius	Little corrosion
150-870/14-76	Bought	3.52	19	Augustus	Obverse	Denarius	Too much corroded
150-870/13-76	Bought	3.57	18	Augustus	Obverse	Denarius	Too much corroded
133-18/8-76	Bought	3.4	18	Augustus	Obverse	Denarius	Too much corroded
123-4/3-76	Bought	3.65	19	Augustus	Obverse	Denarius	Too much corroded
123-4/2-76	Bought	3.82	18	Augustus	Obverse	Denarius	Too much corroded
119-547/15-76	Bought	3.5	18	Augustus	Obverse	Denarius	Too much corroded
5-2091-123/4	Confiscation	3.53	17	Augustus	Obverse	Denarius	Too much corroded
6-2113-37/3	Bought	3.37	17	Augustus	Obverse	Denarius	Too much corroded

A listing of 15457 (up to now) Roman Age Coins present in the Museum of Anatolian Civilizations (MAC), with the name of emperor and the source of acquisition to the MAC and prediction data of metallic composition has been provide; this list contains very useful supporting data for samples handled in this study. A sample for such data is given in Table 4.4.

Table 4. 4: List of Roman coins in the Museum of Anatolian Civilizations including acquistion place and storage area.

Inventory No	Archaeological Site	Emperor	Mint Date	Place in the MAC	Denomination
104-M180	Juliopolis Excavation	Trajan	98-99	Cupboard 7	Denarius
103-M178	Juliopolis Excavation	Antoninus Pius	156-157	Cupborad 2	Denarius
102-M188	Juliopolis Excavation	Faustina II	176	Cupborad 2	Denarius
101-M184	Juliopolis Excavation	Trajan	103-111	Cupborad 2	Denarius
100-M189	Juliopolis Excavation	Hadrian	125-128	Cupborad 2	Denarius
99-M189	Juliopolis Excavation	Hadrian	128-132	Cupborad 2	Denarius
98-M189	Juliopolis Excavation	Vespasian	75	Cupborad 2	Denarius

4.3.1.1 Sample Preparation for P-XRF

Analyses have been carried out by using Portable X-Ray Florescence Spectrometry (P-XRF). Since P-XRF is a surface method, corrosion effect on the surface would be important regarding the penetration of the X-ray beam to the matrix. Therefore, Juliopolis and Zurich silver coins were cleaned by the expert laboratory staff of the MAC.

Cleaning of silver, silver alloys and silver coated coin (Antoninianus) Mechanical cleaning was not used because the samples are rather soft and easily scratched by abrasive agents. For cleaning semi-chemical and chemical processes have been carried out. After removing external artifacts like soil by mechanical ways and with the help of ultrasonic vibration chemical cleaning was applied. Generally copper produces corrosion products which should be removed. In removal disodium salt of ethylene diamine tetra acetic acid (EDTA) (Na_2H_2Y) was used. Depending upon the thickness of the corrosion layer 3-10 % mg/v solution of Na_2H_2Y in water was used. If desired, silver corrosion products such as oxide, sulfide and chloride of silver are cleaned with appropriate chemicals (such as thiourea or ammonia, sodium thiosulphate for cleaning of silver chlorite, for silver sulphide and silver oxide sodium hydroxide or lithium hydroxide and mechanical applications). Finally silver coins are coated with paroloid B7272 thermo plastic resin. With the chemical composition of an ethyl methacrylate co-polymer, paraloid B- is a durable and non-yellowing acrylic polymer used for consolidating materials coins, wall paintings (1-5%), fragile wood (5-20%), etc. It may be used as a fixative agent when diluted with a solvent to secure markings on artifacts and as an adhesive (50%+) for a variety of substrates. Paraloid B-72 is soluble in acetone, toluene and is o-propanol.

In some coins patina condition is different on both sides. In order to analyze the sample, the patina should be absent if possible or as little as possible. Analyses have been carried out from the side of coin that is clean or with less patina.

4.3.1.2 Sample Preparation for SEM

There are often severe restrictions on the quantity of metal that can be removed from an archaeological artifact for metallographic examination. When the rules do not allow taking a sample from the object, and if the object is equal to or smaller than 3 cm that is the size required to fit in the sample holder of SEM, a part of the object can be polished and etched to prepare sample to analyses by a less destructive way.

In order to find different fake coins associated with different emperors who have authentic coins in MAC, fake coins from the emperors were also obtained from Uşak Museum with the permission of Uşak Museum and Ministry of Culture and Tourism.

Figure 4.3: Sample holder of SEM with the size of 3cm in diameter.

4.3.1.2.1 Polishing of the Samples

The best results for most ancient metals are obtained by polishing on diamond-impregnated rotary polishing wheels lubricated with a mineral oil. The diamond powders are usually supplied as tubes of paste. The usual range of diamond powder sizes are, 6 μm, 1 μm, and 0.25 μm.

0.5 and 1 μm Al_2O_3 were used as slurries to polish the sample analysis area. To minimize the directional polishing effects, the sample should be rotated in a direction opposite to that of the wheel rotation.

Figure 4.4 Polishing authentic and fake samples on the cleanest and flat part of them by using the rotary polishing wheels.

4.3.1.2 .2 Etching of Metallurgical Samples

"In most cases, an etching reagent is needed to develop the structure of a metal sample so that the structure can be examined with a metallurgical microscope. The etchant usually attacks the boundaries that separate one grain from another so that the grains of the polished section can be distinguished and their size, shape, and orientation studied.

Before etching, the surface of the polished sample must be cleaned of all grease, oil, and remains of polishing materials. A small amount of the etchant solution is poured into a small petri dish. The mounted sample may then be immersed in the solution for a prescribed period, or a cotton swab may be saturated with the solution and rotated gently on the polished metal surface.

After etching, the sample is washed and dried. Soap and water are adequate for washing, and ethanol or alcohol may be used for rinsing. Drying is usually carried out with a hand drier such as is used for drying hair.

Etched samples should always be stored in a sealed desiccator to keep them dry. Etched metal surfaces are highly reactive and can tarnish rapidly in the air, especially under conditions of high humidity. Once etched, the surface of the specimen should never be touched by hand.

Each metal or alloy system calls for a particular group of etchants for the development of microstructure. Some of the more common etchants useful for the kinds of metals and alloys (MIT summer institute in materials science and material culture laboratory manual 2003)

Etchants for Silver and Silver Alloys that Used For Preparation of Sample

After polishing the samples, the surface of silver or copper coins was etched using a solution containing 90 mL of ethyl alcohol and 10 mL of concentrated nitric acid HNO_3 solution. Each sample was kept 90 second in the solution; it was then first washed with tap water, then with ethyl alcohol and finally dried with a hair dryer. After drying, in order to see the conditions of the Cu grains, the surface was examined using an optical 400X microscope. It is desired that the Cu grains are clearly visible.

4.3.2 Procedures for Analyses

The following procedures were used into analyses.

4.3.2.1 Procedures for P-XRF

Before each swich on P-XRF instrument, it standardized with SS316 steel standard and analyses made by using the battery power supply.

Analyzing depth of P-XRF depends on the sample matrix. Typical depths are given in Table 4.5.

Table 4.5: The analyzed depth of a sample, suitable X-rays and their energies (Romano 2010).

X-Ray	Energy (keV)	Depth (μm)
Sn-Lα	3.42	**5**
Cu-Kα	8.04	**30**
Sn-Kα	25.19	**100**
Ag-Kα	**22.1**	**80**

26 elements can be simultaneously analyzed in *Analytical Mode* that is selected for analysis of the silver coins. The other elements which are not included in this mode are some other elements between 16 Sulfur (S) and 92 Uranium (U); these can be determined using the other modes or investigating the spectrum obtained by the *Analytical Mode*. *Analytical Mode* was selected since the elements involved in this mode match the elements present in our samples.

In Chapter 5 all these elements were searched for each sample; but only the detected and important elements were given in the tables (Table 5.1 to Table 5.22). More details about all P-XRF analyses results were given in Appendix 1.

The elements included in the *Analytical Mode* selected are given in

Table 4.6Table 4.6: Elements determined using the Analytical Mode in P-XRF.

Element, Symbol, Atomic Number (Z)	**Concentration Range, ppm (m/m)**
Titanium, Ti, 22	10–100
Vanadium, V, 23	10–100
Chromium, Cr, 24	10–100
Manganese, Mn, 25	10–100
Iron, Fe, 26	10–100
Cobalt, Co, 27	10–100
Nickel, Ni, 28	10–100
Copper, Cu, 29	10–100
Zinc, Zn, 30	10–100
Zirconium, Zr,40	10–100
Niobium, Nb, 41	10–100
Molybdenum, Mo, 42	10–100
Rhodium, Rh, 45	50–150
Palladium, Pd, 46	50–150
Silver, Ag, 47	50–150
Tin, Sn, 50	50–150
Rhenium, Re, 75	10–100
Iridium, Ir, 77	10–100
Platinum, Pt, 78	10–100
Gold, Au, 79	10–100
Lead, Pb, 82	10–100
Bismuth, Bi, 83)	10–100
Rhodium, Rh, 45	50–150
Palladium, Pd, 46	50–150
Rhodium, Rh, 45	50–150
Palladium, Pd, 46	50–150

4.4 Statistical Techniques Used

In this study the counterfeit coins were analyzed by P-XRF after measurements of diameter and weight along with the notes regarding appearance. The obtained results will be applied to multivariate analysis such as cluster analysis (CA) dendrograms, t-tests and correlation matrix to classify them.

Cluster analysis or clustering is the assignment of a set of results into subsets (called *clusters*) so that results in the same cluster are similar in some sense. Clustering is a method of unsupervised learning,and a common technique for statistical data analysis used in many fields.

CHAPTER 5

RESULTS AND DISCUSSION

In order to produce the silver used in silver coins, silver ore can be taken from mainly three sources; first, native silver and silver minerals which are rare; second, from separation of gold and silver; and last and the most common source is ores of lead which is also rich in terms impurities (polymetallic ores) and needs many stages for purification using cupellation. Cupellation is a separation technology which separates metals from each other by using their gravity difference in molten sate. Nearly all the silver coins analyzed in this study have been produced using the last source mentioned above (Craddock and Lang 2002).

Silver coins constitute the backbone of currency in the Roman Empire and are likely to have been the main media for long-distance monetary exchange. Roman emperors decreased the silver content of coins to solve short-term financial problems frequently caused by government overspending. For the most part, this manipulation involved the reduction of the silver content of the coinage and by decreasing weight coins ((http://archaeologydataservice.ac.uk/ archives/view/coins_lt_2005/ 27.12.2011). One of the definite traps for a coin forger is his lack of knowledge of the political factors that controlled minting procedure in antiquity (Fleming 1975). Beside this technology capacity difference of melting and enrichment of metal change is used to determine forgery.

In the 1970s an important study was published by Walker of Oxford, documenting the silver contents of Roman Imperial silver coins by non destructive XRF analysis (Walker 1976, Walker 1977, Walker 1978). This appeared to be a definitive study of the subject, and until recently was the principal authority and reference for economic historians on the monetary policies of the Roman Empire. Result of our study will be compared with results of Walker in terms of main element Ag and one of minor elements, Pb.

In 1995 and 2001 the silver coinage of the Flavian Emperors issued for the city of Caesarea in Cappadocia were the subjects of an initial enquiry where samples of metal were drilled out from the interior of a representative series of coins. The analytical technique used for this project was AAS (Ponting and Butcher 2005). In 2001 funding was obtained to undertake a one year project to apply this methodology to the coinage of the first Imperial dynasty, that of the Julio-Claudians. A more sensitive analytical technique was employed, ICP-OES was than employed, that enabled much better quality data for important trace elements, such as arsenic, tin and bismuth, to be obtained (Ponting and Butcher 2005).

The correlation between the silver ore and the metal extracted from it to produce the coins is determined by, on the one hand, the type of the ore and the nature of the impurities, and, on the other hand, by the precise conditions of smelting. The cupellation process was commonly used in antiquity to extract silver from the lead ore galena. First step in this method would be smelting the ore to produce silver-rich lead, followed by oxidation to remove most of the lead (as lead oxide), thereby concentrating the silver in the remaining lead. The silver would be then extracted in small vessels (cupelles) containing bone ash. In this process most of the remaining lead was removed, but some inevitably remained, and can be used as an indication of the effectiveness of the procedure. In high quality silver produced by this process the lead concentration was reduced to around 0.5%, and therefore a low lead content is an indication of a good smelting. Bismuth is also reduced during this process, but it is accepted that its concentration in metallic silver reflects to some extent to that of the parent ore. The cupellation process, on the other hand, does not affect the gold concentration. (Rodrigues et al. 2011).

The result of this study will be compared with the result of following studies:

- Ponting and Butcher 2005.
- Walker who analyzed Roman imperial and provincial silver coin by P-XRF, The metrology of The Roman Coinage (Walker 1976, Walker 1977, Walker 1978)
- Beck et al. 2004, analyses made by PIXE and SEM-EDX.
- In addition, the results will be compared with the results of another study made by Fleming 1975.

Craddock reports that the residual lead in cupelled silver can fall anywhere between 0.05% and 2.5%. Lead will often segregate towards the surface of an artifact during solidification, but lead is more prone to corrosion than silver or copper and so will be preferentially leached out of the surface layers of a coin (Craddock 1995). So that lead concentration from the surface analyzed is higher than it is in the bulk of the coins. Therefore when a non-destructive surface technique such as XRF is used, Pb concentration found will always be higher than its bulk value. This difference will appear in both authentic and fake coins.

Information on most of the Roman Imperial coins used in the study and all the Yatağan Hoard coins have been published with numismatic information in the following sources. Data regarding Roman imperial coins from Juliopolis excavation are going to be published soon by Melih Arslan.

Arslan M., 1992, Roman Coins: Museum of Anatolian Civilizations, Kültür Bakanlığı, Ankara-Turkey.

Kızılkaya Y., 1988, Türk Arkeoloji Dergisi Sayı XXVII, "Yatağan Definesi " pp. 141-173, Ankara-Turkey

Online: (http://www.kulturvarliklari.gov.tr/sempozyum_pdf/turk_arkeoloji/27.turk.arkeoloji.pdf).

5.1 P-XRF Results for Silver Coins from Roman Imperial Period

Within the context of this thesis authenticity of Roman Imperial Age silver coins will be investigated. The photos of coins from Juliopolis excavation and Zurich confiscation are given in Appendix A. All the analytical and other relevant data for all silver coins are available in Appendix 2. Roman Imperial Age starts with Emperor Augustus. In the following sections the P-XRF analysis results from silver coins will be given and discussed on the basis of emperors with chronological order. The results will be given only for the elements chosen in *Analytical Mode* selected as given in Table 4.6. With some exceptions for important elements such as Zr, Bi, Pt and Pb, if the concentration is not detected (ND), the element will not be included in the respective table. The elements in tables will be ordered according to their atomic numbers (Table 4.6). All the concentrations given in the tables are in units of percentage (m/m). Different emperors can have coins with the same inventory numbers; this means that the coins were brought to the museum as a group.

5.1.1 Analyses of Augustus (27 B.C. to 14 A.D.) Silver Coins

P-XRF results for the coins in this group are given in Table 5.1. Other data, such as surface condition, weight and diameter of the samples are also given in Table 5.1. In some occasions, a pin hole was used to limit and select the sample surface used for analysis; details are given in section 5.2.

Table 5.1: P-XRF Results for Augustus Silver Coins, concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Denomination	Cu	Zr	Ag	Sn	Pt	Au	Pb	Bi	Decision
1-M 375	Juliopolis	2.94	20	Cleaned	Obverse	Denarius	3.32	ND	95.8	ND	ND	ND	0.8	0.08	A
77-1-77	Bought	3.61	19	WC	Obverse	Denarius	0.44	ND	99..02	ND	ND	ND	0.4	0.06	A
150-870/14-76	Bought	3.52	19	WC	Obverse	Denarius	1.39	ND	98.4	ND	ND	ND	0.06	0.03	A
150-870/13-76	Bought	3.57	18	WC	Obverse	Denarius	0.14	ND	99.6	ND	0.07	ND	0.05	0.08	A
133-18/8-76	Bought	3.4	18	WC	Obverse	Denarius	0.18	ND	99.4	ND	ND	ND	0.11	ND	A
123-4/3-76	Bought	3.65	19	LC	Obverse	Denarius	ND	ND	99.5	ND	0.07	ND	0.08	0.08	A
123-4/2-76	Bought	3.82	18	TMC	Obverse	Denarius	ND	ND	98.7	ND	0.11	ND	0.11	0.16	A
119-547/15-76	Bought	3.5	18	TMC	Obverse	Denarius	0.22	ND	99.2	ND	0.09	ND	0.08	0.13	A
5-2091-123/4	Confiscation	3.53	17	TMC	Obverse	Denarius	0.08	ND	96.8	ND	0.13	2.64	0.08	0.08	A
6-2113-37/3	Bought	3.37	17	WC	Obverse	Denarius	0.15	ND	99.2	ND	ND	ND	0.11	0.09	A
9-1856-749/8	Bought	3.21	21	Clean	Obverse	Denarius	0.57	ND	99.0	ND	ND	ND	0.34	0.09	A
6-1780-297	Bought	3.69	18	TMP	Obverse	Denarius	0.79	ND	99.0	ND	0.06	ND	0.07	0.05	A
12-1648-1	Bought	3.46	21	Clean	Obverse	Denarius	0.63	ND	98.8	ND	ND	ND	0.34	ND	A
916-1	Bought	11.3	25	LC	Obverse	Tetradrahmi	1.94	ND	97.5	ND	ND	ND	0.48	0.06	A
918-1	Bought	11.4	27	LC	Obverse	Tetradrahmi	2.71	ND	96.4	ND	ND	ND	0.89	0.04	A
2-1405-9	Bought	3.28	19	LC	Obverse	Denarius	0.43	ND	98.7	ND	ND	ND	0.6	0.13	A
5-1499-218	Bought	3.51	20	WC	Obverse	Denarius	0.17	ND	99.4	ND	0.08	ND	0.09	0.07	A
11-1571-16/2	Bought	3.41	20		Obverse	Denarius	5.31	ND	93.0	ND	ND	ND	0.24	0.07	A
150-870/14-76	Bought	3.52	19	WC	O PH	Denarius	1.25	ND	98.6	ND	ND	ND	0.04	ND	A
150-870/14-76	Bought	3.52	19	WC	O PH	Denarius	1.28	ND	98.7	ND	ND	ND	0.03	ND	A
150-870/14-76	Bought	3.52	19	WC	O PH	Denarius	1.54	ND	98.3	ND	ND	ND	0.04	ND	A
150-870/14-76	Bought	3.52	19	WC	O WPH	Denarius	1.43	ND	98.0	0.38	ND	ND	0.04	0.03	A
150-870/14-76	Bought	3.52	19	WC	R WPH	Denarius	0.54	ND	98.8	0.46	ND	ND	0.05	0.03	A
150-870/14-76	Bought	3.52	19	WC	R WPH	Denarius	0.37	ND	99.5	ND	ND	ND	0.03	ND	A
150-870/13-76	Bought	3.57	18	WC	O PH	Denarius	0.1	ND	99.8	ND	ND	ND	0.04	0.08	A
150-870/13-76	Bought	3.57	18	WC	O PH	Denarius	0.1	ND	99.8	ND	ND	ND	0.03	0.08	A
150-870/13-76	Bought	3.57	18	WC	R PH	Denarius	0.19	ND	99.6	ND	ND	ND	0.02	0.08	A
150-870/13-76	Bought	3.57	18	WC	R PH	Denarius	0.18	ND	99.6	ND	ND	ND	0.03	0.08	A

Table 5.1 CONTINUED

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Denomination	Cu	Zr	Ag	Sn	Pt	Au	Pb	Bi	Decision
150-870/13-76	Bought	3.57	18	WC	O WPH	Denarius	0.17	ND	99.2	0.40	ND	ND	0.04	0.07	A
150-870/13-76	Bought	3.57	18	WC	O WPH	Denarius	0.16	ND	99.3	0.40	ND	ND	0.04	0.08	A
150-870/13-76	Bought	3.57	18	WC	R WPH	Denarius	0.31	ND	98.9	0.49	ND	ND	0.04	0.08	A
133-18/8-76	Bought	3.4	18	WC	O PH	Denarius	0.12	ND	99.2	ND	ND	ND	0.09	ND	A
133-18/8-76	Bought	3.4	18	WC	O PH	Denarius	0.1	ND	99.4	ND	ND	ND	0.10	ND	A
133-18/8-76	Bought	3.4	18	WC	O PH	Denarius	0.1	ND	99.7	ND	ND	ND	0.09	ND	A
133-18/8-76	Bought	3.4	18	WC	O WPH	Denarius	0.16	ND	99.5	ND	ND	ND	0.09	ND	A
123-4/3-76	Bought	3.65	19	LC	O PH	Denarius	ND	ND	99.7	ND	ND	ND	0.04	0.10	A
123-4/3-76	Bought	3.65	19	LC	O PH	Denarius	ND	ND	99.8	ND	ND	ND	0.04	0.10	A
123-4/3-76	Bought	3.65	19	LC	R PH	Denarius	ND	ND	99.8	ND	ND	ND	0.03	0.09	A
123-4/3-76	Bought	3.65	19	LC	R PH	Denarius	ND	ND	99.7	ND	ND	ND	0.04	0.09	A
123-4/3-76	Bought	3.65	19	LC	O WPH	Denarius	ND	ND	99.7	ND	ND	ND	0.06	0.09	A
123-4/3-76	Bought	3.65	19	LC	R WPH	Denarius	ND	ND	99.7	ND	ND	ND	0.06	0.09	A
123-4/2-76	Bought	3.82	18	TMC	O PH	Denarius	ND	ND	99.3	ND	ND	ND	0.07	0.12	A
123-4/2-76	Bought	3.82	18	TMC	O PH	Denarius	ND	ND	99.1	ND	ND	ND	0.08	0.13	A
123-4/2-76	Bought	3.82	18	TMC	R PH	Denarius	ND	ND	99.7	ND	ND	ND	0.05	0.06	A
123-4/2-76	Bought	3.82	18	TMC	R PH	Denarius	ND	ND	99.6	ND	ND	ND	0.06	0.05	A
123-4/2-76	Bought	3.82	18	TMC	O WPH	Denarius	ND	ND	98.5	0.42	0.08	ND	0.09	0.14	A
123-4/2-76	Bought	3.82	18	TMC	R WPH	Denarius	0.12	ND	95.7	0.42	0.08	3.27	0.07	0.06	A
119-547/15-76	Bought	3.5	18	TMC	O PH	Denarius	0.16	ND	99.7	ND	ND	ND	0.03	0.10	A
119-547/15-76	Bought	3.5	18	TMC	O PH	Denarius	0.15	ND	99.6	ND	ND	ND	0.04	0.11	A
119-547/15-76	Bought	3.5	18	TMC	R PH	Denarius	0.14	ND	99.6	ND	ND	ND	0.03	0.09	A
119-547/15-76	Bought	3.5	18	TMC	R PH	Denarius	0.15	ND	99.6	ND	ND	ND	0.03	0.10	A
119-547/15-76	Bought	3.5	18	TMC	O WPH	Denarius	0.21	ND	99.3	ND	0.07	ND	0.05	0.14	A
119-547/15-76	Bought	3.5	18	TMC	R WPH	Denarius	0.21	ND	99.5	ND	ND	ND	0.05	0.11	A
5-2091-123/4	Confiscation	3.53	17	TMC	O PH	Denarius	ND	ND	99.8	ND	ND	ND	0.05	0.07	A
5-2091-123/4	Confiscation	3.53	17	TMC	O PH	Denarius	ND	ND	99.8	ND	ND	ND	0.05	0.07	A

Table 5.1 CONTINUED

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Denomination	Cu	Zr	Ag	Sn	Pt	Au	Pb	Bi	Decision
5-2091-123/4	Confiscation	3.53	17	TMC	O WPH	Denarius	0.08	ND	96.3	0.43	0.07	2.63	0.06	0.07	A
5-2091-123/4	Confiscation	3.53	17	TMC	R WPH	Denarius	ND	ND	98.9	0.44	0.08	ND	0.05	0.07	A
6-2113-37/3	Bought	3.37	17	WC	O PH	Denarius	0.09	ND	99.4	ND	ND	ND	0.07	0.08	A
6-2113-37/3	Bought	3.37	17	WC	O PH	Denarius	0.09	ND	99.4	ND	ND	ND	0.07	0.09	A
6-2113-37/3	Bought	3.37	17	WC	R PH	Denarius	0.12	ND	99.1	ND	ND	ND	0.08	0.09	A
6-2113-37/3	Bought	3.37	17	WC	O WPH	Denarius	0.14	ND	98.9	0.38	ND	ND	0.08	0.07	A
6-2113-37/3	Bought	3.37	17	WC	R WPH	Denarius	0.17	ND	99.0	ND	ND	ND	0.08	0.07	A
6-1780-297	Bought	3.69	18	TMP	O PH	Denarius	0.66	ND	99.3	ND	ND	ND	0.05	ND	A
6-1780-297	Bought	3.69	18	TMP	O PH	Denarius	0.67	ND	99.3	ND	ND	ND	0.04	0.04	A
6-1780-297	Bought	3.69	18	TMP	R PH	Denarius	0.35	ND	99.6	ND	ND	ND	0.05	0.04	A
6-1780-297	Bought	3.69	18	TMP	R PH	Denarius	0.34	ND	99.6	ND	ND	ND	0.05	ND	A
6-1780-297	Bought	3.69	18	TMP	O WPH	Denarius	1.08	ND	98.5	ND	ND	ND	0.05	0.03	A
6-1780-297	Bought	3.69	18	TMP	R WPH	Denarius	0.45	ND	99.0	0.45	ND	ND	0.05	0.04	A
5-1499-218	Bought	3.51	20	WC	O PH	Denarius	0.10	ND	99.7	ND	ND	ND	0.06	0.06	A
5-1499-218	Bought	3.51	20	WC	O PH	Denarius	0.09	ND	99.8	ND	ND	ND	0.07	0.06	A
5-1499-218	Bought	3.51	20	WC	R PH	Denarius	0.15	ND	99.6	ND	ND	ND	0.08	0.07	A
5-1499-218	Bought	3.51	20	WC	R PH	Denarius	0.11	ND	99.8	ND	ND	ND	0.08	0.06	A
5-1499-218	Bought	3.51	20	WC	O WPH	Denarius	0.17	ND	99.1	0.51	ND	ND	0.07	0.06	A
5-1499-218	Bought	3.51	20	WC	R WPH	Denarius	0.19	ND	99.6	ND	ND	ND	0.08	0.06	A
5-2091-123/4	Confiscation	3.53	17	TMC	R PH	Denarius	ND	ND	99.8	ND	ND	ND	0.03	0.08	A
U-2-4	By Police From Uşak	3.45	19	LC	Obverse	Denarius	2.34	0.006	97.1	ND	ND	ND	0.04	ND	F
U-2-5	By Police From Uşak	3.4	20	LC	Obverse	Denarius	1.81	0.011	97.2	ND	ND	ND	0.03	ND	F
U-2-6	By Police From Uşak	3.43	20	LC	Obverse	Denarius	1.41	ND	97.7	ND	ND	ND	0.02	ND	F

In 78 analyses made on the 21 coins from the age of Emperor Augustus, Ag concentration varied from 93.0 to 99.7% with the average being 98.9%. Among the Ag concentrations, 93.0% seems to be an outlier. It is shown in Table 5.1 that this result corresponds to the sample 11-1571-16/2 which is heavily corroded. According to the literature results, in the silver coins which were minted during the reign of Augustus, Ag concentration is between 97-99% (Fleming 1975, Ponting and Butcher 2005). In addition, according to Walker, analyses made by non-destructive XRF on up to 100 Roman denarius coin samples gave an average value of 97% Ag (Walker 1976). It may be concluded that according to main element Ag concentrations all the coins in this group are authentic.

In order to interpret the concentrations of minor elements in authentic and fake coins, 40 analyses were performed in 33 fake coins obtained from Uşak Museum (Figure 5.1). In addition, results for 15 fake coins in MAC from Hellenistic age were used (Tansel 2012) (Figure 5.2). These results were compared with those from 238 authentic silver coins coming from excavations and hoards (Figure 5.3). The full results are given in Appendix 2.

Regarding the minor elements in addition to Ag, the discussion carried out below will be used as a basis for the evaluation of the results for all other silver coins from the ages of mentioned emperors.

The general tends for some of the indicator elements are given below.

Zr: In the fake coins, Zr may be detected. Its presence is indicative of a fake coin, while its absence is not a proof that the coin is authentic.

Pt and Au: These are materials of high cost. The cost for Pt and Au are 50 and 25 fold higher than the cost of Ag. Therefore, normally it is not used in forgeries. However, Pt and Au can be separated completely from Ag when contemporary technologies are used. In ancient times, however, Pt and Au could not be totally separated from Ag. Pt will melt at 1700 °C and Ag in 900 °C; therefore during the ancient metallurgical processing of Ag, Pt was as an impurity. Au and Ag can also exist together in the same natural alloy of *electrum*; and when separated from each other by salt cementation techniques, about 2% Au will be left as impurity in Ag. Therefore in general, Pt and Au are detected only in authentic coins, but their absence is not a proof that the coin is a fake one. Pt was not detected in fake coins of Roman and Hellenistic age analyses made on 48 silver coins (Figure 5.1-5.2, Table 5.1 and Appendix 2). Pt was detected in 12 of 78 analyses of Augustus coins.

Pb: When the Ag was obtained from a Pb ore, Pb concentration will be relatively high in silver. On the other hand, if Electrum was used, Pb levels will be lower. As a conclusion, Pb at relatively high concentration is a strong indication that the coin is authentic. However, in rare occasions it may be absent in an authentic coin. Pb concentrations in fake coins are less than 0.060% and on the average it is around 0.028%.

Bi: This element has a similar trend to that of Pb. Its presence is a strong indication that the coin is authentic. On the other hand, its absence denotes that the coin may be a fake one. Bi was not detected even in one of the 40 analyses made on 33 fake coins of Roman Imperial Age and 15 coins from Hellenistic Age (Figure 5.1-2 and Table 5.1); the full results are given in Appendix 2. Within this study, among 396 analyses performed on Authentic Silver coins coming from excavations and Hoards, Bi was detected in 348 of the cases (Appendix 2). However, it was not detected in any of the fake coins (Appendix 2). Bi was detected in 90% percent of authentic coins.

Regarding the silver coins of Augustus, following conclusions may be drawn.

Ag: Regarding Ag concentrations all of the coins may be authentic. This concentration level can be easily imitated in fake coins. Therefore, Ag values are not decisive in general.

Zr: From the Roman Imperial period, Zr was detected in 16 out of 40 fake coins. Beside these, in 3 of 15 Hellenistic silver coins Zr was detected (Figure 5.1-2 and Table 5.1). Evaluating P-XRF results of Augustus Silver coins in terms of Zr, U-2-4, and U-2-5 are fake because Zr was detected (Figure 5.3). The suggestion of being fake for U-2-4 and U-2-5 are also supported by the Bi results as will be discussed below.

Au and Pt: In two of Augustus silver coins Au was detected, namely 150-870/14-76 and 150-870/13-76. Therefore these coins are authentic. Although Bi concentration is low in 150-870/14-76 indicating that it may be a fake coin, presence of Au is an indication that it is authentic.

Coins with inventory number 6-1780-297, 123-4/3-76, 123-4/2-76, 119-547/15-76, 5-2091-123-14 and 5-1499-218 are authentic in terms of Au and Pt results. Au and Pt are not detectable when silver produced by contemporary techniques is used for forgery.

Au was not detected in any of fake coins. Depending on the ore used, Au can be detected in authentic coin. Au was detected in two coins with inventory numbers 150-870/14-76 and 150-870/13-76. Therefore the coin 150-870/14-76 which was suspicious in terms of Bi value is proven to be authentic in terms of Au.

Pb: It seems that, the coins with inventory numbers 150-870/14-76, 150-870/13-76, 6-1780-297, 123-4/3-76, 123-4/2-76, 119-547/15-76, 5-2091-123-4, 5-1499-218, U-2-4, U-2-5 and U-2-6 are found to be suspicious because they have Pb concentrations lower than 0.07% which overlaps with Pb content in fake coins. But these coins seem to be authentic in terms of Bi values and other elements. The coins 150-870/14-76 and 150-870/13-76 were purified probably from electrum alloy and they have an average 0.0580% Pb, which is rather low for authentic coins. These values are in agreement with values obtained from other archaeological objects produced using electrum from Uşak Karun Treasure (Aydın, unpublished reports of Uşak Treasure). Only one fake coin has a Pb value up to 0.060% (Table 5.1 and Figure 5.1-5.2). In authentic coins of Juliopolis Excavation and Yatağan and Gümüşhane Hoards, silver coins studied within this study have a Pb average of 0.80% (Figure 5.3 and Appendix 2). Only the coins with inventory numbers 150-870/14-76 and 150-870/13-76 which were sold by the same individual are suspected in terms of Pb values.

Bi: Bi was detected in 62 of 78 analyses performed on Augustus coins (Table 5.1). In 8 coins with inventory numbers 133-18/8-76, 12-1648-1, U-2-4 (Figure 5.102, a), U-2-5, U-2-6, 150-870/14-76 and 6-1780-297, very low or undetectable Bi concentrations indicate that these coins may be fake ones.

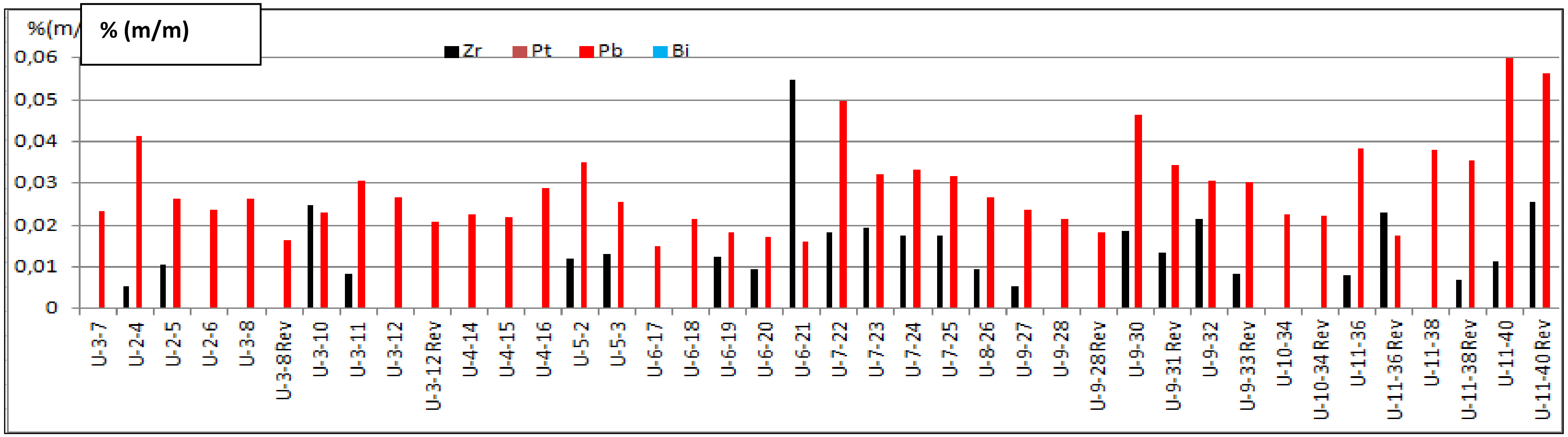


Figure 5.1: P-XRF results (40 analyzes) of 33 fake Silver coins in Uşak Museum from Roman Imperial Age.

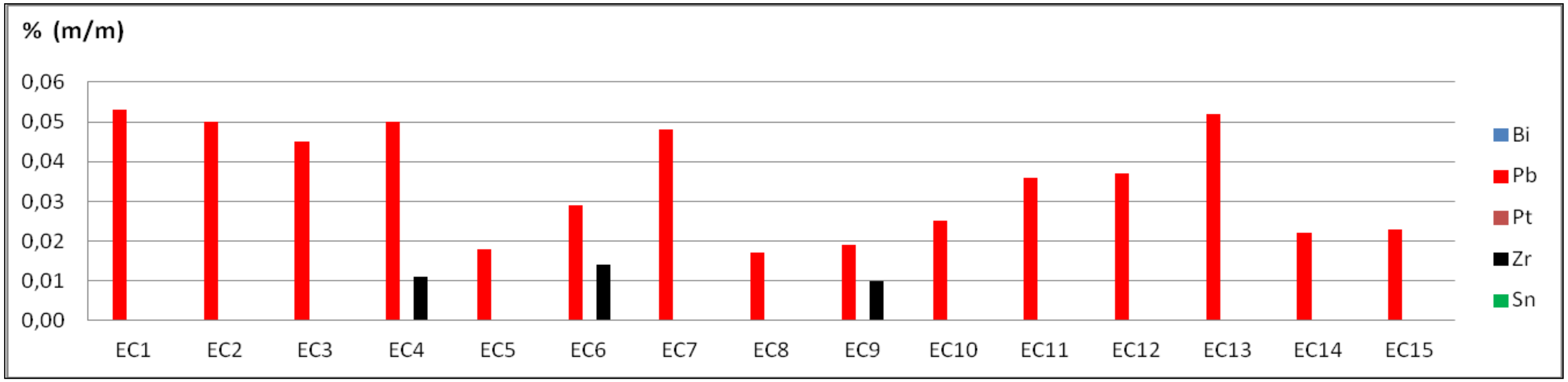


Figure 5.2: P-XRF analyzes results of silver coins made on Fake Great Alexander Drachma, Hellenistic Age (Tansel 2012).

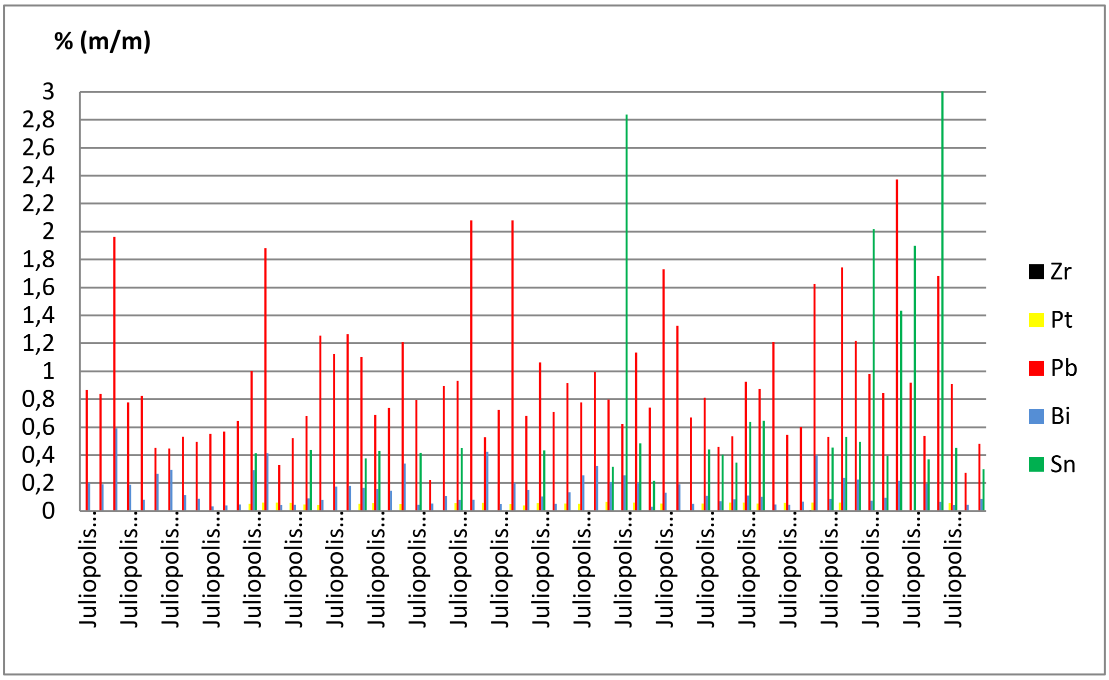


Figure 5.3: P-XRF analyzes results of 66 authentic Silver coins coming from Juliopolis Excavation and dated to Roman Imperial Age

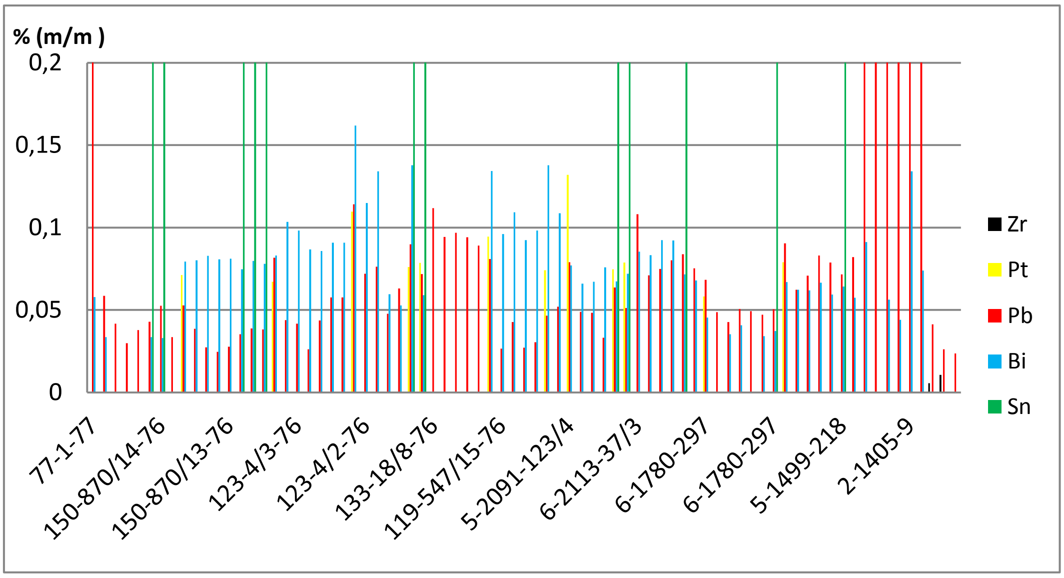


Figure 5.4: Analysis results of Augustus silver coins coming from unreliable sources.

5. 1.2 Analyses of Tiberius (14-37 A.D.) Silver Coins

The P-XRF results are given in Table 5.2. Relevant discussion on results will be presented below. Table 5.2: P-XRF Results for Tiberius silver coins, Concentrations are given in % (m/m).

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Ag	Pb	Bi	Decision
7-2124-208/13	Confiscation	3.57	19	LC	Obverse	0.27	0.24	99.16	0.12	ND	A
5-2019-22/6	Confiscation	3.67	18	LC	Obverse	0.33	ND	98.99	0.16	0.08	A
12-1706-6	Bought	3.66	19	LC	Obverse	0.38	0.029	99.30	0.17	0.033	A
1123-6	Bought	3.57	18	WC	Obverse	0.11	2.76	96.38	0.11	0.10	A
496-1	Bought	3.66	17	LC	Obverse	0.23	ND	99.54	0.18	0.04	A

Silver content of 5 coins from the age of Emperor Tiberius varied from 96.38 to 99.54 percent with the average being 98.67%. The main element Ag is between the expected values and in agreement with the literature results of Fleming and Ponting who stated that the main element of silver coins minted during the reign of Tiberius are up to 98% (Fleming 1975, Ponting 2005). Beside this, Ag content in Tiberius denarius has been reported to be 98% (Walker 1976). According to the concentration of main element, Ag, all coins are authentic.

Evaluating the result in terms of trace elements of Pb, Bi, Pt, Zr and Cu it is seen that all the values are up to 0.10 % as reported by Fleming for plate 8 and in all coins coming from Juliopolis Excavation and other hoards analyzed under this study (Fleming, 1975, pp 123). Comparing to all other results with Figure 1 and Figure 2 which includes the results of fake coins, except the coin on the first row in Table 5.2, in all the coins Bi was detected. In the coin in which Bi was not detected (7-2124-208/13) Pb concentration is fairly high; therefore this is not a fake coin. Moreover Zr is also not detected in the same coin.

5.1.3 Analyses of Claudius (41-54 A.D.) Silver Coins

The results are given in Table 5.3. Some of these values are also given in the histogram form in Figure 5.5. The evaluation of these results will be given in the following paragraphs.

Table 5.3: P-XRF Results for Claudius Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Pt	Pb	Bi	Decision
1954/1-1	Bought	7,18	21	WC	Obverse	3.87	ND	ND	95.9	ND	0.18	0.08	A
5-2020-52-10	Bought	1.55	14	WC	Obverse	6.93	0.05	ND	91.2	0.06	1.05	0.08	A
10-1752-7/6	Bought	1.3	14	Clean	Obverse	1.81	ND	ND	96.8	0.06	0.95	0.07	A
12-1708-405/13	Bought	3.67	19	WC	Obverse	0.1	ND	ND	99.5	ND	0.19	0.08	A
U-3-8	By Police From Uşak	3.48	19	LC	Obverse	2.05	ND	ND	97.7	ND	0.03	ND	F
U-3-8	By Police From Uşak	3.48	19	LC	Reverse	1.76	ND	ND	97.3	ND	0.02	ND	F
U-3-10	By Police From Uşak	3.35	19	LC	Obverse	1.36	ND	0.02	97.2	ND	0.02	ND	F
U-3-11	By Police From Uşak	3.51	19	LC	Obverse	2.27	0.03	0.01	96.5	ND	0.03	ND	F
U-3-12	By Police From Uşak	3.58	19	LC	Obverse	2.04	ND	ND	97.6	ND	0.03	ND	F
U-3-12	By Police From Uşak	3.58	19	LC	Reverse	1.94	ND	ND	96.9	ND	0.02	ND	F
150-870/15-76	Bought	1.65	16	WC	Obverse	12.4	0.06	ND	85.3	0.07	1.28	0.09	A Caesarea
150-870/15-76	Bought	1.65	16	TMC	OPH	7.99	ND	ND	90.3	ND	1.37	0.09	A
150-870/15-76	Bought	1.65	16	TMC	OPH	5.64	ND	ND	93.0	ND	1.31	0.09	A

Silver content of 13 analyzes made from 9 coins of Emperor Claudius varied from 85.3 to 99.5 percent with the average being 95.0%. For Ag, the values of 85.3 % and 91.2% look like as outliers. Silver content of coin which contains 85.3% (150-870/15-76) contained some corrosion on its surface it is also provincial coin from Caesarea. When it was analyzed again using a pin hole; the result was increased to 93%. The main element (Ag) values of the other coins are between expected values. These values are in agreement with the results of others (Fleming 1975 pp 117 plate 6) and Ponting (Ponting and Butcher 2005). In the mentioned references, it is stated that the main element of silver in coins which were minted during the reign of Claudius are up to 97%. According to other results, the average Ag percentage obtained by P-XRF is 98% (Walker 1976).

According to the main element (Ag) all coins seem to be authentic in terms of main elements, except 150-870/15-76 and 5-2020-52-10. Evaluating the results in terms of the minor elements, Pb, Bi, Pt and Zr, it is seen that these two coins are also authentic. Because Pt and Bi were detected only in authentic coins and in these two coins Pt and Bi were detected. When evaluating Pb and Zr results, Zr is not detected in these two coins as it is in authentic coins and Pb percentage is not like the results of fake coins (0.060% or lower).

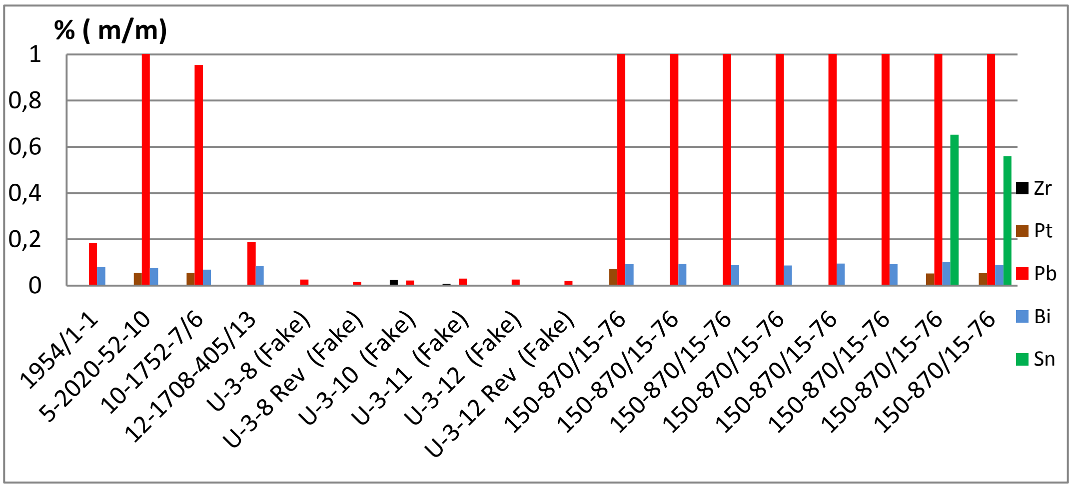


Figure 5.5:P-XRF results for authentic and fake coins of Emperor Claudius.

Evaluating the results by comparing with those in Figure 5.1-3 it is seen that six analyzes made from four coins with inventory number U-3-8, U-3-8 rev, U-3-10, U-3-11 (Figure 5.102), U-3-12, U-3-12 rev are fake; the reasons are stated below.

Zr: It is detected in U-3-10 and U-3-11; Zr is detected only in fake coins.

Pt: This element is also not detected in analyzes of these 4 coins. Its absence supports the suggestion that the above coins are not authentic..

Pb: Its concentration is between 0.030% and 0.02%; these results totally overlap with the results of other fake coins in Figure 5.1-2. Therefore these coins are fake also in terms of Pb values.

Bi: This element is not detected in any coins with inventory numbers U-3-8, U-3-8 rev, U-3-10, U-3-11 (Figure 5.62, b), U-3-12, U-3-12(Rev), Bi is detected in 90% of the authentic coins.

From Table 5.3 results of six analyzes made on 4 fake coins (U-3-8, U-3-10, U-3-11, U-3-12) show that these are fake. Because of high the technology used in the purification of ores, impurities are very low as compared to those in authentic coins.

5.4 Analyses of Nero (54-68 A.D.) Silver Coins

The results are given in Table 5.4. Some of these values are also given in the peak form in Figure 5.6. The evaluation of these results will be given in the following paragraphs.

Table 5.4: P-XRF Results for Nero Denarius Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Ag	Sn	Pt	Pb	Bi	Decision
15-216/1-75	Donation	1.8	15	LC	Obverse	ND	ND	47.2	0.42	**48.6**	ND	F
1574-16/4	Bought	3.41	18	LC	Obverse	3.55	94.8	ND	0.06	**1.4**	0.05	A

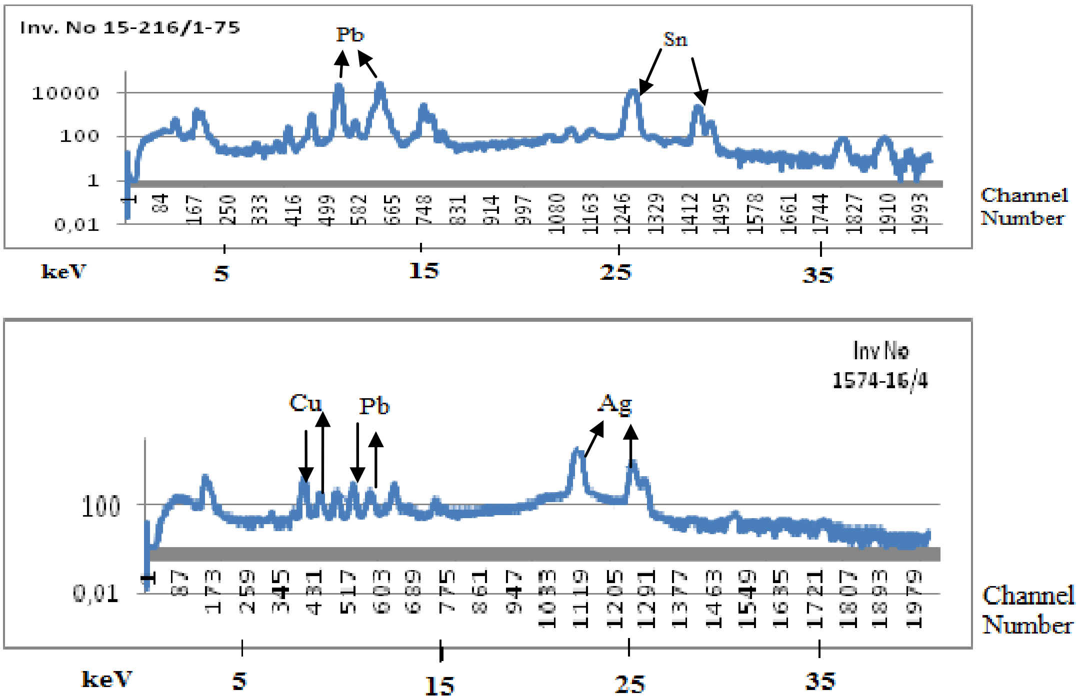


Figure 5.6: P-XRF spectra for the coins with inventory numbers 15-216/1-75 and 1574-16/4.

We have only two coins from the age of Emperor Nero age; one of them (15-216/1-75) is fake in terms of its chemical composition (Figure 5.6). It is obviously seen that it is made of Pb and Sn which is same with the formula Sn 60%, Pb 40% of solder (http://en.wikipedia.org/wiki/Solder 27.12.2011). The reason of donation should be trying to know whether museum experts will find out that it is fake or not (Figure 5.100). If the museum experts find out that the coin is a fake one, the person who brought it cannot be punished because it is a donation. The other coin is authentic in terms of main element Ag, and trace elements Pb and Cu, comparing with literature results (Fleming 1975, Walker 1976, Ponting and Butcher 2005).

5.1.5 Analyses of Galba (68-69 A.D.) Silver Coins

The results are given in Table 5.5. The evaluation of these results will be given in the following paragraphs.

Table 5.5: P-XRF Results for Galba Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Ag	Pt	Pb	Bi	Decision
42-7/2-76	Bought	2.76	17	LC	Obverse	2.72	ND	96.7	ND	0.5	ND	A
7-2113-37/6	Bought	2.14	17	WC	Obverse	3.02	0.03	94.6	0.05	1.3	0.04	A

When interpreting the results of the two coins from the Roman Emperor Galba, regarding the all aspects, main Ag and trace elements (Pb, Cu) and their comparison with other studies (Fleming 1970). These two coins struck under the Roman Emperor Galba authority are authentic.

Pb: It is between 0.51 to 1.39%, as expected from ancient cupellation technology. Two coins of Galba are authentic in terms of Pb.

Bi: In one of the two coins (7-2113-37/6) Bi was detected as 0.045%. Bi can be detected in most of the authentic coins.

Pt: Pt was detected in coin with inventory number 7-2113-37/6 in which Bi was also detected.

Zr: It was not detected in Galba's two coins analyzed in this study.

5.1.6 Analyses of Vitellius (69 A.D.) Silver Coins

The results of the three coins from the age of Roman Emperor Vitellius have been evaluated. The results are given in Table 5.6. Photograph of fake samples are given in Figure 5.7. The main element (Ag) is at the level of 98%. In addition, the trace elements (Pb, Pt, Bi, Zr) and their comparison with other studies (Fleming 1970) show that these three coins from the Roman Emperor Vitellius authority are fake in terms of minor elements.

Table 5.6: P-XRF Results for Vitellius Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquistion	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Pt	Pb	Bi	Decision
U-4-14	By Police From Uşak	LC	Obverse	1.55	ND	98.2	ND	0.02	ND	F
U-4-15	By Police From Uşak	LC	Obverse	1.25	ND	98.1	ND	0.02	ND	F
U-4-16	By Police From Uşak	LC	Obverse	1.73	ND	97.8	ND	0.02	ND	F

Pb: is the values are too low to be produced with cupellation technology, between 0.021 to 0.028%. Three coins of Vitellius are fakes in terms of Pb.

Bi: Bi was not detected in any of the three coins. Bi is detected in 90% of authentic coins.

Pt: It was not detected in any of the coins. Pt, depending on the ore used, is detected only in authentic coins but not as common as Bi. Three coins are fake in terms of Pt.

Zr: It was not detected in Vitellius' three coins analyzed in this study. Zr is, very commonly, detected in fake coins; however, sometimes it cannot be detected because of its low concentration that is below or around the detection limit. Moreover in minted coins, Zr cannot be detected since its probable source is casting technology used in production of fake coins. If this technology was not used, Zr will not be present. Therefore the presence of Zr is not always encountered in fake coins.

Figure 5.7: Fake coins of Vitellius (obverse and reverse of U-4-16, U-4-15 and U-4-14, from left to right).

5.1.7 Analyses of Vespasian (69-79 A.D.) Silver Coins

The results are given in Table 5.7. Some of these values are also given in the histogram form in Figure 5.8. Selected photos of fake and authentic coins were given in Figure 5.9 and 5.10. The evaluation of these results will be given in the following paragraphs.

Table 5.7: P-XRF Results for Vespasian Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Pt	Pb	Bi	Decision
98-M189	Juliopolis Exc.	2.45	19	Cleaned	Obverse	2.6	ND	96.8	ND	0.55	0.03	A
98-M189	Juliopolis	2.45	19	Cleaned	Reverse	3.6	ND	95.8	ND	0.57	0.04	A
63-M154	Juliopolis	2.36	20	WC	Obverse	1.8	ND	95.9	ND	2.08	0.08	A
49-M139	Juliopolis	2.22	19	Cleaned	Obverse	2.3	ND	96.9	ND	0.71	0.05	A
3-M96	Juliopolis	3.09	20	Cleaned	Obverse	3.4	ND	96.3	ND	0.28	0.05	A
1223-28	Bought	3.26	18	Clean	Obverse	3.9	ND	95.0	ND	0.86	0.05	A
1202-7/1	Bought	2.95	18	Clean	Obverse	3.8	ND	94.7	ND	1.05	0.08	A
1202-7/2	Bought	2.71	19	Clean	Obverse	6.2	ND	92.9	ND	0.70	0.08	A
1189-11	Bought	2.99	18	LC	Obverse	2.7	ND	96.5	ND	0.70	0.08	A
111-825-1	Bought	3.05	17	Clean	Obverse	4.8	ND	94.6	ND	0.54	ND	A
518-7	Bought	2.88	20	WC	Obverse	3.4	ND	96.1	ND	0.46	ND	A
9-1529-4	Bought	2.86	18	Clean	Obverse	9.5	ND	89.2	ND	0.47	0.03	A
9-1529-4/1	Bought	2.72	18	Clean	Obverse	2.2	ND	95.3	0.076	2.35	ND	A

Table 5.7 CONTINUED

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Pt	Pb	Bi	Decision
11-1869-52/47	Gümüşhane Hoard	1.51	15	LC	Obverse	4.8	ND	92.4	0.06	0.29	0.13	A
11-1869-52/58	Gümüşhane Hoard	1.27	14	LC	Obverse	3.3	ND	95.4	0.06	0.70	0.04	A
12-1873-476/41	Bought	2.37	18	WC	Obverse	2.3	ND	94.4	0.08	1.20	ND	A
U-5-2	By Police From Uşak	3.45	20	LC	Obverse	1.8	0.01	97.1	ND	0.04	ND	F
98-M189	Juliopolis Exc.	2.45	19	Cleaned	Obverse	2.6	ND	96.8	ND	0.55	0.03	A
98-M189	Juliopolis	2.45	19	Cleaned	Reverse	3.6	ND	95.8	ND	0.57	0.04	A
63-M154	Juliopolis	2.36	20	WC	Obverse	1.8	ND	95.9	ND	2.08	0.08	A
49-M139	Juliopolis	2.22	19	Cleaned	Obverse	2.3	ND	96.9	ND	0.71	0.05	A
3-M96	Juliopolis	3.09	20	Cleaned	Obverse	3.4	ND	96.3	ND	0.28	0.05	A
1223-28	Bought	3.26	18	Clean	Obverse	3.9	ND	95	ND	0.86	0.05	A
1202-7/1	Bought	2.95	18	Clean	Obverse	3.8	ND	94.7	ND	1.05	0.08	A
1202-7/2	Bought	2.71	19	Clean	Obverse	6.2	ND	92.9	ND	0.70	0.08	A
1189-11	Bought	2.99	18	LC	Obverse	2.7	ND	96.5	ND	0.70	0.08	A
111-825-1	Bought	3.05	17	Clean	Obverse	4.8	ND	94.6	ND	0.54	ND	A
518-7	Bought	2.88	20	WC	Obverse	3.4	ND	96.1	ND	0.46	ND	A
9-1529-4	Bought	2.86	18	Clean	Obverse	9.5	ND	89.2	ND	0.47	0.03	A
9-1529-4/1	Bought	2.72	18	Clean	Obverse	2.2	ND	95.3	0.08	2.35	ND	A

Table 5.7 CONTINUED

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Pt	Pb	Bi	Decision
1-1677-50/5	Bought	13.78	27	Little-	Antiochia Obverse	13.3	ND	86.1	ND	0.50	0.04	A
U-5-3	By Police From Uşak	3.54	20	LC	Obverse	1.7	0.01	96.8	ND	0.03	ND	F
5-1499-218	Bought	3.26	19	MC	Obverse	18.1	ND	81.0	0.1	0.62	0.05	A
5-1499-218	Bought	3.26	19	MC	O PH	9.98	ND	89.3	ND	0.66	ND	A
5-1499-218	Bought	3.26	19	MC	O PH	10.4	ND	89.0	ND	0.65	ND	A
5-1499-218	Bought	3.26	19	MC	R PH	7.4	ND	91.9	ND	0.67	ND	A
5-1499-218	Bought	3.26	19	MC	O WPH	11.4	ND	87.3	ND	0.67	ND	A
5-1499-218	Bought	3.26	19	MC	R WPH	7.9	ND	90.9	ND	0.65	ND	A

Silver content in 25 analyses performed in 20 samples varied from 81.0 to 97.1 percent with the average being 93.1%; these values are in agreement with literature values (Walker 1976). Within the samples, the ones with 81.0 % and 86.1 % Ag values seem to be the outliers. When Table 5.7 is examined, it can be seen that these values correspond to two coins samples which have been bought from individuals. Among these, 5-1499-218 has a high level corrosion that might be the reason for the low Ag value. After using the pin hole, the Ag percentage increased from %81 to %92. The coin which seems to be suspicious in terms of the main element Ag is authentic after analyzed by using pin hole during the P-XRF analysis.

The sample with inventory number 1-1677-50/5 is minted in Antiochia (Antakya /Turkey) and these coins are known with their low silver content, such as 86.1 % concentration. Therefore, this rather low value is not due to forgery or corrosion, but it is due to the authority that minted the coin. In general, Roman Provincial coins have lower silver content as compared to the coins of Roman Imperial (Walker 1976).

Similar consideration can also be done by using the results of minor and trace elements. Regarding copper values, these are varied from 1.8 to 18% with the average being 5.12%.

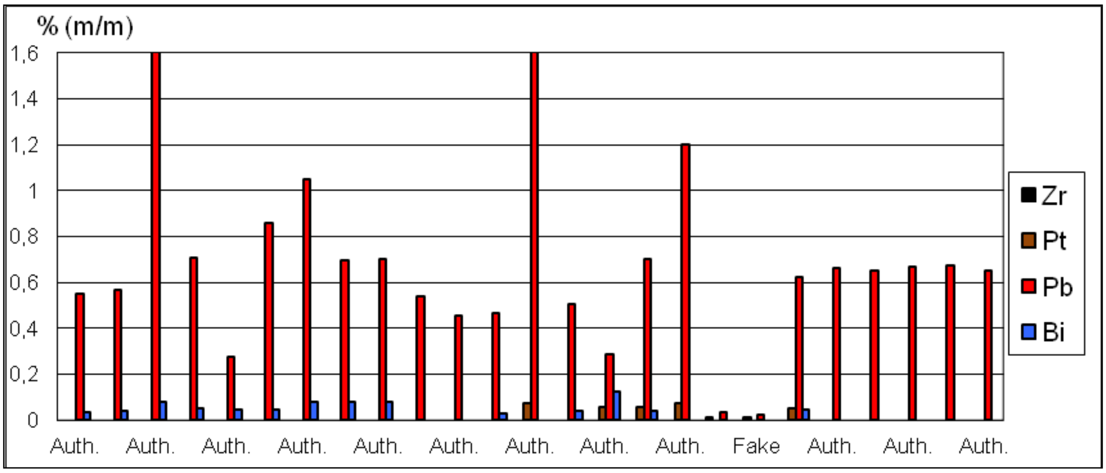


Figure 5.8: Histogram of minor elements in Vespasian silver coins.

Comparing the minor element concentrations, Zr, Pb, Pt and Bi with the values in Figure 5.1-3, the conclusions are given below.

Pb: The coins with inventory numbers U-5-2 and U-5-3 have values 0.035% and 0.025%, respectively, which are in the same range of those from the fake coins. This is a consequence of the high purification technology and these values are far from authentic coin values. Therefore, these two coins are fake in terms of Pb.

Zr: This element is only detected in U-5-2 and U-5-3; these results support the decision obtained from Pb results.

Pt: It is not detected in U-5-2 and U-5-3. Pt results support Zr and Pb results.

Bi: It is not detected in U-5-2 and U-5-3 so that these two coins are fake, supporting the decisions from Bi, Zr and Pb results.

As a result coins with inventory numbers U-5-2 and U-5-3 are fake and the others are authentic.

Figure 5.9: Fake coin example of Vespasian (Inv. No: U-5-2).

Figure 5.10: Authentic coin of Vespasian with inventory number 3-M 96 from Juliopolis Excavation.

5.1.8 Analyses of Domitian (81-96 A.D.) Silver Coins

The results are given in Table 5.8. Some of these values are also given in the histogram form in Figure 5.11. The evaluation of these results will be given in the following paragraphs.

Table 5.8: P-XRF Results for Domitian Silver Coins, Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Sb	Pt	Pb	Bi	Decision
90-M196	Juliopolis Excavation	1.47	19	TMC	Reverse	0,27	ND	ND	99.29	ND	ND	0.1	0,33	0.04	A
90-M196	Juliopolis Excavation	1.47	19	TMC	Obverse	0,51	ND	ND	98.86	ND	ND	0.1	0,52	0.05	A
22-M120	Juliopolis Excavation	2.64	19	WC	Obverse	14,8	ND	ND	97.76	ND	ND	0.1	0,93	0.05	A
5-M110	Juliopolis Excavation	2.2	18	LC	Obverse	1,59	ND	ND	96.44	0.5	ND	0.1	0,87	0.04	A
Z1	By Police From Zurich	3.52	19	Cleaned	Obverse	2,1	ND	ND	96.65	0.6	ND	ND	0,55	0.05	A
Z10	By Police From Zurich	3.31	18	Cleaned	Obverse	2,19	ND	ND	95.96	0.5	ND	ND	0,91	0.043	A
Z10	By Police From Zurich	3.31	18	LC	Reverse	2,96	ND	ND	95.75	0.4	ND	ND	0,52	0.05	A
25-M122	Juliopolis Excavation	1.51	18	WC	Obverse	3,18	0.1	ND	75.25	0.6	ND	0.1	0,54	0.11	A
25-M122	Juliopolis Excavation	1.51	18	WC	Reverse	9,05	0.1	ND	83.43	0.6	ND	0.1	0,61	0.1	A
25-M122	Juliopolis Excavation	1.51	18	TMC	O PH	8,99	ND	ND	77.38	0.6	ND	ND	0,91	0.11	A
25-M122	Juliopolis Excavation	1.51	18	LC	O PH	22,8	ND	ND	89.19	0.7	ND	ND	0,92	0.12	A
25-M122	Juliopolis Excavation	1.51	18	LC	O PH	20,5	ND	ND	89.42	0.6	ND	ND	0,87	0.11	A
25-M122	Juliopolis Excavation	1.51	18	TMC	O WPH	22,7	0.1	ND	74.78	0.8	0.4	0.1	0,87	0.11	A
25-M122	Juliopolis Excavation	1.51	18	LC	R WPH	16,7	0.1	ND	82.1	0.8	ND	0.1	0,90	0.11	A

Silver content of 14 analyzes made from 6 coins varied from 74.78 to 99.29 percent with the average being 89.44%. Within the samples, the values of 74.78, 75.24 %, 82.1% and 83.42 % Ag seem to be outliers. When we look at the values in Table 5.8, these values correspond to obverse and reverse of same sample which is coming from a reliable source, Juliopolis Excavation, 25-M122. When searching the details of 25-M122, it is much corroded so the reason of low Ag value may be corrosion. In order to investigate further, the same coin was analyzed by using a pin hole which gives opportunity of analyzing a selected part of the coin. The Ag content of the coin from a cleaned part by using pin hole increased from 74.78% to 89.42. This value is same with average but it is still low and shows the effect of corrosion. Because, Domitian denarius coins have an average Ag content up to 90% (Walker 1976). When looking the results in Table 5.8 without the taking the Ag results of of 25-M122 in account, Ag value average is up to %94; this value is in agreement with literature (Walker 1976).

It is interesting that other element such as Pb, have values greatly variable in a range of 0.33- 0.92%. These variations may come from the different production technologies used in Roman Imperial age (Fleming 1975). When evaluating the suspicious coin 25-M122 in terms of the minor element Pb, the results are in the range of 0.54 and 0.92 % which are similar to authentic coins.

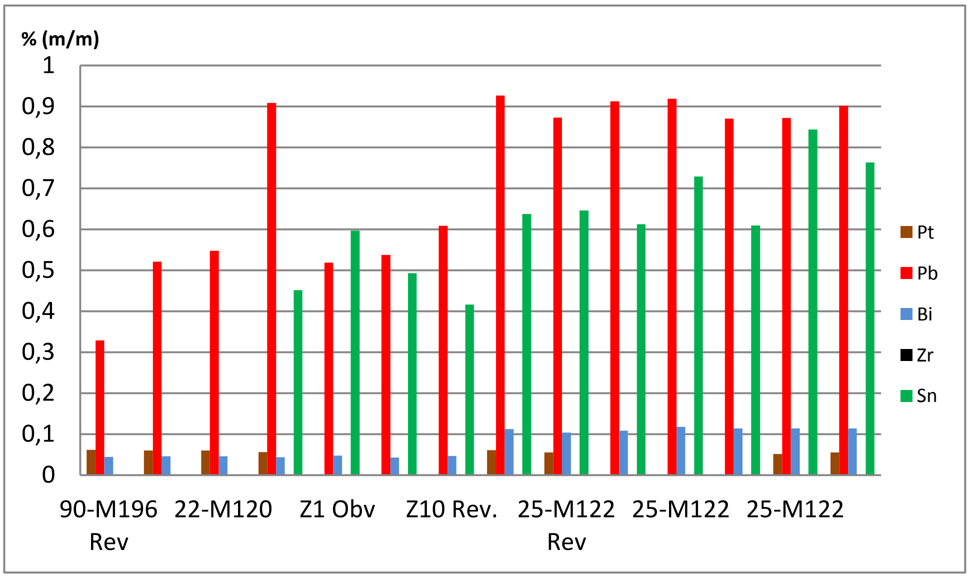


Figure 5.11:A histogram for P-XRF results of Domitian coins.

Comparing minor elements, Zr, Pb, Pt and Bi of values of Domitian coins with each other and the values given in Figures 5.1-3, the following evaluations may be made.

Pb: The results vary from 0.33% to 0.93% with average 0.73 which is relatively high as compared to the results of fake coins which has average value 0.028%; therefore, all the coins of Domitian are authentic in terms of Pb values.

Zr: It has not been detected in any Domitian coins, but detected only in fakes. Therefore, all the coins are authentic in terms of Zr results.

Pt: In 8 analyses Pt was detected between 0.051-0.061 % with an average of 0.057. Pt is detected only in authentic coins.

Bi: In all the coins, Bi was detected between 0.043-0.11% and with an average of 0.078 %. The results of Domitian coins are authentic in terms of Bismuth.

A general conclusion is that all the Domitian coins investigated in this study are authentic.

5.1.9 Analyses of Nerva (96-98 A.D.) Silver Coins

The results are given in Table 5.9. Some of these values are also given in the histogram form in Figure 5.12. The evaluation of these results will be given in the following paragraphs.

Table 5.9: P-XRF Results for Nerva Silver Coins, concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Analyzed Side of Coin and Sampling Option	Surface Condition	Cu	Zn	Ag	Pb	Bi	Decision
Z6	By Police From Zurich	3.25	18	Obverse	Cleaned	1.54	ND	97.8	0.16	ND	A
Z6	By Police From Zurich	3.25	18	Reverse	Cleaned	1.87	ND	97.6	0.08	ND	A
Z6	By Police From Zurich	3.25	18	Reverse	Cleaned	1.88	ND	98,0	0.09	ND	A
1373-16	Bought	3.45	19	Obverse	WC	2.87	ND	96.6	0.46	0.03	A
1373-16	Bought	3.45	19	Reverse	WC	3.16	ND	96.5	0.39	ND	A
1969-IV-1826-17/4	Bought	6.38	21	Obverse	LC	31.9	0.1	67.4	0.42	ND	A Caesarea
1969-IV-1826-17/4	Bought	6.38	21	Reverse	Clean	23.3	0.1	76.1	0.45	ND	A Caesarea

Silver content of 7 analyses from 3 samples varied from 76.13 to 98.03 % with the average being 93.77%; these results are in agreement with those for Nerva's Denarius in literature (Walker 1976). Within the samples, the coin with inventory number 1969-IV-1826-17/4 having 67.4-76.1% Ag seems to be an outlier (Table 5.9 and Figure 5.12). When we look at the values in Table 5.9, these values correspond to the coin sample which was bought from an individual. When other information on this coin is investigated, it is seen that the coin is corroded. Therefore, the reason of low Ag percentage is corrosion. After analyzing the reverse of the same coin, Ag percentage increased from 67.4 to 76.1%. The minor element Pb concentration is also supporting the suggestion that the low Ag percentage is due to corrosion but not because it is fake. Because, the Pb percentage is fairly high (0.45%) and not in the range of those from the fake coins. Another reason of low Ag, it was minted in Caesarea /Kayseri in other word it was provincial coin not Imperial.

The final conclusion is that all the coins under investigation from the age of Nervaare authentic.

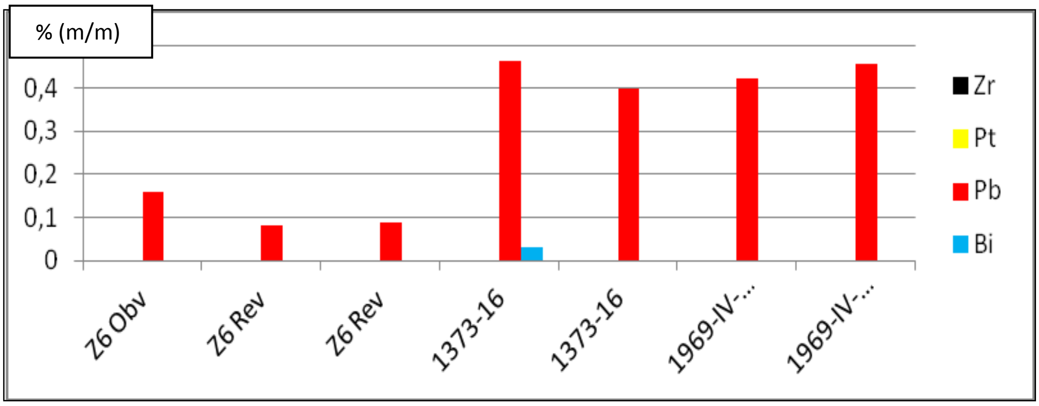


Figure 5.12: Histogram of minor element analyzed from silver coins of Nerva.

5.1.10 Analyses of Trajan (98-117 A.D.) Silver Coins

The values and other relevant data are given in Table 5.10 and Figure 5.13. The evaluation of these results will be given in the following paragraphs.

Table 5.10: P-XRF Results for Trajan Silver Coins. Concentrations are given in % (m/m).

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Surface Condition	Cu	Zr	Ag	Sn	Pt	Pb	Bi	Decision
104-M180	Juliopolis Exc.	2.33	18	Obverse	Cleaned	2.56	ND	96.37	ND	ND	0.87	0.20	A
104-M180	Juliopolis Exc.	2.33	18	Obverse	Cleaned	3.23	ND	95.74	ND	ND	0.84	0.19	A
97-M190	Juliopolis Exc.	2.38	19	Obverse	Cleaned	2.16	ND	97.14	ND	ND	0.64	0.05	A
58b-M148	Juliopolis Exc.	1.6	17	Obverse	Cleaned	3.83	ND	95.02	ND	ND	0.73	0.05	A
48-M139	Juliopolis Exc.	2.44	19	Obverse	Cleaned	3.47	ND	95.43	ND	0.054	0.91	0.13	A
38-M132	Juliopolis Exc.	2.17	18	Obverse	Cleaned	5.62	ND	92.36	ND	0.055	1.73	0.13	A
609-1	Bought	3.27	20	Obverse	Too much clean	3.87	ND	94.66	0.38	ND	0.94	0.07	A
609-1	Bought	3.27	20	Reverse	Too much clean	3.2	ND	95.73	ND	ND	0.92	0.07	A
576-1	Bought	2.64	19	Obverse	Too much clean	4.5	ND	94.43	ND	ND	0.97	0.08	A
576-1	Bought	2.64	19	Reverse	LC	4.39	ND	94.47	ND	ND	0.99	0.09	A
1223-28	Bought	3.2	19	Obverse	Too much clean	2.08	ND	96.65	ND	0.048	0.88	0.20	A
1223-28	Bought	3.2	19	Reverse	LC	2.33	ND	96.53	ND	ND	0.81	0.20	A
1188-11	Bought	3.04	19	Obverse	Too much clean	3.92	ND	95.01	ND	ND	0.93	0.08	A
1188-11	Bought	3.04	19	Reverse	Too much clean	4.37	ND	94.45	ND	ND	0.99	0.09	A
1961 IX -1529-4	Bought	2.58	19	Obverse	Too much clean	2.26	ND	96.69	ND	ND	0.91	0.13	A
1961 IX -1529-4	Bought	2.58	19	Reverse	Too much clean	2.14	ND	96.8	ND	ND	0.90	0.13	A
V-1499-218	Bought	3.1	20	Obverse	LC	6.1	ND	92.89	ND	ND	0.88	0.10	A
V-1499-218	Bought	3.1	20	Reverse	LC	6.77	ND	92.13	ND	ND	0.97	0.10	A
1964 VII-1636-7/1	Bought	2.95	18	Obverse	LC	3.28	ND	95.1	ND	ND	0.94	0.11	A
1962 12-1578-1	Bought	3.59	19	Obverse	WC	7.63	ND	90.14	ND	ND	0.68	0.11	A
1956 11-1405-9	Bought	3.16	20	Obverse	WC	8.93	ND	90.21	ND	ND	0.81	0.05	A
1956 11-1405-9	Bought	3.16	20	Reverse	WC	7.24	ND	91.85	ND	ND	0.82	0.05	A
1127-3	Financial Min.	2.77	19	Obverse	WC	7.3	ND	91.07	0.37	ND	0.99	0.08	A
1127-3	From Financial	2.77	19	Reverse	WC	4.2	ND	94.16	ND	ND	0.94	0.09	A
1947 XII-1212-17	Bought	3.31	19	Obverse	WC	4.53	ND	94.29	ND	ND	1.05	0.13	A
9-1556-2-1	Bought	2.97	19	Obverse	WC	2.29	ND	96.66	ND	ND	0.67	0.05	A
1962- 11-1571-16/4	Bought	3.29	19	Obverse	WC	24.9	ND	72.08	0.49	ND	0.69	ND	F
1962- 11-1571-16/4	Bought	3.29	19	Reverse	WC	24.6	ND	72.25	0.53	ND	0.76	ND	F
101-M184	Juliopolis Exc.	2.63	18	Obverse	LC	3..3	ND	95.2	ND	ND	0.83	0,08	A

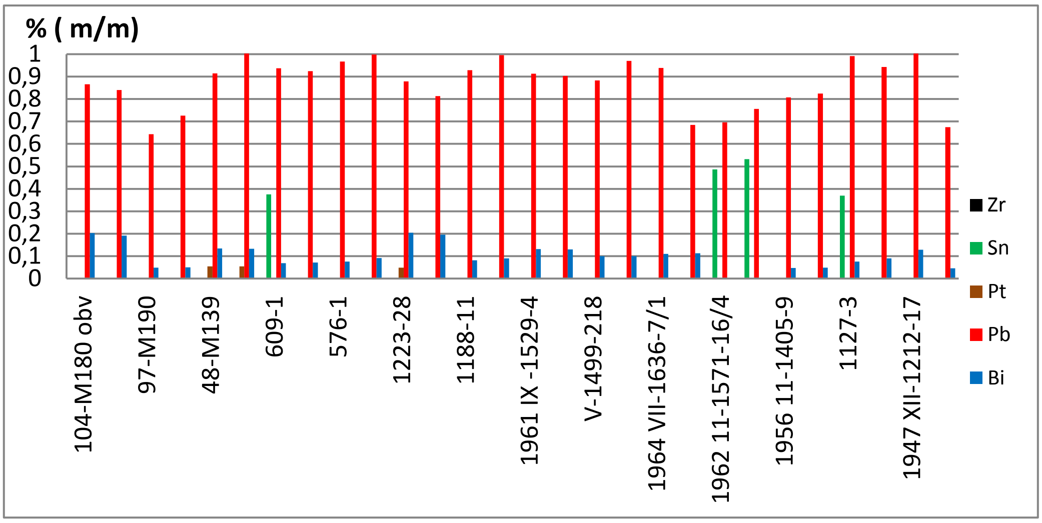


Figure 5.13: Histogram for P-XRF results of minor elements from Trajan's Denarius.

Silver content of 29 analyses from 20 coins varied from 72 to 97% with the average being 92.8 %. For the sample with inventory number 1962 11-1571-16/4, Ag value seems to be outlier. The reason of low value Ag percentage may be corrosion since 0.69-0.76% Pb value is higher than those in a typical fake coin. However high Cu 24.9%, also can be reason of high Pb value.

Comparing minor elements, Zr, Pb, Pt and Bi of Table 5.10 with each other and those in Figure 5.1-3 results of fake and authentic coins, following conclusions may be drawn.

Pb: All the coins have relatively high Pb values (0.6-1.7%). Regarding Pb values of fake coins (under 0.06%) the none of the coin is suspicious interms of Pb. Moreover, the coin with inventory number 1962 11-1571-16/4 has 25% Cu; therefore the reason for its high Pb content, 0.7-0.8%, may be originated from the copper used. This coin should not be interpreted as authentic in terms of Pb value

Zr: It is not detected in any coin of Trajan.

Pt: It is detected only in three samples. In the coin with inventory numbers 48-M139 ans 1223-28 Pt was 0.055 and 0,048%.
Bi: It is detected in all the coins except the outlier/suspicious coin with inventory number 1962 11-1571-16/4 which have corrosion. It is probable that Bi could not be detected because of low Bi value which is close to detection limit and the fact that corrosion is preventing its detection.

The trace element Pb have values greatly varied from 0.6- 1.7% with an average 0.95% which overlap with analyzes results from literature (Fleming 1975) and other all authentic coins coming from reliable sources. Pb results in up to 300 coins from Denarius of Trajan Age analyzed by Walker were between 0.25 to 1.75% (Walker 1976); the results obtained in this thesis study are also in agreement. These variations come from production technology, cupellation, of Roman Imperial Age (Fleming 1975 and Rodrigues et al. 2011).

A marked decrease in the silver content of the alloy of Trajan's denarius between the years 99 and 100 A.D. could be observed. While the denarius of the emperor's second consulate (98–99 A.D.) contain 88% silver on an average, the silver content was reduced to about 80% in the coins of his third consulate (100 A.D.). This remained the standard for the Roman mint adhered to in the following period, until the end of Trajan's reign (117 A.D.) (Rodrigues et al. 2011). Our result do not support Rodrigues' result because the coins with 97-M190, a58-M148 and 48-M139 inventory numbers show that after third consulate of Trajan, average Ag value is up to 95%. Silver percentage results of Walker analyses made on up to 300 coins (Walker 1977) also are higher (mean %92-93 till 107-108 A.D.) than Rodrigues' (Rodrigues et al. 2011). After 107 A.D. average silver percentage of Trajan coins decreased to 89-88%. Our silver average is higher than those reported by Walker and Rodrigues (Walker 1977, Rodrigues et al. 2011). This may be because of the different analysis techniques used.

It may be concluded that apart from coin with inventory number 1962 11-1571-16/4 (Figure 5.102, c) all the other silver coins of Trajan age under investigation are authentic.

5.1.11 Analyses of Hadrian (117-138 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.11, also in Figure 5.14 in a histogram form. Selected coin samples are shown in Figure 5.15 and Figure 5.16.

Table 5.11: P-XRF Results for Hadrian Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Formof acquisition	W, (g)	D, (mm)	Emperor	Surface CoNDition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
100-M189	Juliopolis Exc	2.22	18	Hadrian	LC	Obverse	2.1	ND	ND	97.21	ND	ND	0.45	0.27	A
100-M189	Juliopolis Exc			Hadrian	LC	Reverese	2.3	ND	ND	96.99	ND	ND	0.45	0.29	A
99-M189	Juliopolis Exc	2.71	18.5	Hadrian	LC	Obverse	9.2	0.1	ND	90.11	ND	ND	0.53	0.11	A
99-M189	Juliopolis Exc			Hadrian	LC	Reverse	9.1	0.04	ND	90.32	ND	ND	0.49	0.09	A
83-M179	Juliopolis Exc	2.5	19	Hadrian	LC	Obverse	2.6	ND	ND	96.06	ND	0.0 44	1.26	0.08	A
82-M177	Juliopolis Exc	2.37	19	Hadrian	LC	Obverse	5.2	0.03	ND	93.48	ND	ND	1.13	0.18	A
82-M177	Juliopolis Exc			Hadrian	LC	Reverse	5.8	0.03	ND	92.71	ND	ND	1.26	0.18	A
70-M162	Juliopolis Exc	2.06	19	Hadrian	LC	Obverse	1.8	ND	ND	97.24	ND	ND	0.89	0.11	A
21-M120	Juliopolis Exc	2.62	17	Hadrian	LC	Obverse	2.3	ND	ND	96.65	ND	ND	0.6	0.068	A
37-M131	Juliopolis Exc	2.22	17	Hadrian	Cleaned	Obverse	3.4	ND	ND	95.13	ND	ND	1.32	0.19	A
20-M118	Juliopolis Exc	2.1	17	Hadrian	LC	Obverse	2.4	ND	0.006	95.46	ND	0.0 63	1.63	0.40	A
19-M118	Juliopolis Exc	2.66	18	Sabina	LC	Obverse	1.7	ND	ND	97.26	0.5	ND	0.53	0.09	A

Table 5.11 CONTINUED

Inv. No	Formof acquisition	W, (g)	D, (mm)	Emperor	Surface CoNDition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
14-M113	Juliopolis Exc	2.47	18	Hadrian	LC	Obverse	2.7	ND	ND	95.3	0.5	ND	1.22	0.23	A
U-6-17	By Police From Uşak	3.48	19	Hadrian	LC	Obverse	1.8	ND	ND	97.95	ND	ND	0.02	ND	F
U-6-18	By Police From Uşak	3.55	19	Hadrian	LC	Obverse	1.8	ND	ND	97.43	ND	ND	0.02	ND	F
U-6-19	By Police From Uşak	3.36	19	Hadrian	LC	Obverse	2.1	ND	0.013	96.67	ND	ND	0.02	ND	F
U-6-20	By Police From Uşak	3.46	19	Hadrian	LC	Obverse	2.0	ND	0.009	97.09	ND	ND	0.02	ND	F
U-6-21	By Police From Uşak	3.57	19	Hadrian	LC	Obverse	1.7	ND	0.055	96.26	ND	ND	0.02	ND	F
U-6-1	By Police From Uşak	3.56	19	Hadrian	LC	Obverse	2.1	ND	ND	97.71	ND	ND	0.02	ND	F

In this group, 19 analyses made from 15 silver coins coming from Juliopolis Excavation and Uşak Museum dated to 117-138 A.D. Hadrian Age Ag concentrations in the range of 90.11 % to 97.95 % with the average of 95.52%. Within these samples, none of the Ag values seem to be an outlier. It has been reported that a range of 88-89% was found for Ag content for 324 coins analyzed from the Hadrian age (Walker 1977). The reason of high silver percentage can be well cleaned coins, same techniques but technology difference; silver concentration is higher in the surface than in the bulk (Table 5.11).

Regarding copper, values are varied from 1.7 to 9.2% with the average being 3.4%.

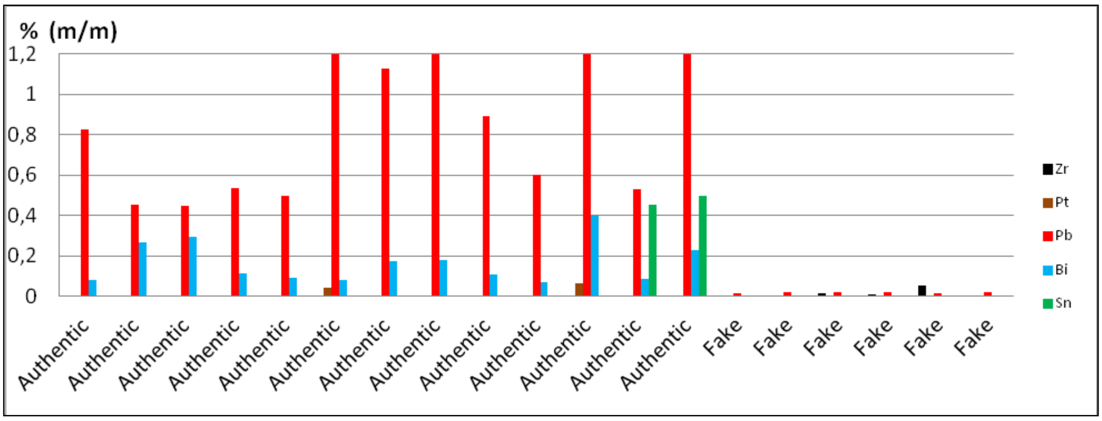


Figure 5.14: Histogram of P-XRF results for Hadrian coins.

If we Compare minor elements, Zr, Pb, Pt and Bi of Figure 5.14 with each other and with Figure 5.1-5.2 results of fake and authentic coins:

Pb: Results of five coins coming from Uşak Museum and with the inventory numbers of U-6-1, U-6-17, U-6-18, U-6-19, U-6-20 and U-6-21, vary from 0.015% to 0.022% with an average 0.018 which overlaps with results of fake coins having an average of 0.028 %). Therefore these 5 coins coming from Uşak Musem are fake according to Pb results. Pb values of the other coins coming from Juliopolis Excavation vary between 0.44 to 1.66% and have an average of 0.86%. All these values overlap with the results of other authentic coins.

Zr: It is detected in fake coins. When we look at the results of U-6-17, U-6-18, U-6-19, U-6-20 and U-6-21, we see that in U-6-19, U-6-20 and U-6-21 (Figure 5.15) Zr was detected in the range of 0.010 to 0.055%. In others coins of Uşak Museum, Zr was not detected. The reason of not detecting Zr in other Uşak Museum may be the low percentage of Zr; it should be remembered that the instrument used has a detection limit in the range of 10-100 ppm (Table 4.6). Coins with inventory numbers U-6-19, U-6-20 and U-6-21 are fake according to Zr results.

In one of Julipolis coin with inventory number 20-M118, Zr was detected in very low percentage 0.0061%. This coin is authentic in terms of all other elements, Pb, Bi, Pt and Ag. Hence, the reason of detecting Zr in this sample may be a result of cleaning of the coin in Restoration Laboratory of The Museum of Anatolian Civilizations.

Figure: 5.15 An example of Fake coins of Hadrian from Uşak Museum (U-6-21).

Figure 5.16: An example of Authentic coin of Hadrian from Juliopolis Excavation (21-M 120).

Pt: It is detected in 20-M118 and 82- M 177 the Pt percentage varies between 0.044% and 0.063%. Pt was not detected in any of the Uşak Museum coins.Pt may be present or absent depending the ore used; it may be detected only in an to authentic silver coin. However, its absence is not an indication that the coin is a fake one.

Bi: In all the coins except those coming from Uşak Museum, Bi was detected between the values of 0.068% and 0.40%, and with average 0.17%. Bi was not detected in any fake coins. Bi is generally detected in authentic coins (Figure 5.16).

According to P-XRF analysis results of Hadrian coins in terms of Bi, Pb and Zr coins with inventory numbers U-6-1, U-6-17, U-6-18, U-6-19, U-6-20 and U-6-21 are fake ones while all the others are authentic.

5.1.12 Analyses of Antoninus Pius and His Wife Faustina I (138-161 A.D.) Silver Coins

The results and other relevant data are given in Table 5.12 and Figure 5.17. Interpretations of the analytical results are given below.

Table 5.12: P-XRF Results for Antoninus Pius and His Wife Faustina I Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D , (mm)	Emperor & Empress	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
103-M178	Juliopolis Exc.	3,36	17	Antoninus Pius	Cleaned	Obverse	6,05	0,04	ND	91,3	ND	ND	1,96	0,59	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	Cleaned	Obverse	15,9	0,07	ND	82,2	0,41	0,053	1.0	0,29	A
92-M198	Juliopolis Exc.	3,12	18	Antoninus Pius	Cleaned	Obverse	7,36	0,03	ND	90,2	ND	0,061	1,88	0,41	A
87-M195	Juliopolis Exc.	2,14	18	Antoninus Pius	Cleaned	Obverse	1,86	ND	ND	96,9	0,44	0,048	0,68	0,09	A
81-M176	Juliopolis Exc.	2,84	19	Antoninus Pius	Cleaned	Obverse	9,83	0,05	ND	87,9	0,38	0,052	1,1	0,17	A
78-M173	Juliopolis Exc.	2,3	18	Antoninus Pius	Cleaned	Obverse	2,91	ND	ND	96,2	ND	ND	0,74	0,15	A
76-M171	Juliopolis Exc.	2,56	18	Faustina I	Cleaned	Obverse	5,44	0,03	ND	92,9	ND	0,050	1,21	0,34	A
54-M147	Juliopolis Exc.	2,58	18	Antoninus Pius	Cleaned	Obverse	2,84	0,03	ND	96,2	ND	0,042	0,68	0,15	A
23-M120	Juliopolis Exc.	3,17	18	Antoninus Pius	TMC	Obverse	63,3	0,14	ND	35,2	ND	ND	1,21	0,05	A
9-M112	Juliopolis Exc.	2,66	18	Faustina I	Cleaned	Obverse	18	0,06	ND	80,8	0,37	ND	0,54	0,2	A
Z3	By Police From Zurich	3,5	20	Antoninus Pius	Cleaned	Obverse	14,3	0,05	ND	83,7	1	ND	0,92	0,09	A
Z20	By Police From Zurich	3,45	18	Antoninus Pius	Cleaned	Obverse	10,8	0,05	ND	88,2	ND	0,053	0,85	0,11	A
Z20	By Police From Zurich	3,45	18	Antoninus Pius	Cleaned	Reverse	18,3	0,06	ND	80,4	ND	0,062	1,06	0,14	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	O PH	15,1	ND	ND	83,5	ND	ND	1,06	0,3	A

Table 5.12 CONTINUED

Inv. No	Form of Acquisition	W, (g)	D (mm)	Emperor &Empress	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	R PH	35,3	ND	ND	63,4	ND	ND	0,96	0,3	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	R PH	31,7	ND	ND	66,6	0,42	ND	0,95	0,31	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	O WPH	15,4	0,06	ND	82,6	0,61	0,056	0,96	0,29	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	R WPH	28,2	0,09	ND	69,7	0,48	0,082	1,15	0,35	A
96-M190	Juliopolis Exc.	2,98	17	Antoninus Pius	TMC	O PH	15,2	ND	ND	82,9	0,49	ND	1,12	0,3	A

Silver content of 19 analyses from 12 coins varied from 35.2 to 96.9%, with the average being 88.9% Ag, not including the sample with inventory numbers 95-M190 and 23-M120 Ag. Within the samples 35.2 % Ag seems to be an outlier. These values correspond to the coin sample which is coming from a reliable source, namely the Juliopolis Excavation. This coin is authentic and the reason of low silver value may be the corrosion on the analyzed surface. It has been reported that 428 coins dated to Antoninius Pius has average Ag value of 85.6% (Walker 1976) which is very close to our average 88.9%. It is concluded that all the coins in this group are authentic in terms of the main element content. This decision will be further supported by the other results given below.

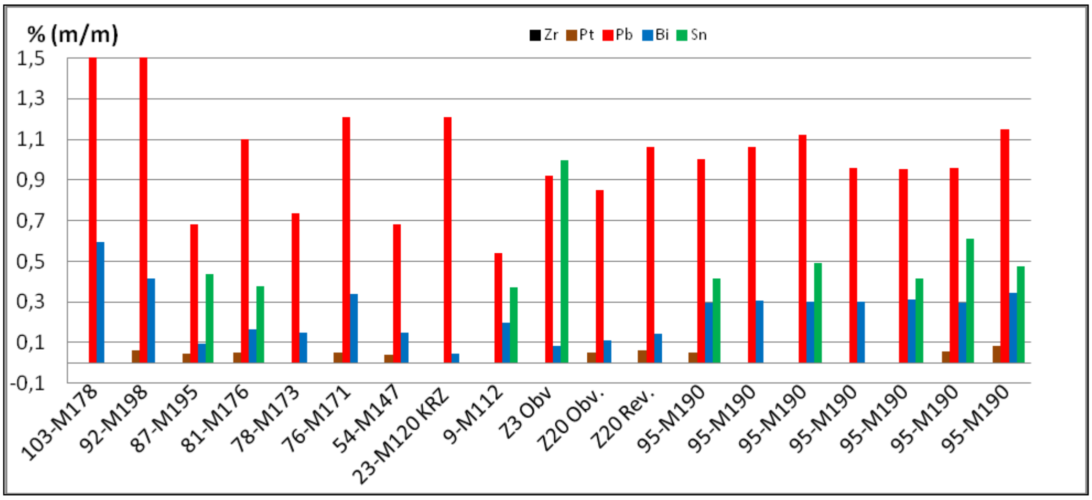


Figure 5.17: Histogram of P-XRF results for Antoninius Pius and Faustina I's silver coins.

Comparing minor elements, Zr, Pb, Pt and Bi of Table 5.12 with each other and those from Figure 5.1-3, the following conclusions may be reached.

Pb: The results vary from 0.53% to 1.96% with an average of 1.05% which is very high if compared to results of fake coins which has an average value 0.028%. Hence, all the coins of Antoninius Pius and Faustina I are authentic in terms of Pb.

Zr: It is not detected in any Antoninius Pius and Faustina I coin; Zr had been analyzed only in fakes, so that all coins are authentic in terms of Zr results.

Pt: In 10 analyses of 19, Pt was detected between 0.042 and 0.082% with average of 0.055%. Pt could only be detected in authentic silver coins.

Bi: In all the coins, Bi was detected between 0.05 and 0.59% and with average 0.24 %. Bi had not been detected in any of the fake coins and is generally detected only in authentic silver coins. The results of Antoninius Pius and Faustina I coins are authentic in terms of Bismuth.

According to main and trace elements all the coins in this study coming from either Juliopolis Excavation or Zurich (Police confiscation at airport) are authentic.

5.1.13 Analyses of Marcus Aurelius (161-180 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.13 and in Figure 5.18 in a histogram form.

Table 5.13- P-XRF Results for Marcus Aurelius Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Sn	Pt	Pb	Bi	Decision
61-M151	Juliopolis Exc.	3,39	18	TMC	Obverse	26	ND	72.6	ND	0.058	0,53	0,42	A
55-M148	Juliopolis Exc.	2,68	17	WC	Obverse	5.5	ND	91.9	ND	0.050	2,08	0,2	A
47-M139	Juliopolis Exc.	2,45	18	WC	Obverse	39.0	ND	59.7	ND	0.052	0,78	0,26	A
47-M139	Juliopolis Exc.	2,45	18	WC	Reverse	13.7	ND	84.9	ND	ND	0,1	0,32	A
41-M138	Juliopolis Exc.	2,4	18	WC	Obverse	0.90	ND	97.1	0.48	0.061	1,14	0,2	A
15-M114	Juliopolis Exc.	2,13	17	WC	Obverse	2.44	ND	94.7	0.53	0.061	1,74	0,24	A
2-M86	Juliopolis Exc.	3,35	18	TMC	Obverse	55.9	ND	43.0	0.3	ND	0,48	0,087	A
1936 1-218-1	Bought	2,7	18	Clean	Obverse	6.01	ND	91.6	0.7	0.051	1,53	0,1	A
1936 1-218-1	Bought	2,7	18	WC	Reverse	17.5	ND	79.9	0.62	0.074	1,33	0,09	A
611-1	Bought	3,06	18	Clean	Obverse	2.55	ND	95.6	0.4	ND	0,35	0,27	A
611-1	Bought	3,06	18	Clean	Reverse	4.32	ND	93.5	ND	0.071	0,82	0,63	A
638-1	Bought	3,28	18	WC	Obverse	4.38	ND	93.7	ND	ND	1,68	0,24	A
638-1	Bought	3,28	18	WC	Reverse	5.78	ND	92.0	ND	ND	1,95	0,29	A
1023-1	Bought	2,85	19	WC	Obverse	4.06	ND	94.9	ND	ND	0,89	0,16	A

TABLE 5.13 CONTINUED

Inventory No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Ag	Sn	Pt	Pb	Bi	Decision
1128-67	Bought	2,79	19	WC	Obverse	11.7	ND	87.0	ND	ND	0.97	0.24	A
1969 X-1861-243/3	Yatagan Hoard	3,15	19	WC	Obverse	5.5	ND	92.9	ND	ND	1.36	0.2	A
1969 X-1861-243/3	Yatagan Hoard	3,15	19	WC	Obverse	4.8	ND	93.4	ND	ND	1.41	0.21	A
1960 XII-1512-1	Bought	3,55	18	WC	Obverse	7.09	ND	91.3	0.42	ND	0.1	0.09	A
133-118-76	Bought	3,28	18	WC	Obverse	8.5	ND	89.6	0.55	ND	0.90	0.37	A
133-118-76	Bought	3,28	18	WC	Obverse	9.5	ND	88.5	0.48	ND	0.97	0.39	A
98-407/21-76	Bought	3,43	19	WC	Obverse	10.4	ND	88.6	ND	ND	0.62	0.21	A
98-407/20-76	Bought	3	18	WC	Obverse	7.5	ND	91.1	ND	ND	0.94	0.29	A
788-23	Bought	3,48	19	WC	Obverse	16.8	ND	81.6	ND	0.048	1.09	0.17	A
1128-67	Bought	2,79	19	WC	Obverse	10.2	ND	88.5	ND	ND	0,88	0,22	A

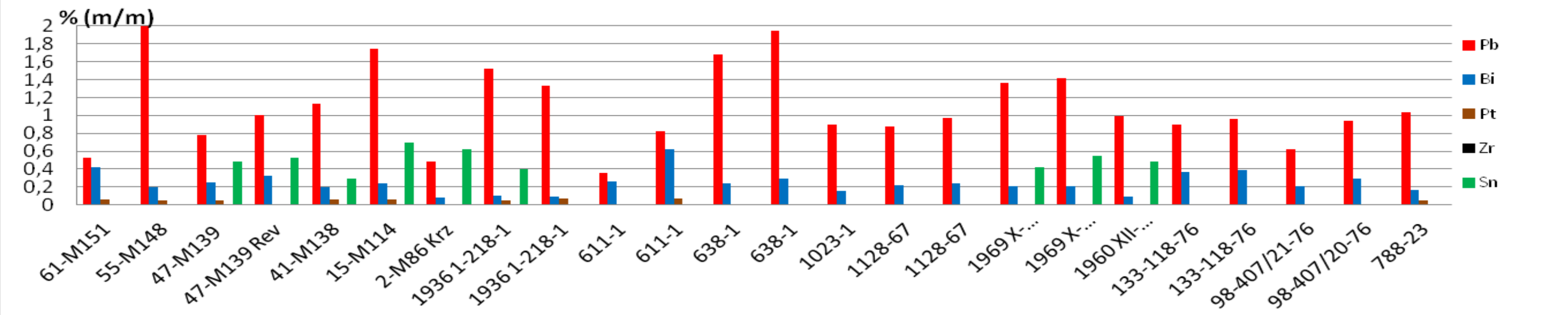


Figure 5.18: Histogram of P-XRF results for Marcus Aurelius silver coins.

Silver content of 24 analyses varied from 43.0 to 97.1% with the average being 86.6%. Within the samples, 43.0, 59.7 and 72.6% Ag values seem to be outliers. If these values are not included, the average value for Ag increases to 90.58%. As shown in Table 5.13, these values correspond to the three coin samples which are coming from the reliable source of Juliopolis Excavation; therefore, the reason of low silver value may be the surface corrosion. The sample 47-M139 was subjected to analysis on both obverse and reverse sides. While the obverse analysis result is 59.7%, the cleaner reverse side gave a result of 84.9% Ag. The other outlier values also originate from the corrosion.

The XRF analyses reported on 391 Denarius samples in groups had mean values in the range of 77-83% for Ag content; the values were in the range of 65 to 92% (Walker 1977). In our study, the results are between 72% and 97% Ag (Table 5.13). The reason for the difference between Juliopolis Excavation originated Roman Imperial coins and those reported in literature (Walker 1977) may be due to different technologies used in XRF techniques in two studies. It is possible that different depth of penetration of X-rays and surface corrosion conditions caused a difference in results.

Similar consideration are also due by using the results of minor and trace elements. Copper values vary from 0.90 to 55.95% with the average being 19.53%. Cu values of 55.95, 39.03 and 26.00 % seem to be outliers. Like silver, copper values also show that these three samples are highly corroded ones. Due to the presence of copper oxide, X-ray beam cannot efficiently penetrate the region where Ag is contained; the result is a higher Cu concentration registered, while Ag contents seems to be lower than its real value.

The other elements such Pb have values greatly varied in the range of 0.35 to 2.37% with an average of 1.09%. These variations may come from the production technology of Roman Imperial age (Fleming 1975 and Rodrigues et al. 2011). The average Pb percentage of reported for similar coins are research is around 0.50% (Rodrigues et al. 2011).

Pb: Results vary from 0.35% to 2.08% with average 1.09 which is very high comparing to the results of fake coins which has average value 0.028% so all coins of Marcus Aurelius and Faustina II are authentic in terms of Pb.

Zr: It is not detectable in any Marcus Aurelius and Faustina II coin; Zr is detected only in fake coins. Therefore, all the coins analyzed are authentic in terms of Zr results.

Pt: In 9 analyses out of 24, Pt was detected between 0.048%-0.074 with average of 0.052%. Pt is detected only in authentic coins.

Bi: In all the coins analyzed, Bi was detected between 0.087% and 0.63% with an average of 0.24%. Bi has not been detected in any fake coins and generally detected in authentic coins. The results of Marcus Aurelius and Faustina II coins are authentic in terms of Bismuth.

According to the results of main and trace elements, all the analyzed coins of Marcus Aurelius coming from Juliopolis Excavation and Yatağan Hoard and bought from individuals are authentic.

5.1.14 Analyses of Pertinax (193 A.D.) and Pescennius Niger (193-194 A.D.) Silver Coins

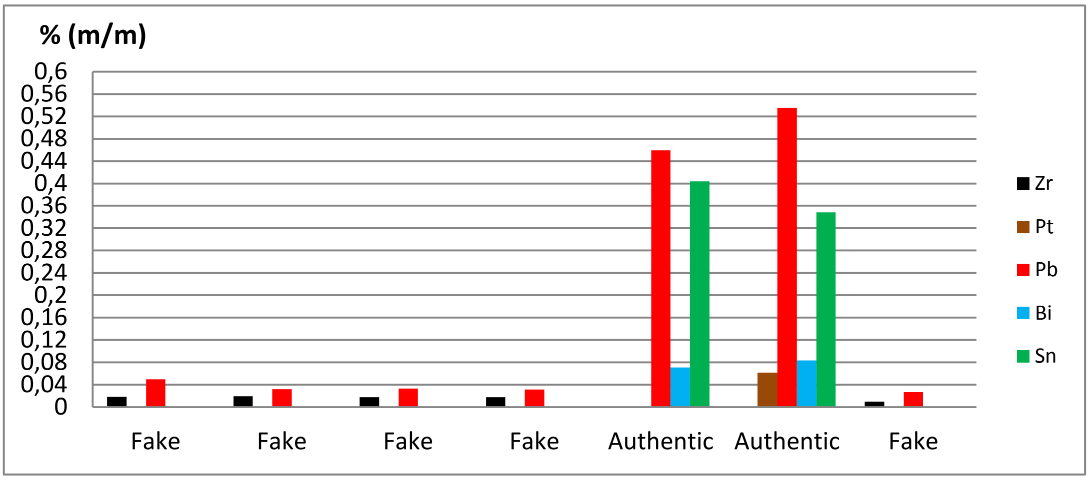
The results for P-XRF analyses and relevant data are given in Table 5.14, also in Figure 5.20 in a histogram form. Selected coin samples are shown in Figure 5.19. Related discussion is given below.

Table 5.14: P-XRF Results for Pescennius Niger and Pertinax Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Emperor	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Pt	Pb	Bi	Decision
U-7-22	By Police From Uşak	3.58	20	Pertinax	LC	Obverse	2.8	0.04	0.018	95.0	ND	0.05	ND	F
U-7-23	By Police From Uşak	3.51	20	Pertinax	LC	Obverse	1.5	0.04	0.02	96.8	ND	0.032	ND	F
U-7-24	By Police From Uşak	3.48	20	Pertinax	LC	Obverse	2.4	0.08	0.017	95.1	ND	0.033	ND	F
U-7-25	By Police From Uşak	3.48	20	Pertinax	LC	Obverse	1.5	ND	0.018	96.3	ND	0.032	ND	F
27-M123	Juliopolis Exc.	2.44	18	Pescennius Niger	LC	Obverse	12	0.06	ND	86.9	ND	0.459	0.07	A
27-M123	Juliopolis Exc.	2.44	18	Pescennius Niger	LC	Reverse	10	0.05	ND	88.4	0.06	0.535	0.08	A
U-8-26	By Police From Uşak	3.47	20	Pescennius Niger	LC	Obverse	2.1	0.03	0.01	96.5	ND	0.027	ND	F

a)  b)

Figure 5.19: a) Fake sample from Pertinax (U-7-22) b) Authentic coin of Pescennius Niger from Juliopolis Excavation (27-M123).



5.20: Histogram of P-XRF results for Pertinax and Pescennius Niger silver coins.

Silver content of 7 samples varied from 86.9 to 96.8% and) with the average being 93.6%. Analyses of 11 Pertinax coins reported had an average of 87.11% Ag (Walker 1978). In our study, the average value for Ag is 87% for the coins assigned as authentic from the age of Pertinax and Pescennius Niger, in good agreement with the literature value given above.

Ag values of U-7-22, U-7-23, U-7-24, U-7-25, U-8-26 are higher than the average Ag value reported as 87% in literature (Walker 1978) and that of Juliopolis denarius (27-M123).

Interpretations for the results of minor elements Zr, Pb, Pt and Bi are given below.

Pb: Coins with inventory numbers U-7-22, U-7-23, U-7-24, U-7-25, U-8-26 have Pb values equal to or less than 0.050% which is very low for the ancient purification technology supposedly used, namely cupellation. The coin with the inventory number 27-M123 is coming from a reliable source, Juliopolis Excavation; the values obtained are 0.46 and 0.53% Pb. These values are reasonable regarding the ancient cupellation technique used in manufacturing the coin. Coins with inventory numbers U-7-22, U-7-23, U-7-24, U-7-25, U-8-26 are fake ones according to Pb values.

Zr: Zr is detected in coins with inventory numbers U-7-22, U-7-23, U-7-24, U-7-25 and U-8-26. These results indicate that the coins may be fake ones according to Zr values.

Pt: Pt was detected only in the Juliopolis Excavation coin (27-M123) at a level of 0.06%. In the other coins Pt was not detected, supporting the suggestion that these are fake ones. 27-M123 coin is most probably authentic (Table 5.14).

Bi: This element was detected only in Juliopolis coin (27-M123); this result is in agreement with the above suggestion that the coin is authentic. In the other coins, Bi was not detectable, indicating that these are fake ones. Coins with the inventory numbers of U-7-22, U-7-23, U-7-24, U-7-25 and U-8-26 are fakes in terms Bi.

5.1.15 Analyses of Septimius Severus and His Wife Julia Domna (193-211 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.15; sample photographs are depicted in Figure 5.21. A histogram for results is shown in Figure 5.22. The results are discussed in the following paragraphs.

Table 5.15: P-XRF Results for Septimus Severus and His Wife Julia Domna Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Emperor & Emperess	Surface condition	Analyzed Side of Coin and Sampling Option	Cu	Zr	Ag	Sn	Pt	Pb	Bi	Decision
64-M154	Juliopolis Exc.	3.4	17	Julia Domna	Cleaned	Obverse	29	ND	69.8	0.4	0.056	0.93	0.08	A
43-M138	Juliopolis Exc.	1.77	20	Julia Domna	Cleaned	Obverse	7.2	ND	88.9	2.8	ND	0.62	0.26	A
12-M112	Juliopolis Exc.	2.31	20	Julia Domna	WC	Obverse	33	ND	65.4	0.4	ND	0.84	0.1	A
Z4	By Police From Zurich	2.99	19	Julia Domna	Cleaned	Obverse	14	ND	83.9	0.6	ND	1.07	0.09	A
Z8	Zurich	2.96	19	Julia Domna	Cleaned	Obverse	17	ND	81.7	0.5	ND	0.87	0.06	A
Z8	Zurich	2.96	19	Julia Domna	Cleaned	Reverse	9.7	ND	88.7	0.6	ND	0.86	0.08	A
Z16	Zurich	3.32	20	Julia Domna	Cleaned	Obverse	14	ND	85	ND	ND	1.22	0.08	A
Z16	Zurich	3.32	20	Julia Domna	Cleaned	Obverse	19	ND	80	ND	ND	1.18	0.1	A
Z17	Zurich	3.0	19	Julia Domna	Cleaned	Obverse	17	ND	81.9	ND	ND	0.43	0.1	A
Z17	Zurich	3.0	19	Julia Domna	Cleaned	Reverse	16	ND	82.5	0.5	ND	0.44	0.11	A
45-M138	Juliopolis Exc.	2.6	17	Sept. Severus	Cleaned	Obverse	23	ND	75.6	0.3	0.065	0.8	0.21	A
U-9-27	By Police From Uşak	3.41	20	Sept. Severus	LC.	Obverse	2.3	0.01	96.9	ND	ND	0.02	ND	F
U-9-28	By Police From Uşak	3.5	20	Sept. Severus	LC.	Obverse	1.5	ND	97.5	ND	ND	0.02	ND	F
U-9-28	By Police From Uşak	3.5	20	Sept. Severus	LC.	Reverse	1.7	ND	98.1	ND	ND	0.02	ND	F
U-9-30	By Police From Uşak	3.51	20	Sept. Severus	LC.	Obverse	1.9	0.02	96.1	ND	ND	0.05	ND	F
U-9-31	By Police From Uşak	3.5	20	Sept. Severus	LC.	Reverse	2.0	0.01	96.6	ND	ND	0.03	ND	F
U-9-32	By Police From Uşak	3.45	20	Sept. Severus	LC.	Obverse	1.9	0.02	95.9	ND	ND	0.03	ND	F
U-9-33	By Police From Uşak	3.50	20	Sept. Severus	LC.	Reverse	2.0	0.01	96.9	ND	ND	0.03	ND	F

Silver content in 18 analyses varied from 65.4 to 98.1% with the average being 86.7 %. When supposedly fake coins are not included, the average is 80.3% Ag. Within the samples none of the Ag values seems to be an outlier. Reported results for a coin of Septimius Severus (193-196 A.D.) (coming from Chateaubleau excavation) with SEM-EDX and PIXE have shown that while the surface analysis by SEM-EDX gave 99% Ag, the SEM-EDX using the bulk of the same coin showed that the Ag content is 74% Ag (Beck et al 2004). The same coin analyzed by PIXE from the surface revealed a result of 96%Ag, while the value using the bulk was 77% (Beck et al. 2004). Our Ag average of 80.3 % is in agreement with the bulk values reported by Beck. Coins coming from Juliopolis Excavation have been subjected to a cleaning process in the Museum of Anatolian Civilization laboratory. This is an important point for getting the correct results when a surface technique such as P-XRF is used. It has been reported that the Ag content on the surface is higher than that in the bulk (Cope 1972). Generally coin metrology books and articles including Septimius Severus coins state that in this era debased silver coins were minted (Cope 1972). Comparing minor element concentrations, Zr, Pb, Pt and Bi as given in Table 5.15-and in Figure 5.22 among themselves and the results of fake and authentic coins (Figure 5.1-5.3) the following discussions have been made.

a) b)

Figure 5.21: Samples from Septimius Severus silver coins. a) Authentic coin of Septimius Severus (45-M 138), b) Fake coin of Septimius Severus (Inv No U-9-27).

Pb: Coins with inventory numbers U-9-27, U-9-28, U-9-28 (Rev), U-9-30, U-9-31 (Rev), U-9-32, U-9-33 (Rev) have Pb values equal to or less than 0.050 %. This value is very low level for Pb content considering the ancient cupellation technology used for purification. Coins coming from the reliable source of Juliopolis Excavation have Pb values in the range of 0.62-0.93% that is reasonable for cupellation technology. Coins with the inventory number U-7-22, U-7-23, U-7-24, U-7-25, U-8-26 are fake coins according to Pb values.

Zr: It was detected in coins with the inventory numbers U-9-27, U-9-30, U-9-31 (Rev), U-9-32, U-9-33 (Rev). Since Zr could be detected only in the fake coins, these are fake ones in terms of Zr results.

Pt: It was detected in Juliopolis and Zurich Coins between 0.056 -0.065%. Pt was not detected in fake coins.

Bi: In all the Juliopolis and Zurich coins, Bi was detected while it was not detectable in the other ones which were also assigned as fake coins according to their Pb and Zr contents. Coins with the inventory numbers U-9-27, U-9-28, U-9-28 (Rev), U-9-30, U-9-31 (Rev), U-9-32, U-9-33 (Rev) are fake ones in terms and the others are authentic in terms of Bi.

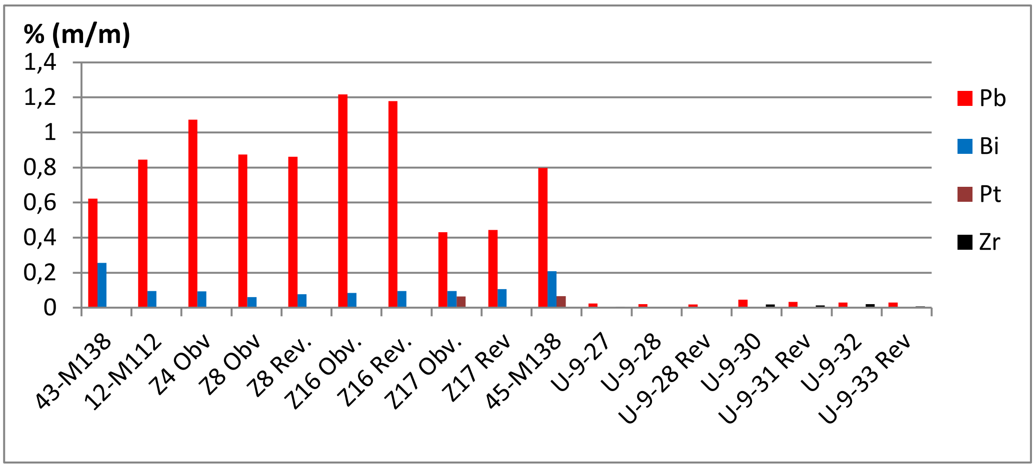


Figure 5.22: Histogram of P-XRF results for Septimius Severus and Julia Domna silver coins.

5.1.16 Analyses of Caracalla (211-217 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.16. Variations of Ag and Cu concentrations are depicted in Figure 5.23. Results are also given in histograms in Figure 5.24. Interpretations of results are given in the following paragraphs.

Table 5.16: P-XRF Results for Caracalla Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
79-M174	Juliopolis Excavation	1.63	19	L C	Obverse	21,2	0,08	ND	77.4	0.4	0.05	0.69	0.16	A
71-M164	Juliopolis Excavation	2.35	19	TMC	Obverse	22,1	0,08	ND	77.51	ND	ND	0.22	0.06	A
7-M112	Juliopolis Excavation	2.54	19	L C	Obverse	19,4	0,25	ND	74.21	4.3	ND	1.68	0.07	A
10-1861-243/95	Yatağan Hoard	2.77	19	L C	Obverse	20,3	0,12	ND	76.87	0.7	ND	1.25	0.13	A
10-1861-243/95	Yatağan Hoard	2.77	19	L C	Reverse	9,62	0,08	ND	88.05	0.6	ND	1.43	0.13	A
10-1861-243/96	Yatağan Hoard	2.98	21	L C	Obverse	11,4	0,07	ND	84.75	1.2	ND	2.19	0.18	A
10-1861-243/97	Yatağan Hoard	2.38	21	L C	Obverse	12,5	0,08	ND	85.91	0.4	ND	0.91	0.09	A
10-1861-243/98	Yatağan Hoard	3.69	19	L C	Obverse	13,2	0,08	ND	84.96	0.5	ND	1.05	0.13	A
10-1861-243/100	Yatağan Hoard	3.42	19	L C	Obverse	11,6	0,08	ND	86.42	0.5	ND	1.08	0.25	A
10-1861-243/100	Yatağan Hoard	3.42	19	L C	Reverse	13,6	0,09	ND	83.85	0.7	ND	0.96	0.24	A
10-1861-243/101	Yatağan Hoard	2.84	19	L C	Obverse	17,1	0,09	ND	80.5	0.5	ND	1.11	0.18	A
10-1861-243/102	Yatağan Hoard	3.03	19	L C	Obverse	19,8	0,13	ND	78.39	0.3	ND	1.2	0.11	A
10-1861-243/102	Yatağan Hoard	3.03	19	L C	Reverse	30,6	0,11	ND	67.03	0.5	ND	1.16	0.1	A

Table 5.16 CONTINUED

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
10-1861-243/85	Yatağan Hoard	3	19	Clean	Obverse	11	0,05	ND	87.87	0.6	ND	0.66	0.07	A
10-1861-243/86	Yatağan Hoard	3.14	19	Clean	Obverse	5.8	0,04	ND	92.87	0.4	ND	0.62	0.08	A
10-1861-243/87	Yatağan Hoard	2.85	19	Clean	Obverse	14	0,06	ND	85.25	0.4	ND	0.55	0.14	A
10-1861-243/88	Yatağan Hoard	3.24	19	LC	Obverse	5	0,04	ND	93.42	ND	ND	1.3	0.06	A
10-1861-243/89	Yatağan Hoard	3.16	19	LC	Obverse	14	0,07	ND	84.01	0.4	ND	0.96	0.15	A
601-1	Bought	3.02	19	LC	Obverse	15	0,11	ND	83.11	0.4	ND	1.12	0.12	A
601-1	Bought	3.02	19	LC	Reverse	15	0,13	ND	83.2	0.5	ND	1.1	0.11	A
1223-28	Bought	3.00	19	Clean	Obverse	40	0,13	ND	58.48	0.5	0.06	0.9	0.05	A (Billion)
1223-28	Bought	3.00	19	LC	Reverse	27	0,09	ND	71.1	0.6	ND	0.89	0.05	A (Billion)
1772-186	Museums Gen. Mng	2.98	21	LC	Obverse	6.7	0,05	ND	90.08	1.5	ND	1.61	0.05	A
Z2	By Police From Zurich	3.51	19	Cleaned	Obverse	28	0,08	ND	70.46	0.9	ND	0.72	0.15	A
Z2	By Police From Zurich	3.51	19	Cleaned	Reverse	16	0,06	ND	82.01	0.9	ND	0.67	0.14	A
Z5	By Police From Zurich	2.97	18	Cleaned	Obverse	10	0,05	ND	87.89	1	ND	0.65	0.1	A

Table 5.16 CONTINUED

Inv. No	Form of acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side of Coin and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
Z7	By Police From Zurich	3.05	20	Cleaned	Obverse	9.7	0,06	ND	87.37	1.8	ND	0.95	0.08	A
Z7	By Police From Zurich			Cleaned	Reverse	18	0,09	ND	79.66	1.7	ND	0.94	0.08	A
Z15	By Police From Zurich	3.29	20	Cleaned	Obverse	14	0,07	ND	84.87	ND	ND	0.86	0.06	A
Z15	By Police From Zurich			Cleaned	Reverse	7.3	0,04	ND	91.69	ND	0.1	0.84	0.05	A
Z21	By Police From Zurich	3.17	20	Cleaned	Obverse	21	0,16	ND	76.18	0.6	ND	1.9	0.1	A
Z21	By Police From Zurich	3.17	20	Cleaned	Reverse	25	0,18	ND	72.71	0.5	ND	1.65	0.09	A

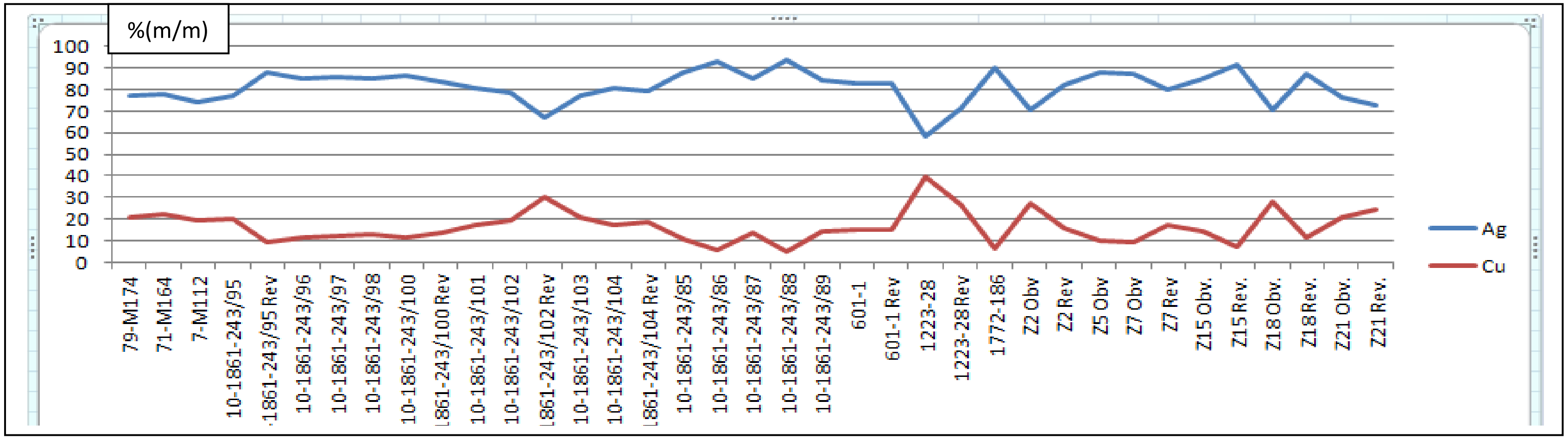


Figure 5.23: Variations in Ag and Cu concentrations in Caracalla silver coins.

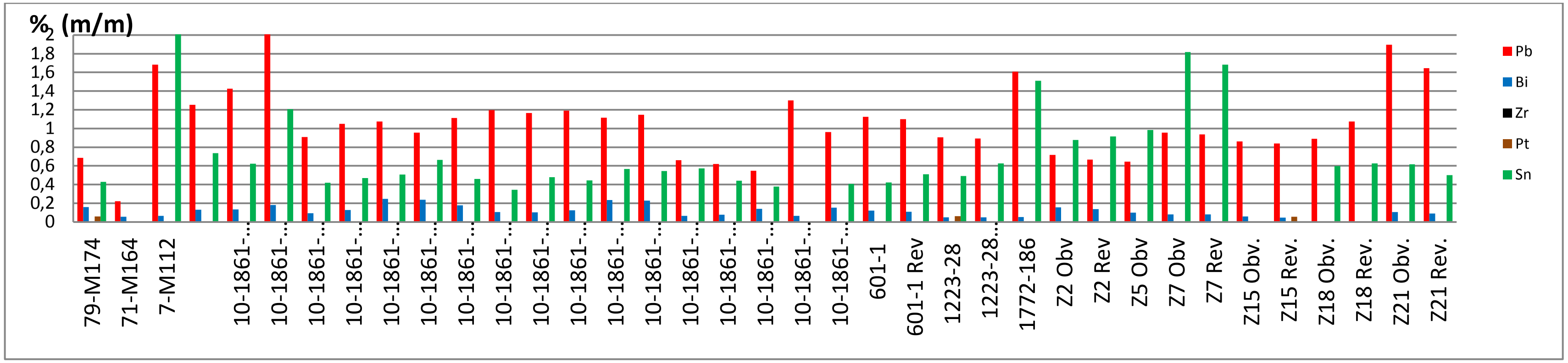


Figure 5.24: Histogram of P-XRF results for minor element concentrations for Caracalla silver coins.

In this group of coins, 37 analyses were made from 26 coins coming from Yatağan Hoard, Juliopolis Excavation, police and purchasing from individuals by MAC. The coins dated to 198-217 A.D. (Caracalla) have silver concentrations varying from 58.48% to 93.42% with the average of 81.15%. Within these samples the value of 58.48% seems to be an outlier; this coin has an inventory number of 1223-28 and has been bought from an individual. The coin was analyzed using both obverse and reverse sides. The obverse result is 58.48% Ag and cleaner reverse analysis result is 71.10% Ag. The reverse of this coin is very close to average Ag value of Caracalla silver coins excluding 58.48%, which is 71.10%. Regarding the Ag values only, a conclusion cannot be drawn. The reason of low silver is that it is bullion (silver coin minted by city state of Rome and including lower Ag comparing to Denarius).

Cu: Regarding the copper, values are varied from 5.04 to 39.81% with the average being 16.73%. When we look at the Table Cu value of 39.81% seems to be outlier and the coming from corroded obverse of silver coin with inventory number 1223-28 and reverse of same coin has 20 % Cu which is very close to average percentage of Cu. In Figure 5.23, the symmetry for Ag and Cu values is interesting showing that Cu has been used for compensation when Ag value was low.

Pb: All the coins analyzed from Caracalla era have Pb values between 0.22 and 2.19% which are in agreement with cupellation technology. Therefore all these coins are authentic in terms of Pb results.

Zr: Zr was not detected in any of the coins, indicating but not definitely proving that these coins are authentic.

Pt: It was detected in only three Caracalla's silver coins between with the values in the range of 0.05 to 0.06%. Depending on the ore used, Pt may or may not be detected in an authentic coin, but is detected only in authentic ones.

Bi: We know from the previous results that Bi was detected only in authentic coins. Apart from the two results in all denarius coins of Caracalla, Bi was detected in the range of 0.05 to 0.25%. In only two analyses for the sample Z18 using obverse and reverse sides of same coin, Bi was not detectable. The coin Z18, however, seems to be authentic according to concentrations of Ag, Pb and Zr.

It may be concluded that all the coins in this group are authentic ones.

5.1.17 Analyses of Geta (211 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.17. A histogram for results is shown in Figure 5.25. Some sample photographs are depicted in Figure 5.26 and Figure 5.27. The results are discussed in the following paragraphs.

Table 5.17: P-XRF Results for Geta Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
73-M168	Juliopolis Exc.	2.84	19	TMC	Obverse	36.5	0.11	ND	62.15	0.42	ND	0.79	0.05	A
Z12	By Police From Zurich	4.19	20	Cleaned	Obverse	23.3	0.07	ND	74.98	0.5	ND	1.1	0.07	A
Z12	By Police From Zurich	4.19	20	Cleaned	Reverse	13.5	0.05	ND	84.66	0.57	ND	1.1	0.08	A
Z14	By Police From Zurich	2.91	19	Cleaned	Obverse	4.77	0.05	ND	93.07	0.56	0.057	1.39	0.11	A
Z14	By Police From Zurich	2.91	19	Cleaned	Reverse	6.51	0.07	ND	91.48	0.41	ND	1.43	0.1	A
X-1861-243/128	Yatagan Hoard	3.1	19	Clean	Obverse	9.32	0.05	ND	86.18	3.31	ND	0.82	0.21	A
X-1861-243/128	Yatagan Hoard	3.1	19	WC	Reverse	6.01	0.04	ND	89.22	3.62	ND	0.8	0.2	A
X-1861-243/127	Yatagan Hoard	2.77	19	LC	Obverse	9.76	0.05	ND	89.15	0.41	ND	0.33	0.21	A
X-1861-243/127	Yatagan Hoard	2.77	19	Clean	Reverse	9.89	0.05	ND	89.00	0.42	ND	0.34	0.25	A
X-1861-243/126	Yatagan Hoard	3.15	19	Clean	Obverse	10.4	0.06	ND	88.09	ND	ND	1.16	0.15	A
X-1861-243/126	Yatagan Hoard	3.15	19	Clean	Reverse	10.6	0.06	ND	87.42	0.46	ND	1.31	0.16	A
X-1861-243/125	Yatagan Hoard	3.24	22.5	LC	Obverse	21.2	0.08	ND	77.49	ND	ND	1.07	0.15	A
X-1861-243/124	Yatagan Hoard	2.82	20	LC	Obverse	14.0	0.06	ND	84.54	ND	ND	1.09	0.22	A
X-1861-243/123	Yatagan Hoard	2.80	19.5	LC	Obverse	12.0	0.06	ND	86.43	ND	ND	1.26	0.14	A
X-1861-243/123	Yatagan Hoard	2.80	19.5	LC	Reverse	21.6	0.07	ND	76.73	ND	ND	1.33	0.15	A
X-1861-243/122	Yatagan Hoard	3.70	20.5	LC	Obverse	11.1	0.05	ND	87.64	ND	ND	1.03	0.09	A
X-1861-243/121	Yatagan Hoard	3.35	18.5	LC	Obverse	7.47	0.04	ND	89.77	0.6	ND	1.91	0.11	A
X-1861-243/136	Yatagan Hoard	2.76	20.5	Clean	Obverse	8.15	0.05	ND	89.76	0.69	ND	1.27	0.09	A
X-1861-243/136	Yatagan Hoard	2.76	20.5	Clean	Reverse	11.7	0.07	ND	85.96	0.77	ND	1.25	0.09	A
X-1861-243/144	Yatagan Hoard	3.5	18.5	Clean	Obverse	10.5	0.05	ND	87.97	0.39	ND	0.87	0.17	A
X-1861-243/142	Yatagan Hoard	2.98	20	Clean	Obverse	17.1	0.06	ND	80.6	0.59	0.054	1.38	0.08	A

TABLE 5.17 CONTINUED

Inv. No	Form of Acquisition	W, (g)	D, (mm)	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
X-1861-243/141	Yatagan Hoard	2.93	19.5	Clean	Obverse	6.55	0.05	ND	92.23	ND	ND	0.8	0.16	A
1176-41	Bought	3.64	18	Clean	Obverse	23.0	0.21	ND	74.51	0.52	0.053	1.58	0.1	A
1176-41	Bought	3.64	18	Clean	Reverse	27.4	0.12	ND	70.4	0.51	ND	1.5	0.08	A
1420-3-1956	Bought	2.78	19	WC	Obverse	20.3	0.09	ND	76.97	0.33	ND	0.91	0.06	A
1420-3-1956	Bought	2.78	19	WC	Reverse	23.7	0.09	ND	74.43	ND	ND	0.87	0.06	A
U-10-34	By Police From Uşak	3.42	20	LC	Obverse	1.42	ND	ND	98.45	ND	ND	0.02	ND	F
U-10-34	By Police From Uşak	3.42	20	LC	Reverse	1.44	ND	ND	98.09	ND	ND	0.02	ND	F

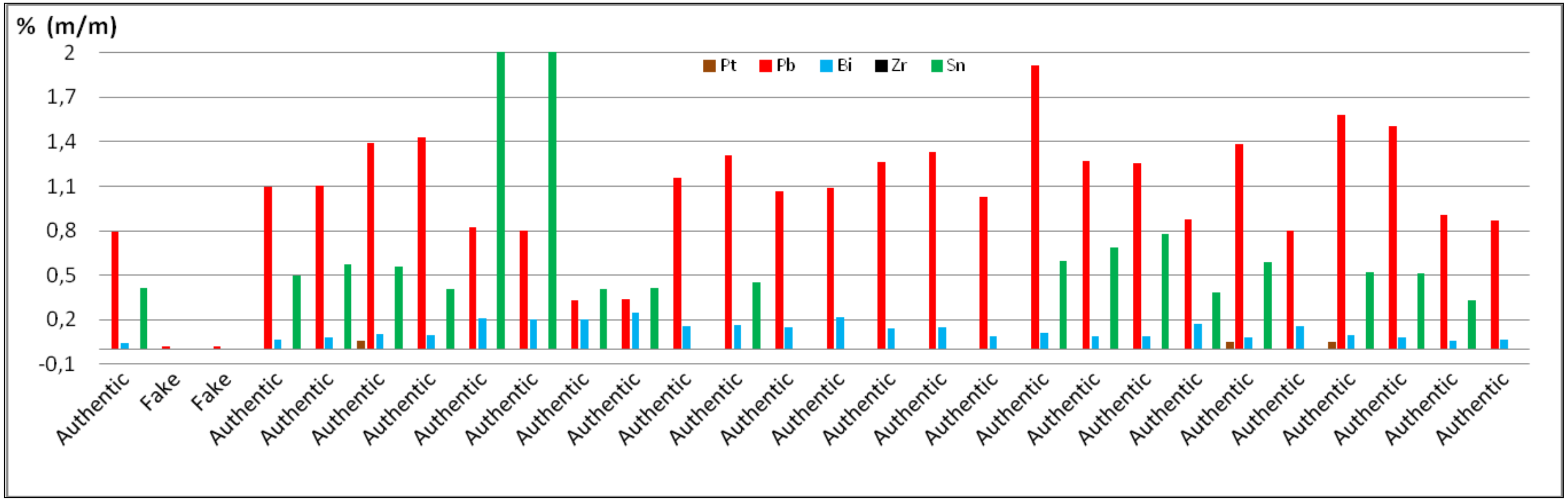


Figure 5.25: Histogram of P-XRF analyses results on minor elements for Geta silver coins.

Silver contents in 28 analyses performed on 18 coins varied from 62.15 to 98.45% with the average being 84.54%. Within these values, 62.15% seems to be an outlier. If this value is not included, the average is 85.37% Ag. Since this coin with the outlier Ag value (73-M168) has been acquired from the reliable source of Juliopolis Excavation, the reason for the lower silver content may be surface corrosion (Figure 5.26).

Pb: Coins with inventory number U-10-34, U-10-34rev. have Pb value under 0.0500% which is very low level (0.022) for Ag and Pb ancient purification technology cupellation. Geta's silver coins coming from reliable source Yatağan Treasure has Pb value 0.33-1.91% Pb that overlap with cupellation technology results. Coins with inventory number U-10-34 is fake according to Pb values (Figure 5.27). The coin with inventory number U-10-34 is outlier in terms of Ag percentage because of it has too high Ag value 98 for comparing to other Geta's Silver Coins with average 84%Ag.

Zr: Most generally Zr was detected in fake coins. Zr is not detected in coin with inventory number U-10-34 (Figure 5.25-5.2.7 and Table 5.17).

Pt: Pt was detected in three coins in this group. Its presence indicates authenticity while its absence is not a proof of fake coins.

Bi: In all the Juliopolis Excavation, Yatağan Hoard and Zurich coins Bi was detected, supporting the suggestion that these are authentic. On the other hand, Bi was not detectable in the coin that was assigned as a fake one, U-10-34, from its Pb content. Both sides of U-10-34 had the similar concentration trend regarding Pb and Bi. Bi results support the suggestion that this coin is a fake one. The other coins are authentic in terms of Bi content.

a) b)

Figure 5.26 Authentic coins of Geta: a) Inv No Z 14, b) Inv. No 73- M168

Figure 5.27: Fake coin of Geta (U-10-34).

5.1.18 Analyses of Macrinus and His Son Diadumenian (217-218 A.D) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.18. A histogram for results is shown in Figure 5.28. The results are discussed in the following paragraphs.

Table 5.18: P-XRF Results for Macrinus and His son Diadumenian Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Emperor	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pb	Bi	Decision
U-11-36	By Police From Uşak	3.55	20	Diadumenian	LC	Obverse	2.26	0.02	0.008	96.5	ND	0.04	ND	F
U-11-36	By Police From Uşak	3.55	20	Diadumenian	LC	Reverse	2.14	ND	0.023	95.6	ND	0.02	ND	F
U-11-38	By Police From Uşak	3.48	20	Diadumenian	LC	Obverse	2.21	ND	ND	97.4	ND	0.04	ND	F
U-11-38	By Police From Uşak	3.48	20	Diadumenian	LC	Reverse	2.24	0.03	0.007	96.9	ND	0.04	ND	F
U-11-40	By Police From Uşak	3.47	20	Diadumenian	LC	Obverse	2.62	0.06	0.011	96.0	ND	0.06	ND	F
U-11-40	By Police From Uşak	3.47	20	Diadumenian	LC	Reverse	2.79	0.06	0.025	94.8	ND	0.06	ND	F
X-1861-243/155	Yatagan Hoard	3,15	18,5	Macrinus	LC	Obverse	14.9	0.08	ND	82.8	1.4	0.73	ND	A
X-1861-243/154	Yatagan Hoard	3,03	18,5	Macrinus	LC	Obverse	26.9	0.09	ND	70.7	1.4	0.72	ND	A
X-1861-243/154	Yatagan Hoard	3,03	18,5	Macrinus	LC	Reverse	20.7	0.15	ND	74.5	2.3	2.19	ND	A
X-1861-243/153	Yatagan Hoard	2,60	21,5	Macrinus	LC	Obverse	12.1	0.06	ND	86.4	0.5	0.63	0.06	A
X-1861-243/153	Yatagan Hoard	2,60	21,5	Macrinus	LC	Reverse	8.25	0.04	ND	90.5	0.5	0.60	0.06	A
X-1861-243/152	Yatagan Hoard	3,19	20	Macrinus	Clean	Obverse	7.8	0.04	ND	90.9	0.4	0.67	0.14	A

Table 5.18 CONTINUED

Inv. No	Form of acquisition	W, (g)	D, (mm)	Emperor	Surface Condition	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pb	Bi	Decision
X-1861-243/151	Yatagan Hoard	2.89	18.5	Macrinus	Clean	Obverse	16.9	0.08	ND	81.9	0.6	0.46	0.12	A
X-1861-243/151	Yatagan Hoard	2.89	18.5	Macrinus	Clean	Reverse	15	0.07	ND	83.9	0.5	0.41	0.12	A
X-1861-243/150	Yatagan Hoard	3.44	20.5	Macrinus	LC	Obverse	10.5	0.05	ND	88.4	0.4	0.31	0.13	A
X-1861-243/150	Yatagan Hoard	3.44	20.5	Macrinus	Clean	Reverse	11.8	0.05	ND	87.1	0.5	0.35	0.13	A
V-1339-12	General mang. Of Museum	2.89	20	Macrinus	TMC	Obverse	38.5	0.1	ND	59.9	0.5	0.21	0.08	A
V-1339-12	General mang. Of Museum	2.89	20	Macrinus	TMC	Obverse	29.1	0.08	ND	68.0	0.5	0.22	0.09	A

Silver contents obtained from of 18 analyzes made in 10 coins varied from 59.9 to 97.4% with the average being 85.7 %. Within these results, 59.9% seems to be the outlier. When the outlier and the results for the supposedly fake coins are excluded, the average value is 82.3. When the values in Table 5.18 are examined, the outlier value, 59.9%, corresponds to V-1339-12 which is the most corroded coin. The reason of low silver value must be surface corrosion; because when another analysis from a cleaner part was performed, this value increased from 59 .9 to 68.0%. It should be noted that even the outlier coins regarding Ag and Cu values fall in the range reported elsewhere (Walker 1978).

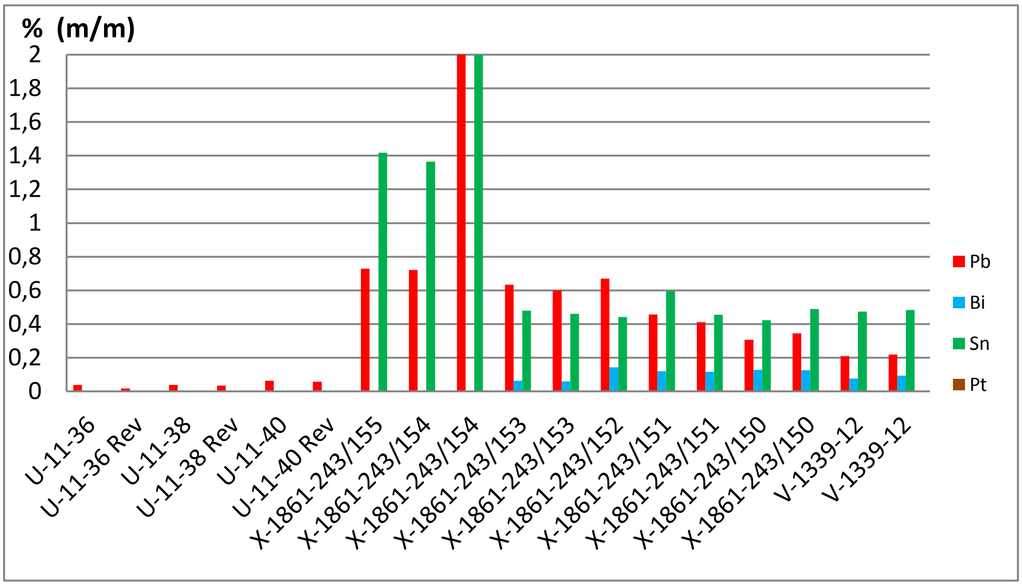


Figure 5.28: Histogram of P-XRF analyzes results of minor elements for the silver coins of Macrinus and his son Diadumenian.

Pb: The results for Pb corresponding to U-11-36, U-11-36 (Reverse), U-11-38, U-38 (Reverse), U-11-40 and U-11-40 (Reverse) are equal to or less than 0.06% which is very low for ancient cupellation technique supposedly used in purification. Denarius coins coming from the reliable source of Yatağan Treasure has Pb contents in the range of 0.31-2.19% with an average value of 0.67% these values are also in agreement with expectations from cupellation technology. The three coins, with the inventory numbers U-11-36, U-11-38 and U-11-40 are fake coins according to Pb values (Table 5.18, Figure 5.28). These coins with the inventory numbers U-11-36, U-11-38, and U-11-40 also have Ag concentrations which are relatively high, average is 96%, as compared to other Macrinus denarius coins with an average 82%Ag.

Zr: In the coins with inventory numbers U-11-36, U-11-38 and U-11-40, Zr was detected, supporting the suggestion that these are fake coins.

Pt: Is not detected in any coin. According to the other results, its presence or absence is not very decisive.

Bi: Bi was not detected in the three coins suggested to be fake ones above. According to Bi results, these three coins, U-11-36, U-11-38 and U-11-40, are fake coins. Apart from the two Yatağan Hoard coins, X-1861-243/154 and X-1861-243/155, in all the samples Bi values was between 0.06-0.14%.

As a result, only three coins, U-11-36, U-11-38 and U-11-40, are fake coins; all the others are authentic coins.

5.1.19 Analyses of Elagabalus (218-222 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.19; a histogram for results is shown in Figure 5.29. The results are discussed in the following paragraphs. A sample coin is shown in Figure 5.30.

Table 5.19: P-XRF Results for Elagabalus Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W (g)	D. (mm)	Analyzed Side and Sampling Option	Denomination	Surface Condition	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
10-M112	Juliopolis Exc.	1.73	18	Obverse	Denarius	WC	24.9	0.09	ND	72.13	1.898	ND	0.92	ND	A
10-1861-243-163	Yatağan Hoard	2.91	20	Obverse	Denarius	LC	5.97	0.03	ND	92.97	ND	ND	0.89	0.05	A
10-1861-243-162	Yatağan Hoard	2.94	20	Obverse	Denarius	LC	8.32	0.04	ND	90.7	ND	ND	0.81	ND	A
10-1861-243-161	Yatağan Hoard	2.31	19	Obverse	Denarius	LC	11.6	0.04	ND	85.91	1.187	ND	1.19	ND	A
10-1861-243-160	Yatağan Hoard	2.73	20	Obverse	Denarius	LC	11.5	0.06	ND	87.29	ND	ND	0.78	0.03	A
10-1861-243-158	Yatağan Hoard	2.78	19	Obverse	Denarius	LC	14.1	0.07	ND	82.91	1.655	ND	1.06	0.13	A
7-1903-1	Bought	2.83	18	Obverse	Denarius	LC	25.5	0.13	ND	71.68	1.423	ND	0.92	0.12	A
10-1861-243-/166	Yatağan Hoard	3.54	18	Reverse	Denarius	LC	10.3	0.08	ND	84.85	2.363	ND	2.08	0.06	A
10-1861-243-/165	Yatağan Hoard	2.19	19	Obverse	Denarius	WC	8.48	0.06	ND	90.29	0.437	ND	0.52	0.1	A
VII-1903-1	Bought	2.82	19	Obverse	Denarius	LC	25.8	0.15	ND	71.34	1.418	ND	0.82	0.12	A
VII-1903-1	Bought	2.82	19	Reverse	Denarius	LC	22.7	0.14	ND	74.6	1.388	ND	0.81	0.14	A
X-1861-243/165	Yatagan Hoard	3.29	19	Obverse	Denarius	LC	6.64	0.05	ND	92.22	0.405	ND	0.45	0.09	A
1967-VI-1733-732/165	Bought	4.4	22	Obverse	ARant	LC	43	0.16	ND	52.42	0.846	0.073	3.37	ND	A
1967-VI-1733-732/165	Bought	4.4	22	Reverse	ARant	LC	36.4	0.13	ND	62.18	0.476	0.069	0.48	0.04	A
Z18	Zurich	3.17	21	Obverse	Denarius	Cleaned	28	0.09	ND	70.68	0.6	ND	0.89	ND	A
Z18	Zurich	3.17	21	Reverse	Denarius	Cleaned	11	0.05	ND	86.91	0.6	ND	1.07	ND	A

In this sample group 16 analyses were made on 13 coins acquired from Yatağan Hoard, Juliopolis Excavation and buying from individuals by MAC, dated to Elagabalus 218-222 A.D. Silver concentrations vary from 52.4% to 92.2% with the average of 79.3%. Within the samples 52.4% and 62.2% Ag values correspond to obverse and reverse sides of the coin 1967-VI-1733-732/165 seem to be outliers. Two analyzes made on same coin which has visible corrosion (Table 5.19). The coin is ARant so it has low Ag value. The analyses results of the coin 1967-VI-1733-732/165 are not too low as compared with some literature results (Walker 1978). It has been reported that some of the Ag values for different years of Elagabalus silver coins are in the range of 45-48% and their weights can vary from 2.96 g to 4.94 g (Walker 1978). Even the lowest value in this study is higher than that reported by Walker (Walker 1978) who also used XRF.

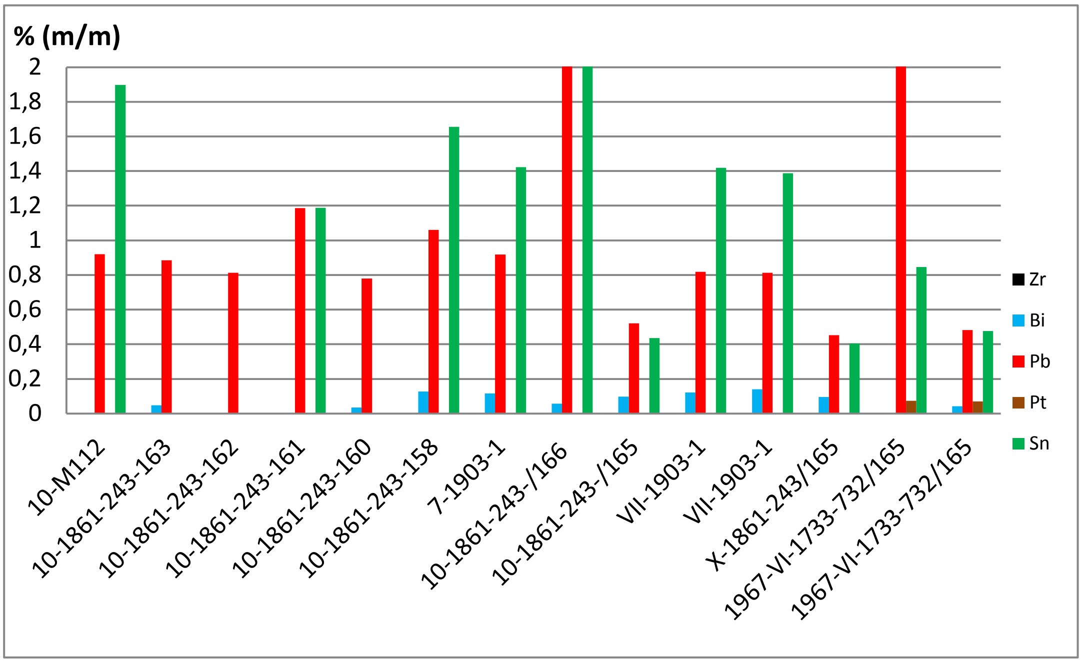


Figure 5.29: Histogram of P-XRF results for minor elements in Elagabalus silver coins.

Pb: All the coins have Pb concentrations between 0.45 and 3.37%; the average is 1.07% Pb that is in agreement with the cupellation technique supposedly used. (Figure5.29).

Zr: Zr was not detected in any of the Elagabalus coins, supporting the idea that they are all authentic (Figure 5.29).

Pt: Is detected in two analyses made on the coin with inventory number 1967-VI-1733-732/165 (Figure 5.30) which is an outlier in terms of Ag value. Pt was detected only in authentic coins depending on the ore used. However, all the authentic coins do not contain Pt.

Bi: Apart from the three coins, Bi was detected in all the Elagabalus coins. The presence of Bi is another proof that the coins are authentic. However, in this study since Bi was not detected in fake coins but detected in 90% of the authentic coins, its absence is not a definite proof that the coin is a fake one.

When all the analytical results are evaluated, it can be concluded that all the coins in this group are authentic coins.

Figure 5.30: Denarius of Elagabalus (1967-VI-1733-732/165).

5.1.20 Analyses of Severus Alexander (222-235 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.20; sample photographs are depicted in Figure 5.31. A histogram for results is shown in Figure 5.32, only for Ag and Cu concentrations. The results are discussed in the following paragraphs.

Table 5.20: P-XRF Results for Severus Alexander Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of Acquisition	W , (g)	D, (mm)	Emperor	Analyzed Side and Sampling Option	Surface Condition	Cu	Zr	Ag	Sn	Pt	Pb	Bi	Decision
80-M174	Juliopolis	2.01	19	Severus Alexander	Obverse	TMC	45.92	ND	51.5	0.85	0.052	1.06	0.18	A ARant
10-1861-243/191	Yatağan H.	3.9	20	Severus Alexander	Obverse	LC	13.1	ND	83.2	1.66	ND	1.63	0.16	A
10-1861-243/190	Yatağan H.	3.03	19	Severus Alexander	Obverse	LC	9.93	ND	87.8	0.56	ND	1.15	0.22	A
10-1861-243/189 .	Yatağan H.	2.84	20	Severus Alexander	Reverse	LC	12.88	ND	85.8	0.38	ND	0.78	0.04	A
10- 1861-243/188	Yatağan H.	2.75	20	Severus Alexander	Obverse	LC	11.41	ND	87.7	ND	0.069	0.6	0.08	A
10-1861-243/187	Yatağan H.	2.65	20	Severus Alexander	Obverse	LC	8.921	ND	90.2	ND	0.06	0.6	0.04	A
10- 1861-243/186	Yatağan H.	2.75	20	Severus Alexander	Obverse	LC	12.28	ND	84.8	1.43	ND	1.28	0.05	A
10-861-243/185	Yatağan H.	2.1	19	Severus Alexander	Obverse	LC	8.09	ND	86.8	2.34	ND	2.24	0.05	A
10-1861-243/184	Yatağan H.	2.46	20	Severus Alexander	Obverse	LC	9.221	ND	89.9	ND	ND	0.65	0.05	A
10-1861-243/183	Yatağan H.	2.88	20	Severus Alexander	Obverse	LC	13.86	ND	85	ND	ND	0.46	0.09	A
10-861-243/182	Yatağan H.	2.85	20	Severus Alexander	Obverse	LC	14.16	ND	85	ND	ND	0.51	0.13	A
10-1861-243/181	Yatağan H.	3.43	19	Severus Alexander	Obverse	LC	20.71	ND	78.3	ND	ND	0.63	0.03	A
10-1861-243/181	Yatağan H.	3.43	19	Severus Alexander	Reverse	LC	21.00	ND	78	ND	ND	0.66	0.04	A
10-1861-243/180	Yatağan H.	2.98	19	Severus Alexander	Obverse	LC	17.75	ND	81.3	ND	ND	0.7	0.04	A
10-1861-243/179	Yatağan H.	3.14	20	Severus Alexander	Obverse	LC	9.493	ND	86.7	1.44	ND	2.26	ND	A
10-1861-243/178	Yatağan H.	2.77	19	Severus Alexander	Obverse	LC	21.99	ND	75.6	1.27	ND	0.89	0.05	A
10- 1861-243/177	Yatağan H.	2.53	20	Severus Alexander	Obverse	LC	8.209	ND	87.3	2.63	ND	1.57	0.09	A
10- 1861-243/184	Yatağan H.	2.86	21	Severus Alexander	Obverse	LC	9.839	ND	89.5	ND	ND	0.46	0.06	A
10- 1861-243/176	Yatağan H.	2.59	19	Severus Alexander	Obverse	LC	6.205	ND	86.7	3.52	0.06	3.18	0.07	A
11-788-23	Bought	3.16	19	Severus Alexander	Obverse	LC	38.65	ND	59.3	0.66	0.062	0.89	0.21	A
1128-67	Bought	3.32	19	Severus Alexander	Obverse	LC	28.5	ND	66.9	1.07	ND	1.16	0.06	A
5-1339-12	Bartın Museum	2.7	20	Severus Alexander	Obverse	LC	24.39	ND	74.9	ND	ND	0.48	0.12	A

a)

b)

Figure 5.31: Samples from Severus Alexander silver coins. a) 80 -M 174, Ag 51.5%, Cu 45.9%,

b) 11-788-23, Ag 59.3%, Cu 38.7%.

Silver content of 22 analyses samples from 20 coins varied between 51.5 and 90.2% with the average being 81.00%. Within these samples, 51.5% (80-M174), 59.3% (11-788-23) and 66.9% (1128-67) Ag values seems to be outliers. When we look at the Table 5.20 it can be seen that two of these coins, 11-788-23 and 1128-67 were bought from individuals; the other one, 80-M174, is coming from Juliopolis excavation. It is well known that sometimes the emperor ordered that the silver content is reduced and Cu is used for compensation (Rodrigues et al. 2011). Moreover after Caracalla, Antoninus plated bronze coins which are called with his name Antoninianus (ARant) with silver by using amalgation technology that was also very common in this period. The above mentioned outlier Severus Alexander coins are in agreement with the results reported where the average value for Ag was 50% (Walker 1978). The coin with inventory number 80-M174 is ARant so its Ag was lower than others.

Pb: All the coins have Pb values between 0.46 and 3.18%; the average is 1.08%. The presence of Pb at such levels is a strong indication that cupellation was used on a Pb ore. All the coins are authentic in terms of Pb.

Zr: Zr was detected in none of Severus Alexander coins. Most generally Zr was detected in fake coins. All the coins are authentic in terms of Zr.

Pt: It is detected in five coins; two of these, 80-M174 and 11-788-23, have Ag values that were outliers in terms of Ag percentage. Pt was detected only in authentic coins but depending on the ore used, it was not always detected in authentic coins. 80-M174, 11-788-23, 10- 1861-243/176, 10-1861-243/187 and 10-1861-243/188 coins are authentic in terms of Pt.

Bi: Apart from the coin with inventory number 10-1861-243/179 in all the coins Bi was detected. The same coin was also assigned as authentic in terms of Ag and Pb values. Bi was not detected in fake coins and was detected in 90% of authentic coins. All the coins of Severus Alexander studied in this research are authentic in terms of Bi values.

As a general conclusion, all the silver coins from the age of Severus Alexander handled in this study are authentic.

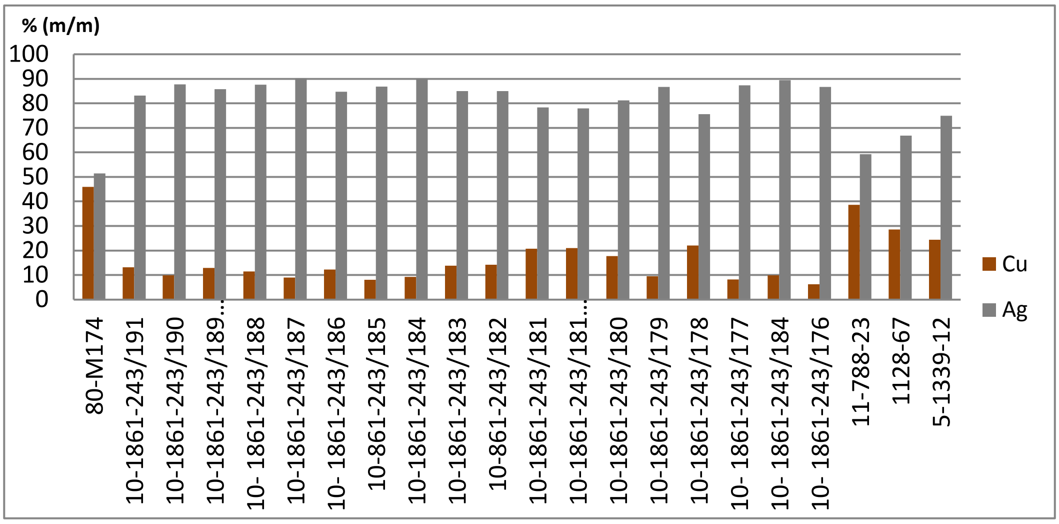


Figure 5.32: Histogram of P-XRF results for Severus Alexander silver coins for only Ag and Cu.

5.1.21 Analyses of Maximinus I (235-238 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.21. A typical XRF spectrum is given in Figure 5.33. A histogram for results is shown in Figure 5.34. The results are discussed in the following paragraphs.

Table 5.21: P-XRF Results for Maximinus I Silver Coins. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of acquisition by MAC	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Surface Condition	Cu	Zn	Mo	Ag	Sn	Sb	Pb	Bi	Decision
10-1861-243/219	Yatağan Treasure	2.93	20	Obverse	LC	17.7	0.07	ND	78.3	2.3	ND	1.263	ND	A
10-1861-243/218	Yatağan Treasure	2.8	21	Obverse	WC	16.4	0.06	ND	82.1	0.5	ND	0.872	ND	A
10-1861-243/217	Yatağan Treasure	2.28	22	Obverse	LC	10.9	0.06	ND	86.9	0.4	0.49	1.095	0.08	A
10-1861-243/217	Yatağan Treasure	2.28	22	Reverse	LC	4.9	0.04	ND	93.6	ND	ND	1.239	0.09	A
10-1861-243/216	Yatağan Treasure	2.91	21	Obverse	LC	21.8	0.08	0.008	76.5	0.4	0.53	0.506	0.11	A
10-1861-243/214	Yatağan Treasure	2.58	20	Obverse	LC	24.6	0.08	0.006	74.4	0.4	ND	0.373	0.03	A
10-1861-243/214	Yatağan Treasure	2.58	20	Reverse	LC	15.4	0.05	ND	83.6	0.4	ND	0.422	0.03	A
10-1861-243/213	Yatağan Treasure	3.25	20	Obverse	LC	9.99	0.05	ND	88.9	0.4	ND	0.48	ND	A
10-1861-243/212	Yatağan Treasure	1.99	21	Obverse	LC	14.5	0.05	ND	84.1	0.4	ND	0.422	ND	A
10-1861-243/212	Yatağan Treasure	1.99	21	Reverse	LC	12.8	0.05	ND	85.5	0.4	0.44	0.52	0.04	A
10-1861-243/210	Yatağan Treasure	2.78	20	Obverse	LC	10.9	0.04	ND	88.2	0.4	ND	0.454	ND	A
10-1861-243/211	Yatağan Treasure	2.22	20	Obverse	LC	12.3	0.05	ND	86.5	ND	0.46	0.513	ND	A

Table 5.21 CONTINUED

Inventory No	Form of acquisition by MAC	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Surface Condition	Cu	Zn	Mo	Ag	Sn	Sb	Pb	Bi	Decision
10-1861-243/209	Yatağan Treasure	3.03	19	Obverse	LC	16.5	0.05	ND	82.5	0.4	ND	0.413	0.04	A
10-1861-243/208	Yatağan Treasure	3.16	19	Obverse	LC	9.76	0.04	ND	89.7	ND	ND	0.432	ND	A
10-1861-243/207	Yatağan Treasure	2.32	22	Obverse	LC	7.65	0.04	ND	91.2	0.4	ND	0.477	0.1	A
10-1861-243/206	Yatağan Treasure	2.71	18	Obverse	LC	17.4	0.07	ND	80.9	0.4	0.47	0.467	0.03	A
10-1861-243/205	Yatağan Treasure	2.52	20	Obverse	LC	18.4	0.07	ND	78.0	2.2	ND	1.082	ND	A
10-1861-243/204	Yatağan Treasure	3.51	20	Obverse	LC	17.1	0.06	ND	80.6	0.4	ND	1.661	ND	A
10-1861-243/204	Yatağan Treasure	3.51	20	Reverse	LC	12.4	0.05	ND	84.9	0.5	0.46	1.591	ND	A
84-3-75	Bought	3.55	21	Obverse	TMC	41.6	0.08	0.008	56.4	0.5	0.3	0.71	ND	A

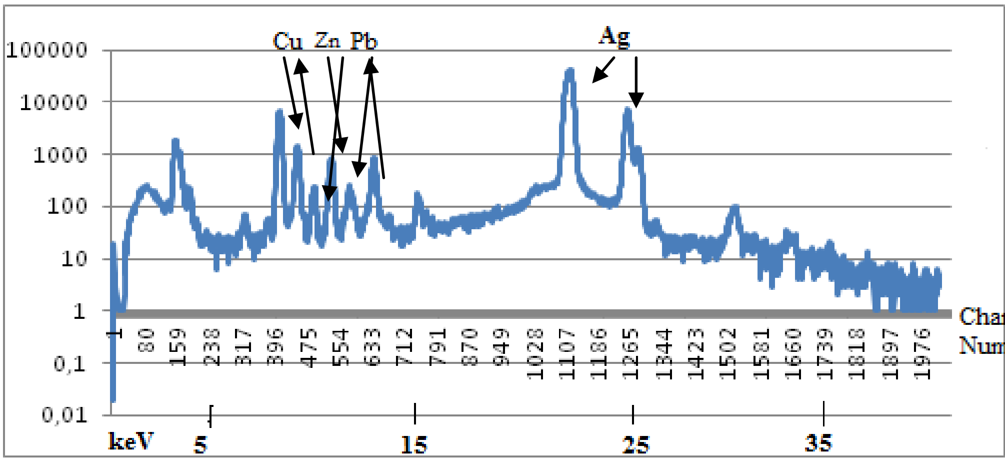


Figure 5.33:Spectrum of coin with inventory number 10-1861-243/204Rev.

In this sample group, 19 coins out of 20 are coming from Yatağan Hoard; one coin was bought from an individual. All the coins have been dated to Maximinus I (235-238 A.D.). The silver concentration values are in the range of 56.4- 93.6% with the average of 82.9%. Among these results, 56.4% seems to be an outlier on the low side. When the results in Table 5.21 are examined, this value corresponds to the coin sample which was bought from an individual (84-3-75). Naturally, the Cu concentration is also relatively high, 41.6%. Moreover the same coin has higher weight comparing to other coins of the same emperor. The reason of the low Ag and high Cu should be too much corrosion.

Comparing the results of this study in terms of Ag and Cu, the values, including even the outlier, are in agreement with those reported by Walker (Walker 1978).

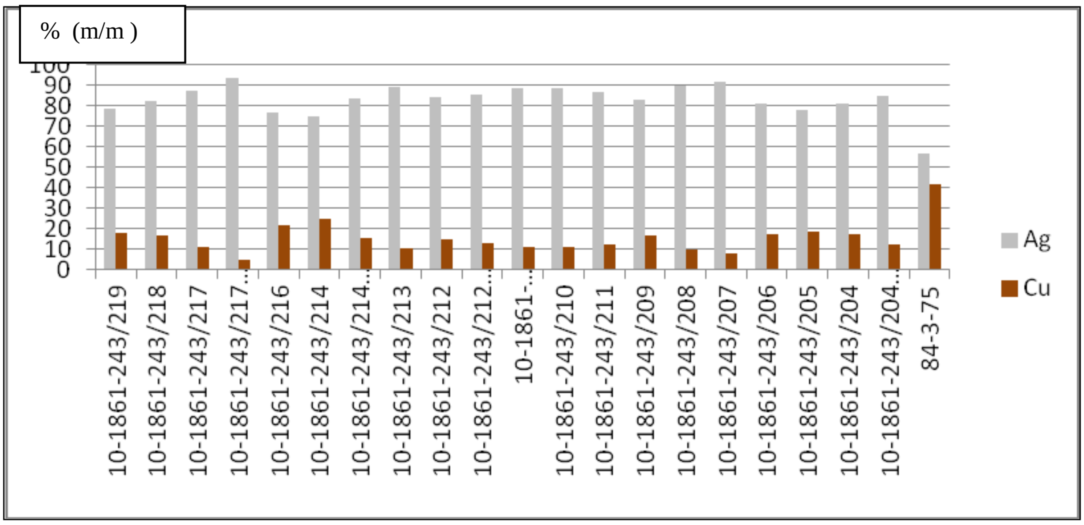


Figure 5.34: Histogram of P-XRF results for Ag and Cu concentrations percentages of Maximinus I silver coins.

Similar considerations can also be done by using the results of minor and trace elements. Regarding copper, values are varied from %4.9 to 41.6 with the average being 11.1%. When we look at the Table 5.21, Cu value of 41.6% seems to be an outlier for this study (84-3-75). There are two samples, namely 10-1861-243/216 and 10-1861-243/214, with Ag values of 76.5 and 74.44% and copper values of 21.8 and 24.6%, respectively; these coins have relatively low Ag and high Cu concentrations as compared to others. They may be minted at different times from the other coins. It is well known that from time to time emperors decreased (debasement) or increased silver content which is always accompanied a change in Cu content. In addition, in these two samples and the sample bought from the individual, Mo could be detected at a level of 73 ppm. Detectable presence of Mo may be due to a positive correlation between Cu and Mo; when Cu values are relatively high, Mo became detectable. This behavior may be related to ore used that may have Cu and Mo togerher.

Pb: It is interesting that in this group of samples, Pb concentration values remarkably vary in a rather large range of 0.37-1.66 % average being 1.38%. It is possible to assume that the original material is a lead ore which contains Cu, Ag and other impurities. According to Pb value all the coins are authentic. However, if the source of Cu is a Pb ore, Pb concentration may be higher even in fake coins.

Bi: In the 10 coins out of 21 samples, Bi was not detected. These are the coins indicated in the Table with with inventory numbers 10-1861-243/219, 10-1861-243/218, 10-1861-243/213, 10-1861-243/212, 10-1861-243/210, 10-1861-243/211, 10-1861-243/208, 10-1861-243/205, 10-1861-243/204 and 84-3-75. The presence of Bi in these coins supports the decision that these are authentic coins.

Zr: Zr was detected in none of the Maximinus I's coins. Zr is mostly detected in fake coins. This is another supporting evidence that the coins are authentic.

Pt: In none of the Maximinus I coins Pt was detected**.** Depending on the ore composition, Pt may or may not be detected in authentic coins. In this study a total of 81 Yatağan coins were analyzed from the ages of Severus Alexander, Caracalla and Gordian III using P-XRF, only in 6 of them Pt was detected and all the results were at levels below to 0.06%.

As a conclusion, all the coins in this group were assigned as authentic; the strongest evidence was the presence of Pb at high levels supported in some coins by Bi presence.

5.1.22 Analyses of Gordian III (238-244 A.D.) Silver Coins

The results for P-XRF analyses and relevant data are given in Table 5.22; sample photographs are depicted in Figure 5.35. Variations of Ag and Cu concentrations are depicted in Figure 5.36. Typical XRF spectra are shown in Figure 5.37. Evaluations of results are given in the following paragraphs.

Table 5.22: P-XRF Results of Gordian III silver coins. Concentrations are given in % (m/m), A: Authentic, F: Fake

Inventory No	Form of acquisition by MAC	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Surface Condition	Cu	Zn	Ag	Sn	Pt	Pb	Bi	Decision
11-M112	Juliopolis Exc.	1.3	22	Obverse	WC	14.0	0.069	81.40	1.435	ND	2,37	0.21	A
11-788-23	Bought	3.44	19	Obverse	LC	36.6	0.215	61.00	1.181	0.051	0.85	ND	A
7-1741-10/8	Bought	2.98	20	Obverse	LC	8.49	0.050	89.01	0.971	0.069	1.20	0.11	A
10-1861-243/238	Yatağan Hoard	3.02	19	Obverse	LC	10.8	0.075	87.58	0.668	ND	0.48	ND	A
10-1861-243/227	Yatağan Hoard	2.47	21	Obverse	LC	15.62	0.064	83.66	ND	0.058	0.44	0.04	A
10-1861 243/226	Yatağan Hoard	2.94	20	Obverse	LC	21.2	0.08	77.58	0.531	ND	0.481	ND	A
10-1861-243/225	Yatağan Hoard	2.67	20	Obverse	LC	15.55	0.06	82.26	0.957	ND	0.993	0.06	A
10-1861-243/224	Yatağan Hoard	3.01	20	Obverse	LC	26.08	0.09	71.93	0.773	ND	0.807	0.06	A
10-1861-243/231	Yatağan Hoard	2.91	22	Obverse	LC	13.68	0.05	84.84	0.531	ND	0.788	ND	A
10-1861-243/232	Yatağan Hoard	3.1	21	Obverse	LC	6.44	0.04	91.61	1.031	ND	0.611	0.06	A
10-1861-243/233	Yatağan Hoard	3.17	21	Obverse	LC	7.03	0.04	92.22	ND	ND	0.503	0.03	A
10-1861-243/234	Yatağan Hoard	2.82	20	Obverse	LC	12.3	0.04	85.76	0.967	ND	0.714	0.08	A
10-1861-243/235	Yatağan Hoard	2.37	21	Obverse	WC	15.81	0.08	82.42	0.845	0.068	0.63	0.03	A

Table 5.22 CONTINUED

Inventory No	Form of acquisition by MAC	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Surface Condition	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
10-1861-243/236	Yatağan Hoard	2.95	20	Obverse	LC	10.8	0.05	ND	87.80	0.468	ND	0.58	0.03	A
10-1861-243/237	Yatağan Hoard	2.87	19	Obverse	LC	17.1	0.07	ND	81.42	0.643	ND	0.60	ND	A
10-1861-243/238	Yatağan Hoard	2.70	21	Obverse	WC	6.3	0.042	ND	92.10	0.636	ND	0.63	0.05	A
10-1861-243/239	Yatağan Hoard	2.47	20	Obverse	LC	11.5	0.058	ND	87.03	0.67	0.06	0.56	ND	A
10-1861-243/240	Yatağan Hoard	2.60	20	Reverse	LC	11.8	0.061	ND	86.71	0.63	ND	0.61	ND	A
10-1861-243/241	Yatağan Hoard	3.48	21	Obverse	LC	21.4	0.076	ND	77.49	0.41	ND	0.51	ND	A
10-1861-243/242	Yatağan Hoard	2.07	20	Obverse	LC	10.5	0.048	ND	87.69	0.458	ND	1.10	0.10	A
10-1861-243/243	Yatağan Hoard	2.67	20	Obverse	WC	11.0	0.055	ND	87.13	0.766	ND	0.86	0.07	A

In this group, 21 analyses were performed on a total of 20 silver coins with sources of Yatağan Hoard, Juliopolis Excavation and buying from an individual. All the coins have been dated to Gordian III (238-244 A.D). The concentration of the main element, Ag, vary from 61.00% to 92.22% with the average of 84.55%.Within the results, 61.00 Ag value seems to be an outlier (Table 5.22 and Figure 5.35). It can be seen that this value correspond to the coin sample (11-788-23) which was bought from an individual. Except the rather low Ag value mentioned above, regarding Ag concentrations there is no indication for any forgery.

Evaluations of minor elements can also be carried out by using the results of minor and trace elements. Regarding copper, values vary in a range of 6.3-36.6% with an average of 14.1% (Table 5.22). The Cu value of 36.6 % seems to be an outlier on the high side, corresponding to the coin 11-788-23, bought from an individual. As will be discussed below, the presence of Pt indicates that the coin is authentic and the reason of the low Ag value may be a reduction of Ag percentage by the emperal authority. Its weight and diameter values are within the expected value range.

Figure 5.35: Silver Coin of Gordian III (11-788-23).

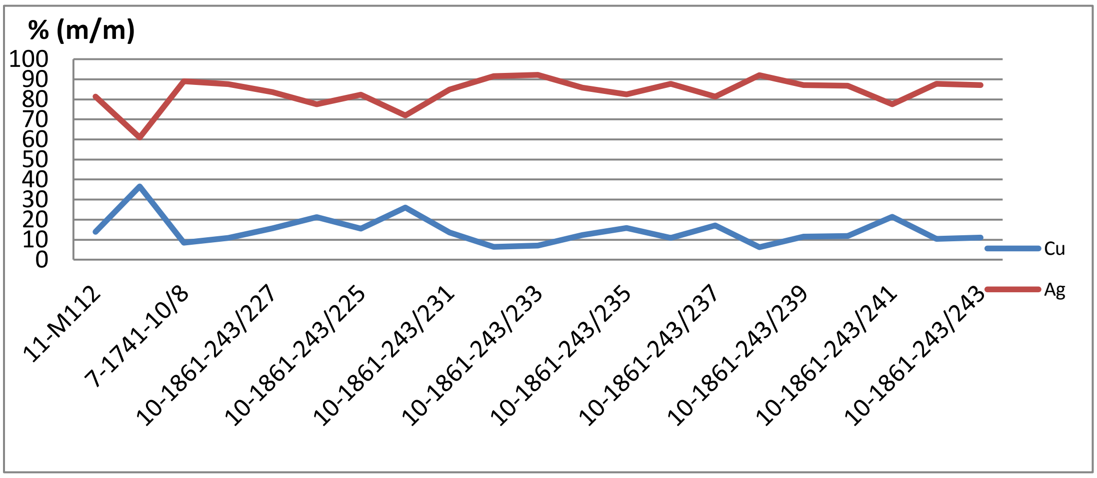


Figure 5.36: Variations in Ag and Cu concentrations in Gordian III silver coins.

There are three samples, 10-1861-243/226, 10-1861-243/224 and 10-1861-243/24,1 having Ag values of 77.58, 71.93, 77.49% and copper values of 21.2, 26.1 and 21.4 %, respectively. These three coins have relatively low Ag and high Cu concentrations. They might have been minted at different times by the emperor compared with other coins. The difference may be a result of debasement as mentioned before (Rodrigues et al. 2011). In Figure 5.36, the symmetry for Ag and Cu values is demonstrating that Cu has been used for compensation when Ag value was low. Similar behavior was also shown in Figure 5.23 for Caracalla’s coins.

Pb has values varied in a large range of 0.44-2.37 %, average being 1.29%. It is possible to assume that the sources of Ag and Cu were lead ores.

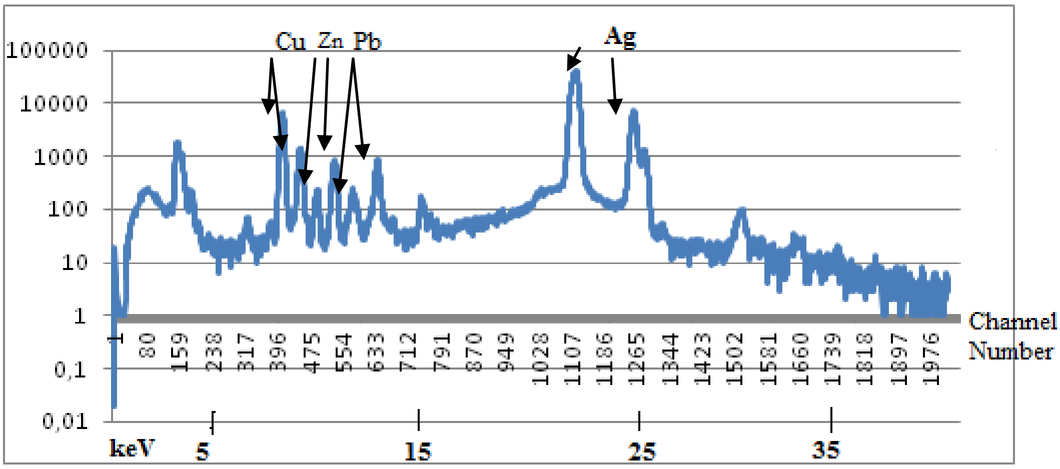


Figure 5.37: Spectrum of coin with inventory no 10-1861-243/238 (Reverse).

The XRF spectra of the coins with inventory no 10-1861-243/238 from Yatağan Hoard are shown in Figure 5.37 respectively.
Zr was not detected in any of the coins in this group; this supports the suggestion that there may be no fake coins. Although Bi was detected in many of the Gordain III's silver coins, there are some coins where Bi was not detectable. However, in all the coins Pb was detected. Pt was detected in 4 coins. As a conclusion, there is no strong evidence that any of the coins is a fake coin. All the samples handled in this group are authentic coins.

5.2 P-XRF Studies with Pin Hole

The biggest problem of working with P-XRF for the analysis of ancient coin samples is the surface corrosion. XRF is a surface analysis technique and the P-XRF instrument used in this study does not allow focusing of the exciting beam on a particular area. If this was the case, it would have been possible to clean a rather small area and work on it. This is not possible and as a result, P-XRF works as an integrator of the relatively large area exposed to X-ray beam. Another limitation is the position of the detector that will collect and measure the fluorescence signal. Both the exciting beam and the detector are confined in a small volume in P-XRF instrument. In order to minimize this problem, the manufacturing company has designed a metal masking device which is called *pin hole* that has a small channel with dimensions of 0.4 X 1.6 cm to reduce the analyzed area to these dimensions while the normal viewing area without a mask is 2.0 cm X 2.0 cm. The pin hole device is shown in Figure 5.38.

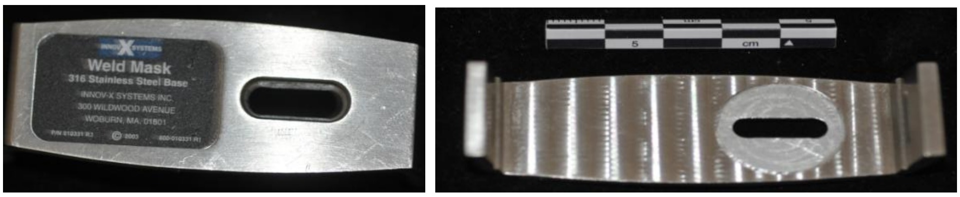


Figure 5.38: Photos of pin hole used in P-XRF analyses.

In order to evaluate the usefulness of pin hole, some coins were selected for P-XRF analysis. The 7 coins were selected, with inventory numbers 150-870/15-76 of Claudius, 5-1499-218 of Vespasian, 25-M122 of Domitian, 23-M120 and 95-M190 of Antoninus Pius, 9-M112 of Faustina I and 47-M139 of Marcus Aurelius. These selected coins were outliers in terms of their low Ag concentration. It was believed that the low Ag values were caused by surface corrosion. The purpose of this study is to investigate the effect of using pin hole on results, aiming to analyze cleaner portions on the coins. On the other hand, this study is expected to give an idea about the repeatability of P-XRF results.

5.2.1 Effect of Working with Pin Hole on Claudius Silver Coin

Photographs of the selected Claudius coin, 150-870/15-76, are shown in Figure 5.39. P-XRF results without and with pin hole are given in Table 5.23 and Table 5.24, respectively. This particular hemi drachma coin was bought from an individual; the surface condition of the coin can be seen on Figure 5.39, there are black points all over the coin.

a) *b)*

Figure 5.39: Use of pin hole with selected areas for P-XRF analysis of Claudius Hemi drachma, 150-870/15-76. a) Obverse b) Reverse.

Table 5.23: Analyzes results of Claudius Silver Coins without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake

Inventory No	**Form of acquisition**	**W, (g)**	**D, (mm)**	**Analyzed Side and Sampling Option**	**Denomination**	**Ti**	**Fe**	**Cu**	**Zn**	**Zr**	**Ag**	**Sn**	**Pt**	**Pb**	**Bi**	**Decision**
150-870/15-76	Bought	1.65	16	O W PH	Hemi Drachma	0.25	0.59	12.4	0.06	ND	**85.3**	ND	0.07	1.28	0.09	A

Table 5.24: Analyzes results of Claudius Silver Coins by using pin hole with P-XRF. Concentrations are given in % (m/m), A: Authentic, F: Fake

Inventory No	**Analyzed Side and Sampling Option**	**Selected Area**	**Ti**	**Fe**	**Cu**	**Zn**	**Zr**	**Ag**	**Sn**	**Pt**	**Pb**	**Bi**	**Decision**
150-870/15-76	O PH	#13	ND	0.23	8.74	ND	ND	89.57	ND	ND	1.34	0.09	A
150-870/15-76	O PH	#14	ND	0.25	9.98	ND	ND	88.25	ND	ND	1.42	0.096	A
150-870/15-76	R PH	#10	ND	0.11	6.43	ND	ND	91.98	ND	ND	1.34	0.10	A
150-870/15-76	R PH	#11	ND	0.51	11.02	ND	ND	87.17	ND	ND	1.21	0.087	A
150-870/15-76	R PH	#12	ND	0.34	8.16	ND	ND	90.15	ND	ND	1.25	0.096	A

The analyses without pinhole gave 85.3% Ag (Table 5.23). When pin hole was used, higher values were obtained this value increased, although there were variations depending on the selected area. The result for Ag concentration is (89.42±1.84) % Ag, percent relative standard deviation (RSD) is 2.06% for N=5. However, it should be noted that this average is significantly different than 85.30%, the value obtained without a pin hole. Using pin hole allowed the selection of cleaner parts, the result obtained should be more reliable. On the other hand, Fe, Cu and Zn values are higher without a pin hole. This shows that when a rather large area was taken, the corroded parts with higher Fe, Cu and Zn content cause a lower Ag result. Minor elements Pt, Zn and Ti which were detected without using pin hole could not be detected when pin hole was used (Table 5.23, Table 5.24). In general, there were no new findings to affect the previous decision that the coin is authentic.

5.2.2 Effect of Working with Pin Hole on Vespasian Denarius

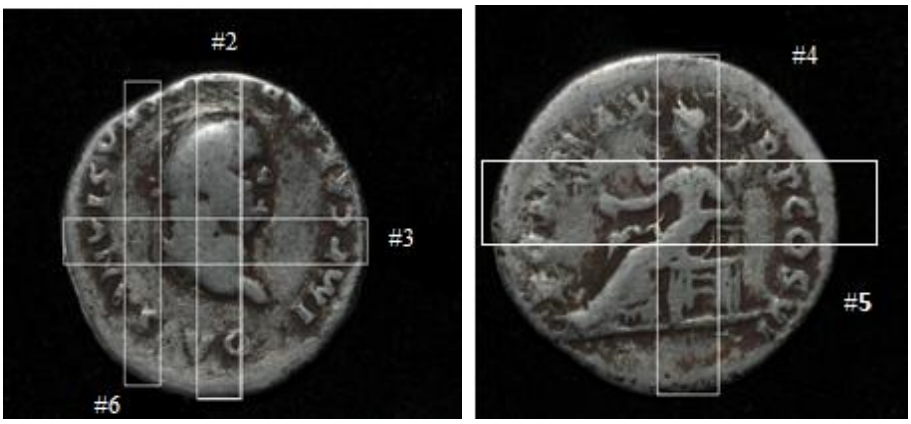
Photographs of the selected Vespasian coin, 5-1499-218, are shown in Figure 5.40. P-XRF results without and with pin hole are given in Table 5.25 and Table 5.26, respectively. This particular coin was bought from an individual; the surface condion of the coin can be seen on Figure 5.40, there are dirty and corroded parts especially on the lower points on the coin surface.

Table 5.25: P-XRF Results of Vespasian silver coin (5-1499-218) without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Analyzed side and sampling option	Fe	Cu	Zn	Ag	Pt	Pb	Bi	Decison
5-1499-218	OWPH	0.06	18	ND	81.08	0.1	0.62	0.05	A

Table 5.26: P-XRF Results of Vespasian silver coin (5-1499-218) using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Analyzed Side and Sampling Option	Selected Area	Fe	Cu	Zn	Ag	Pt	Pb	Bi	Decision
5-1499-218	O PH	#2	ND	16.5	ND	**82.9**	ND	0.59	0.04	A
5-1499-218	O PH	#3	ND	19.1	ND	**80.3**	ND	0.58	0.05	A
5-1499-218	R PH	#4	ND	22.22	ND	**77.2**	ND	0.54	0.04	A
5-1499-218	O PH	#6	0.05	18.2	0.066	**81.1**	ND	0.60	0.05	A
5-1499-218	R PH	#5	ND	16.2	ND	**83.1**	ND	0.62	0.04	A



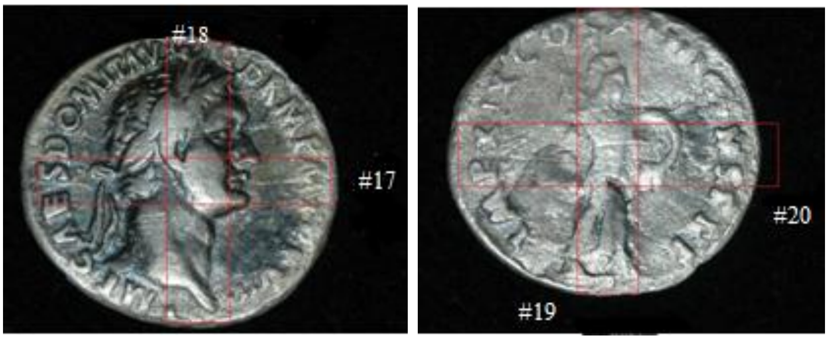
a) b)

Figure 5.40: Use of pin hole with selected areas for P-XRF analysis of Vespasian coin, 5-1499-218. a) Obverse, b) Reverse.

The result for Ag concentration was found to be 81.08%. When pin hole was used, the result for selections on both sides was (80.90±2.39)%, in average and standard deviation; repeatability for N=5 is 3.0% RSD. The average result for pin hole, is not significantly different from the result without a pin hole. However, the experiment demonstrates that the repeatability is acceptable for such a surface technique. There is no significant difference regarding Pb, Bi and Zr concentrations to affect the previous decision that the coin is an authentic one.

5.2.3 Effect of Working with Pin Hole on Domitian Denarius

Photographs of the selected Domitian coin, 25-M122, are shown in Figure 5.41. P-XRF results without and with pin hole are given in Table 5.27 and Table 5.28, respectively. This coin obtained by Juliopolis Excavation, a reliable source. As discussed in the section 5.1.8 it was assigned as an authentic coin. On the obverse side, there are darker regions at the low points; the surface condion of the coin can be seen on Figure 5.41.



a) b)

Figure 5.41: Use of pin hole with selected areas for P-XRF analysis of Domitian coin, 25-M122. a) Obverse, b) Reverse.

Analyses of Domitian deanrius with the inventory number 25-M122, using obverse and reverse sides, resulted in Ag concentrations of 75.2 and 83.4%, respectively. When pin hole was used, the overall result using selections from both sides was (81.02±4.75)%, repeatability was 5.87% RSD for N=4. It should be noted that the obverse side gave a lower result, (77.34±1.46)%, than the reverse side (84.70±3.40); the difference may be attributed to the fact that the former has lower points full of dark patina that could not be effectively cleaned. On the other hand, the reverse side looks cleaner (Figure 5.41).

The minor element Zn, Sn and Pt which were detected without using pin hole could not be detected when pin hole was used. The reason should be the very low percentages of minor element near detection limit; and when restricted area is used, detection is not possible. Regarding the trends for Pb, Bi and Zr, there is no significant difference to affect the authenticity test. The coin is assigned as authentic.

Table 5.27: P-XRF Results of Domitian silver coin (25-M122) without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
25-M122	1.51	18	O WPH	23	0.1	ND	**75.2**	0.6	0.06	0.9	0.11	A
25-M122	1.51	18	R WPH	15	0.1	ND	**83.4**	0.6	0.06	0.9	0.1	A

Table 5.28: P-XRF analyzes of Domitian Silver Coin (25-M122) by using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Analyzed Side and Sampling Option	Selected Area	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
25-M122	O PH	#17	20.5	ND	ND	**78.37**	ND	ND	0.991	0.114	A
25-M122	O PH	#18	22.65	ND	ND	**76.31**	ND	ND	0.928	0.112	A
25-M122	R PH	#19	11.26	ND	ND	**87.10**	0.6	ND	0.895	0.106	A
25-M122	R PH	#20	16.67	ND	ND	**82.29**	ND	ND	0.919	0.108	A

5.2.4 Effect of Working with Pin Hole on Antoninus Pius Denarius

Photographs of the selected Antonius Pius coin, 95-M190 and 23-M120, are shown in Figure 5.42 and Figure 5.43, respectively. P-XRF results without and with pin hole are given in Table 5.29, Table 5.30 and Table 5.31, Table 5.32, respectively. Both of the coins have been obtained through the Juliopolis Excavation and have been assigned as authentic (Section 5.1.12).

The first coin (95-M190), gave a higher result of 82.44% on obverse side as compared with the reverse side (69.95%). When pinhole was used on 4 different selected areas on obverse and reverse sides, gave a result of (81.15±3.21)% Ag with an RSD value of 3.96% (N=4). This result is a better representation of both the Ag concentration and the repeatability obtained in this surface analysis.

Figure 5.42: Use of pin hole with selected areas for P-XRF analysis of Antoninus Pius coin, 95-M190.

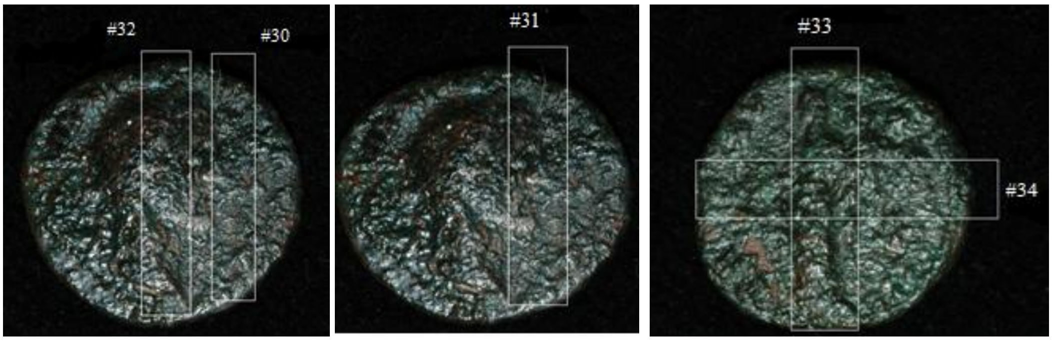
Table 5.29: P-XRF analyzes Antoninus Pius of silver coin (95-M190) of without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Form of acquisition	W, (g)	D, (mm)	Analyzed Side and Sampling Option	Fe	Cu	Zn	Ag	Sn	Pt	Pb	Bi	Decision
95-M190	Juliopolis Exc.	2.98	17	Obverse	ND	16	0.07	82.2	0.41	0.1	1.00	0.29	A
95-M190	Juliopolis Exc.	2.98	17	Obverse	0.04	15	0.06	82.6	0.61	0.1	0.95	0.29	A
95-M190	Juliopolis Exc.	2.98	17	Reverse	ND	28	0.09	69.6	0.48	0.1	1.14	0.35	A

Table 5.30: P-XRF Results for Antoninus Pius silver coin (95-M190) using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Analyzed Side and Sampling Option	Selected Area	Fe	Cu	Zn	Ag	Sn	Pt	Pb	Bi	Decisiom
95-M190	O PH	#13	ND	15.94	ND	82.69	ND	ND	1.0	0.30	A
95-M190	O PH	#14	ND	16.00	ND	82.56	ND	ND	1.1	0.31	A
95-M190	R PH	#15	ND	22.20	ND	76.34	ND	ND	1.1	0.34	A
95-M190	R PH	#16	ND	15.51	ND	83.00	ND	ND	1.1	0.33	A

The analyses result in terms of Ag percentage from obverse with pin hole and without pin hole approximately resulted with 82% Ag. Analyzes of Reverse without pin hole resulted with 69% Ag by using pin hole this value increased to 83%. Evaluating minor element in analyzes made by pin hole most of minor elements Fe. Zn, Sn could not be detected when using pinhole in analyzes (Table 5.27 and 5.28 and Figure 5.42). This results put out that in order to see the real Ag percentage in partially contaminated and corroded coin it is use full to pin hole but for determination of minor elements it is disadvantage to use pin hole.



a) b)

Figure 5.43: Use of pin hole with selected areas for P-XRF analysis of Antoninus Pius Denarius coin, 23-M120 a) Obverse, b) Reverse.

Table 5.31: Antoninus Pius coin with inventory number (23-M120) studied with without Pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of acquisition	Analyzes Side of Coin	Fe	Ni	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
23-M120	Juliopolis Excavation	O WPH	0.1	0.02	63.0	0.14	ND	**35.16**	ND	ND	1.21	0.05	A

Table 5.32: P-XRF analyzes of Silver coin of Antoninus Pius with pinhole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

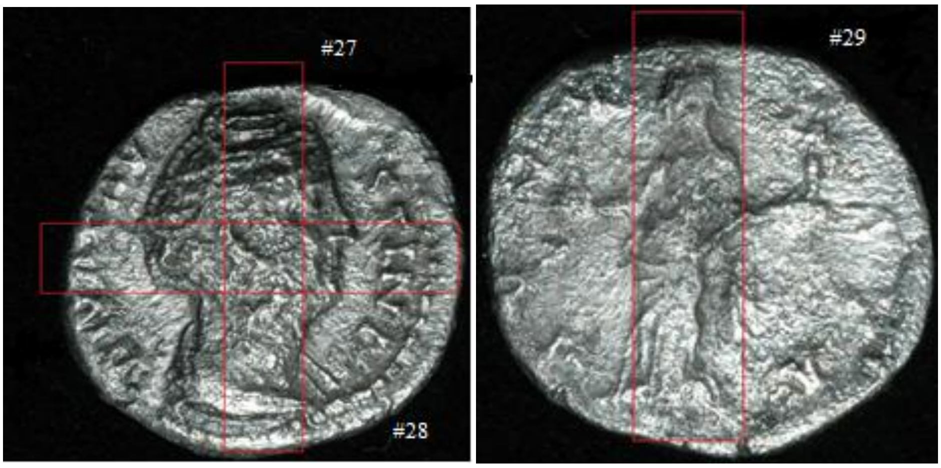
Inventory No	Emperor	Analyzed Side and Sampling Option	Selected Area	Fe	Ni	Cu	Zn	Zr	Ag	Sn	Pt	Pb	Bi	Decision
23-M120	Antoninus Pius	O PH	#30	0.09	ND	68.54	ND	ND	**30.4**	ND	ND	0.977	ND	A
23-M120	Antoninus Pius	O PH	#31	0.08	ND	64.25	ND	ND	**34.4**	ND	ND	1.203	0.055	A
23-M120	Antoninus Pius	O PH	#32	0.04	ND	58.79	ND	ND	**39.8**	ND	ND	1.311	0.053	A
23-M120	Antoninus Pius	O PH	#33	0.094	ND	55.96	ND	ND	**42.4**	ND	ND	1.497	0.06	A
23-M120	Antoninus Pius	O PH	#34	0.33	ND	60.89	ND	ND	**37.7**	ND	ND	1.007	0.041	A

The second coin (23-M120) is heavily corroded and looks like a bronze coin rather than a silver one (Figure 5.43). Without the pin hole, the result for Ag was 35.16%. When the pinhole was used, the Ag concentration varied between 30.4 and 42.4%. The analysis of the reverse side resulted in slightly higher result. Evaluating results in terms of other minor elements, Zn could not be detected by using pin hole and Fe had lower values (Table 5.31 and Table 5.32). As the sample is heavily corroded (Figure 5.43), selections of different areas did not result in a higher Ag concentration. In such cases, a bulk analysis is expected to yield a more accurate value.

For both of the Antonius Pius silver coins, there is not any striking difference between the results obtained with and without pin hole regarding Zr, Pb and Bi concentrations. The coins have been assigned as authentic coins as discussed before in section 5.1.12.

5.2.5 Effect of Working with Pin Hole on Faustina I Denarius

Photographs of the selected Faustina I coin, 9-M112, are shown in Figure 5.44. P-XRF results without and with pin hole are given in Table 5.33 and Table 5.34, respectively. This coin was obtained through Juliopolis Excavation, a reliable source. Its authenticity has also been supported by the discussion in Section 5.1.12. The surface condition of the coin can be seen on Figure 5.44, there are dirty and deep locations on the obverse side.



a) b)

Figure 5.44: Use of pin hole with selected areas for P-XRF analysis of Faustina I Denarius coin,

9-M112. a) Obverse, b) Reverse

Table 5.33: P-XRF Results for Faustina I silver coin (9-M112) without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	W, (g)	D, (mm)	Emp.	Analyzes Side and Samp. Option	Fe	Cu	Zn	Ag	Sn	Pb	Bi	Decision
9-M112	2.66	18	Faustina I	O WPH	0.1	18	0.06	**80.7**	0.3	0.53	0.2	A

Table 5.34: P-XRF Results for Faustina I silver coin (9-M112) using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inv. No	Analyzed Side and Sampling Option	Selected Area	Fe	Cu	Zn	Ag	Sn	Pt	Pb	Bi
9-M112	O PH	#27	ND	19.3	ND	**79.9**	ND	ND	0.562	0.17
9-M112	O PH	#28	ND	15.9	ND	**83.4**	ND	ND	0.523	0.15
9-M112	R PH	#29	ND	7.7	ND	**91.5**	ND	ND	0.556	0.16

Analysis performed on the obverse side without using pin hole gave a result of 80.79% Ag. When pin hole was used, the result obtained from both sides was (84.93±5.95) with an RSD of 7.01% (N=3). This result reflects a reasonable repeatability. It must be noted that the reverse side with smoother and cleaner surface gave the highest Ag value, 91.5%.

Minor elements Fe, Zn and Sn which could be detected without using pin hole, were not detectable by using pin hole. There was not remarkable difference regarding Pb and Bi contents.

5.2.6 Effect of Working with Pin Hole on Marcus Aurelius Denarius

a) b)

Figure 5.45: Use of pin hole with selected areas for P-XRF analysis of Marcus Aurelius Denarius coin (47-M139). a) Obverse, b) Reverse.

Table 5.35: P-XRF Results for Marcus Aurelius silver coin (47-M139) without using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Form of acquisition	Analyzed Side and Sampling Option	Denominations	Cu	Zn	Mo	Pd	Ag	Sn	Pt	Pb	Bi	Decision
47-M139	Juliopolis Excavation	O WPH	Denarius	39.04	0.15	0.01	ND	**59.7**	ND	0.1	0.78	0.26	A
47-M139	Juliopolis Excavation	R WPH	Denarius	13.74	0.06	ND	ND	**84.9**	ND	ND	1	0.32	A

Table 5.36: P-XRF Results for Marcus Aurelius silver coin (47-M139) with using pin hole. Concentrations are given in % (m/m), A: Authentic, F: Fake.

Inventory No	Analyzed Side and Sampling Option	Selected area	Cu	Zn	Mo	Pd	Ag	Sn	Pt	Pb	Bi	Decision
47-M139	O PH	#22	35.37	ND	ND	ND	**63.4**	ND	ND	0.898	0.2861	A
47-M139	O PH	#23	36.13	ND	ND	ND	**62.8**	ND	ND	0.811	0.2349	A
47-M139	R PH	#24	7.24	ND	ND	ND	**91.4**	ND	ND	1.002	0.3148	A
47-M139	R PH	#25	24.84	ND	ND	ND	**73.9**	ND	ND	0.948	0.3223	A

Analysis performed without using pin hole from the obverse side gave a result of 59.7% Ag, while this value was found to be 84.9% for the cleaner reverse side. The value for the obverse side increased to 63.4% Ag by using pin hole. Analysis of the reverse side using pin hole the values were still higher as compared with the obverse side; it was (82.65±12.27)% Ag with an RSD of 14.97%. This value shows that depending on the selected are repeatability may be rather low usinf P-XRF, especially on the surfaces with heterogeneous patina.Pb and Bi levels are not remarkable different when pin hole was used.

5.2.7 Evaluation of P-XRF Studies Using Pin Hole

Using a pin hole has both advantages and disadvantages. The advantage is that a cleaner area relatively free of corrosion can be selected to give a better representation of the bulk composition. Therefore, if the selection of area has been carefully made, the attained accuracy will be higher. It should be remembered that an area that looks very clean to naked eye may not be so clean in chemical terms. Different selected areas should be used and compared for better accuracy. On the other hand, the area viewed is smaller when a pin hole is used, causing a lower sensitivity. The consequence is that some of the trace elements may not be detected when pin hole is used; therefore some important information for the testing of authenticity will be lost. It is suggested that these considerations should be taken into account when a pin hole is used. A good approach is to take measurements both without and with the pin hole. The results should be evaluated considering the advantages and disadvantages of both measurements. Another analytical consideration is that using a pin hole on several selected areas, the precision of results is more realistic as compared with using the total sample area in the absence of this device. Considering the difficult nature of the measurements, problem of local corrosions, differences between the surface and bulk compositions and the limitations of a P-XRF instrument, repeatability at the order of 10% RSD should be expected.

In the following paragraphs, the results

5.3 General Evaluation of P-XRF Results on Authentic and Fake Coins

The determination of the main element Ag is compulsory. However, this analysis will yield useful information only in the case where the result is unrealistically low. Some low Ag values are due to debasement made by emperors for economical reasons (Rodrigues et al. 2011).

Contents of the main element Ag are shown in a histogram in Figure 5.46; in this histogram, average values were taken for each emperor, using the results in Table 5.1 to Table 5.22 The concentration of Ag in fake coins can easily be adjusted. It should be noted that in some cases the Ag concentration in fake coins may even exceed the authentic ones; examples are Geta coins and others as shown in Figure 5.46. As a result, although determination of Ag is always required, this is not sufficient to give a decision; minor elements must also be determined.

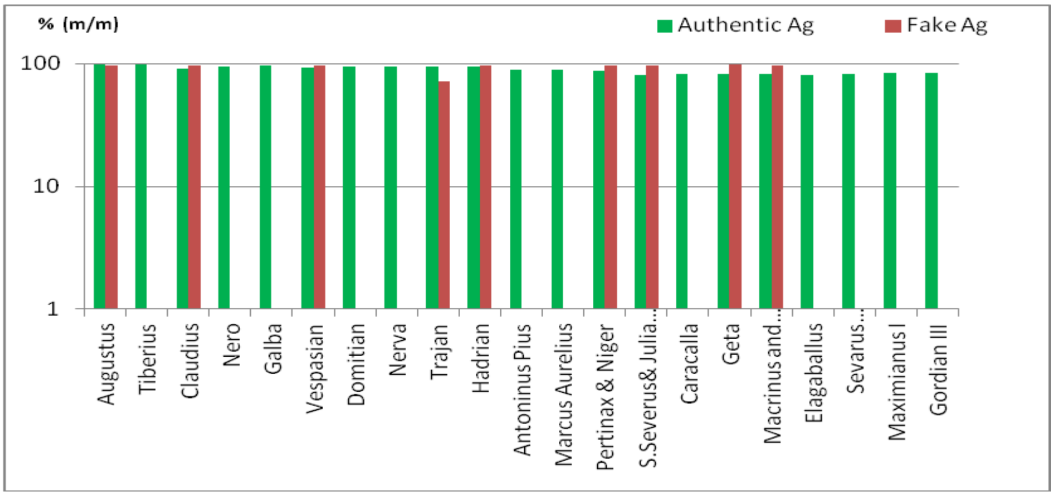


Figure 5.46: Main element (Ag) average contents of fake and authentic denarius coins of Roman Emperors.

5.3.1 Minor Elements (Zr, Sn, Pt, Pb, Bi, Pb) in Authentic Silver Coins

Concentrations of the minor elements in authentic coins under study are shown in Figure 5.47 in a histogram.

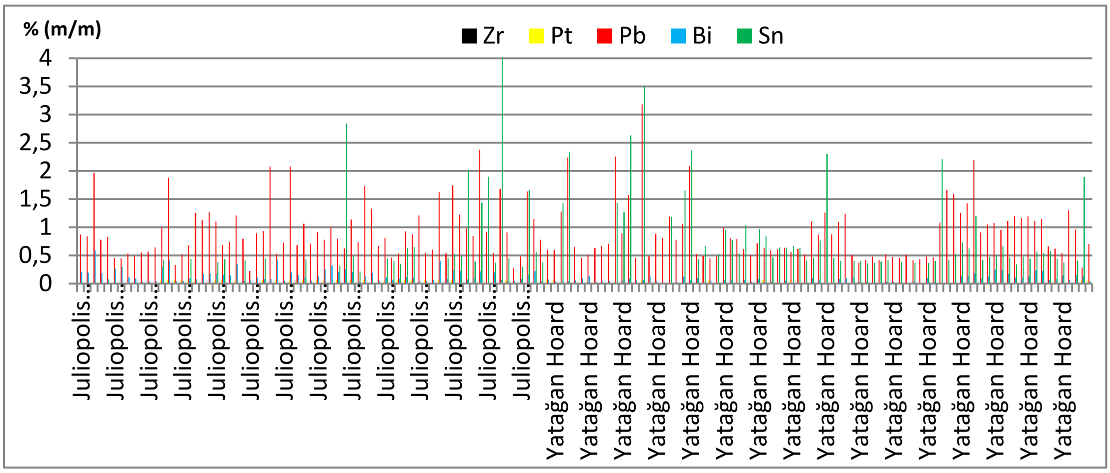


Figure 5.47: Minor element contents in authentic coins.

Evaluation of minor elements determined in 150 coins coming only from reliable sources of Juliopolis Excavation and Yatağan Hoard revealed the following results.

Zr: Only in one of the 150 analyses from silver coins, Zr was detected as 0.0061%; this coin is coming from the Juliopolis Excavation and it was cleaned in the restoration laboratory of The Museum of Anatolian Civilizations. Zr is detected mostly in fake coins, the reason should be the production technology of fake coins by using casting.

Sn: In 90 of 150 coins Sn was detected between 0.2 and 4.30%. Sn was also used to give a new and high Ag content appearance in ancient Denarius coins. In 64% of the authentic coins Sn was detected (Figure 5.47).

Pt: In 35 of 150 silver coins Pt was detected between 0.041 and 0.069%. Depending on the ore used, Pt has been detected in %25 percent of the authentic coins.

Pb: In all the authentic silver coins coming from reliable sources (excavations and hoards) Pb was detected between 0.22 and 2.28%. Pb was detected in 100 percent of authentic silver coins.

Bi: In 129 of 150 silver coins Bi was detected between 0.029 and 0.59%. Bi was detected in %88 of authentic coins.

5.3.2 Minor Elements (Zr, Sn, Pt, Pb, Bi, Pb) in Fake Silver Coins

Concentrations of the minor elements in authentic coins under study are shown in Figure 5.48 in a histogram.

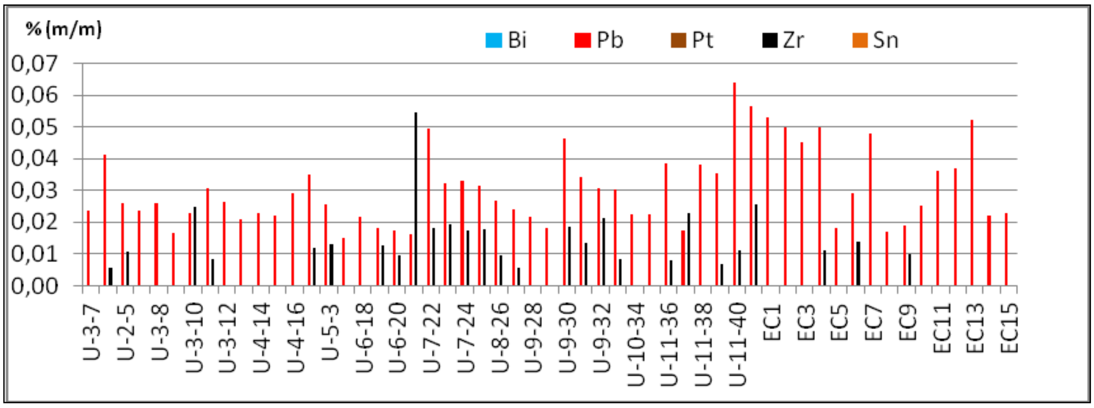


Figure 5.48: Minor element contents in fake silver coins.

A total of 55 fake silver coins were selected for this study, 41 from Roman Imperial denarius coins and 15 from Great Alexander Drachma coins. Since the modern purification technology can yield highly pure silver, P-XRF analyses gave rather low results of minor elements as compared with the authentic coins. The results on the basis of elements are given below.

Zr: In 27 of 55 fake silver coins, Zr was detected between 0.01and 0.05%. In nearly 50% of the fake coins Zr was detected; the concentrations are very low and is close to detection limits (0.001-0.01%). Since the fake coins may contain Zr at very low levels, more sensitive spectrometers should be used in suspicious coins. It should not be forgotten that in minted fake coin Zr was not since probably only in the casted fakes Zr is expected to be present. The reason should be the production technologies used for fake coins as disussed in Section 2.1; re-usable metal casts may contain Zr (http://www.etoplum.com/zirkonyum-hafniyum-madeni-kullanim-alanlari-hakkinda-bilgi.html 09.06.2012).

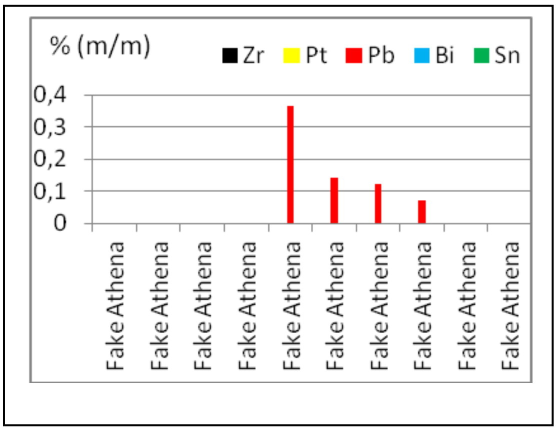
Sn: Sn was not detected in any of the 55 fake silver coins.

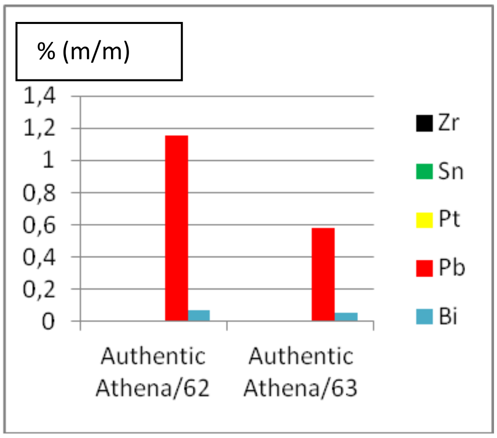
Pt: Pt was not detected in any of the 55 fake silver coins.

Pb: In all the fake silver coins Pb was detected between 0.02 and 0.06% which is very low to be expected from ancient cupellation technology even if the process was repeated few times for better purity (Figure 5.48). However it should not be forgotten that there is a positive correlation between Pb and Cu in the fake coins; if the Cu content is high, Pb concentration will be also higher as the inpurity in copper. This may give the impression that the coin is authentic. In such cases determination of Bi and Ag results will be more important to decide about authenticity.

In addition to the emperor coins chosen in this study, some Hellenistic coins of Athena, both authentic and fake, were also analyzed. In the authentic coins Pb level was between 0.6 and 1.2%, while Bi was in the range of 0.03-0.05% that is low but detectable. On the other hand, in the fake Athena coins, Pb was in the range of 0.07-0.37% and Bi could not be detected (Figure 5.49). For the latter, Pb concentration somewhat overlaps with the values for the authentic ones; however, the coin is a fake one based on other evaluations; absence of Bi is a strong evidence. Previous numismatic evaluation also supported and assured that the Athena coins handled here are fake coins (Sayles 2000).

Bi: Bi was not detected in any of the 55 fake silver coins. Its presence is a strong indication of authenticity while its absence is even a stronger evidence for forgery.





a) b)

Figure 5.49: P-XRF analysis results of Athena coins a) fake b) authentic.

A generalized histogram showing the minor element concentrations in authentic and fake coins are given in Figure 5.50. On this figure the fake ones have been located on the right hand side. The difference in the concentration levels can easily be seen for the minor elements, Zr, Sn, Pt, Pb and Bi. In the authentic coins, levels are high with exception of Zr. For the fake ones, Zr is occasionally detected while Pb levels are usually detectable but relatively low as compared to the authentic coins.

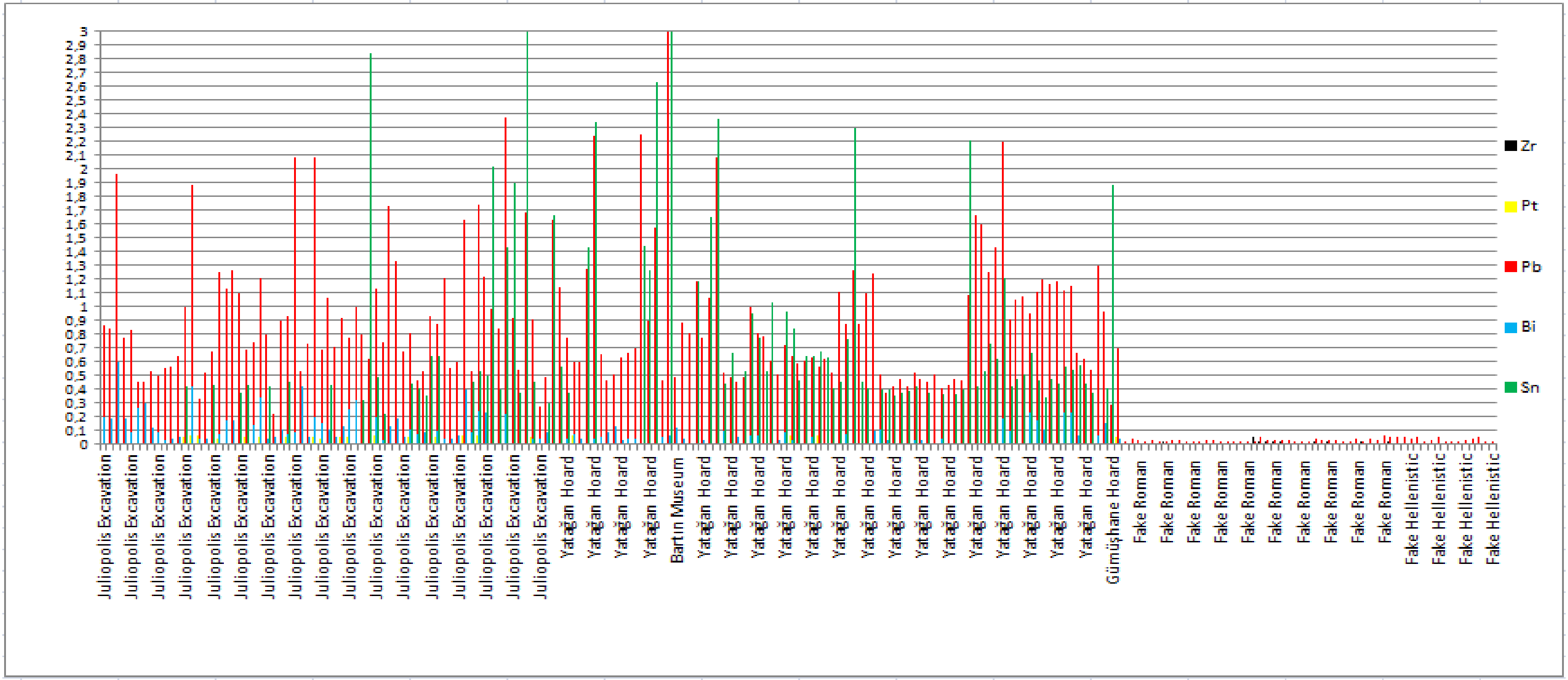


Figure 5.50: Minor elements concentrations in authentic and fake coins.

5.4 Results from SEM-EDX and LSEM-EDX Analyses

The coins are made by preparing an alloy followed by shaping into the final form. As the hot liquid alloy solidifies, some segregation may take place resulting in copper-rich phases. Various measurements on such sample surfaces of newly poured metals therefore show large variations in the copper content. Some of the black spots in the SEM images may correspond to these copper-rich regions. On the other hand, if sufficient time is allowed, the concentration gradient between the copper-rich phase and the matrix will diminish as a result of slow diffusion. In order to understand if the molten metal was poured recently or not, copper-rich phases (black spots) may be analyzed by SEM-EDX and line scanning electron microscopy-energy dispersive X-ray spectrometry (LSEM-EDX) as reported elsewhere by using PIXE (Demortier 2003). If the copper-rich phase differs significantly as compared to matrix, it can be said that the formation of alloy was made on a recent date. Therefore, if such black spots are analyzed in a fake coin, a relatively large difference of copper concentration should be detected along the interface between the matrix and the copper-rich phase. On the other hand, such a behavior is either not expected or the concentration gradients will be softer for an authentic coin. This approach has been tested on both authentic and fake coins. The results are given and evaluated in the following paragraphs.

5.4.1 Experiments on Authentic Coins from Juliopolis Excavation by using SEM-EDX and LSEM-EDX

In this section, several measurements were made on some selected authentic and fake coins. After obtaining a SEM image as shown in Figure 5.51, several measurements were performed on either black spots and/or the gray area representing matrix. Black spots may be copper-rich phases. After the preliminary search on the black spots and the matrix, LSEM-EDX analysis was performed on a line crossing the matrix and the black spots.

5.4.1.1 Authentic Antoninus Pius Silver Coin (78-M173) Coming from Juliopolis Excavation

The first sample was an authentic silver coin from the age of Antoninus Pius, obtained from the reliable source of Juliopolis Excavation, with inventory number of coin 78-M173. Its SEM image is given in Figure 5.51. One of the black spots selected yielded the EDX spectrum shown in Figure 5.52 while the replicate measurements on the matrix excluding black spots are given on Figure 5.53 and Figure 5.54. The spectrum on Figure 5.52 yielded 95.34% Ag and 4.66% Cu. The spectra on Figure 5.53 and Figure 5.54 resulted in values representative of the matrix, 97.84% Ag, 2.16% Cu and 97.46% Ag, 2.54% Cu, respectively. There is no striking difference in the Cu values from the black spot and matrix, indicating that the black spot selected was not actually very rich in copper. It is possible that this location corresponds to a dendrit that diffused into the matrix with time elapsed since the authentic coin was produced.

probably because of production technology (during melting of the ore charcoal or wood were used) Carbon has been detected in the black spot (Figure 5.52); this is another indication of authenticity since the ancient heating technologies depended on carbon based fuels .Nevertheless, carbon has also been detected in some fake coins probably because of contamination; another possibility is that for heating carbon based fuels were used instead of an electrical oven.

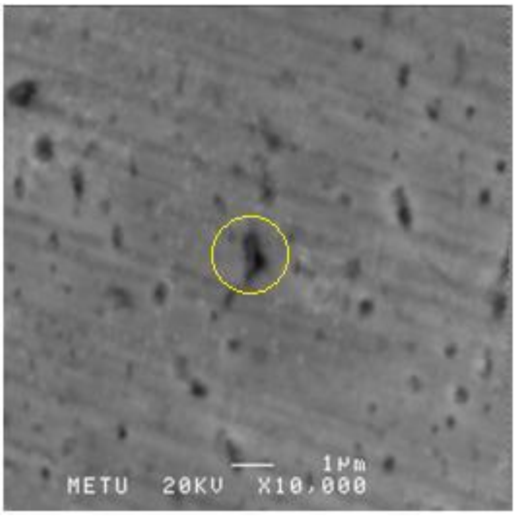


Figure 5.51: SEM image of authentic Antoninus Pius silver coin78-M173 coming from Juliopolis Excavation.

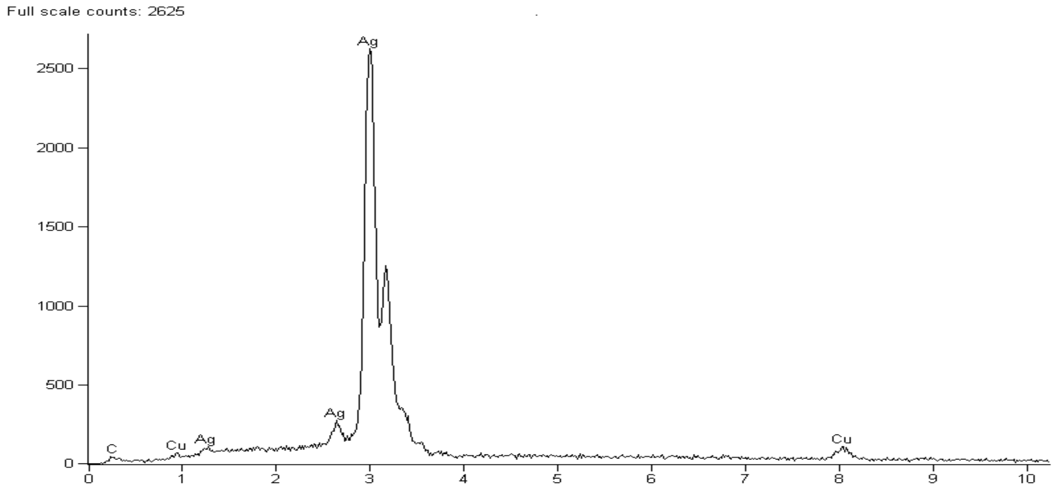


Figure 5.52: EDX spectrum of a black spot on authentic Antoninus Pius silver coin, 78-M173.

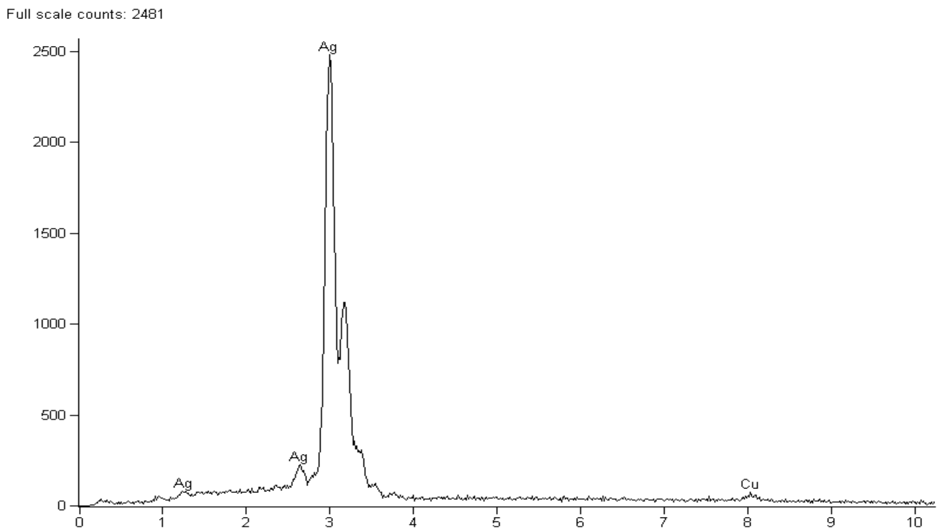


Figure 5.53: EDX spectrum of a black spot on authentic Antoninus Pius silver coin, 78-M173.

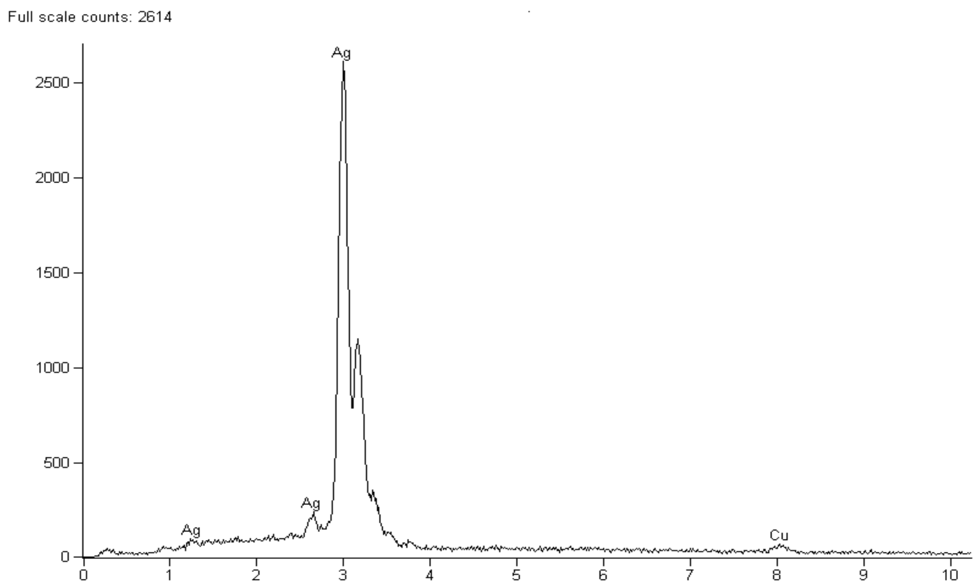
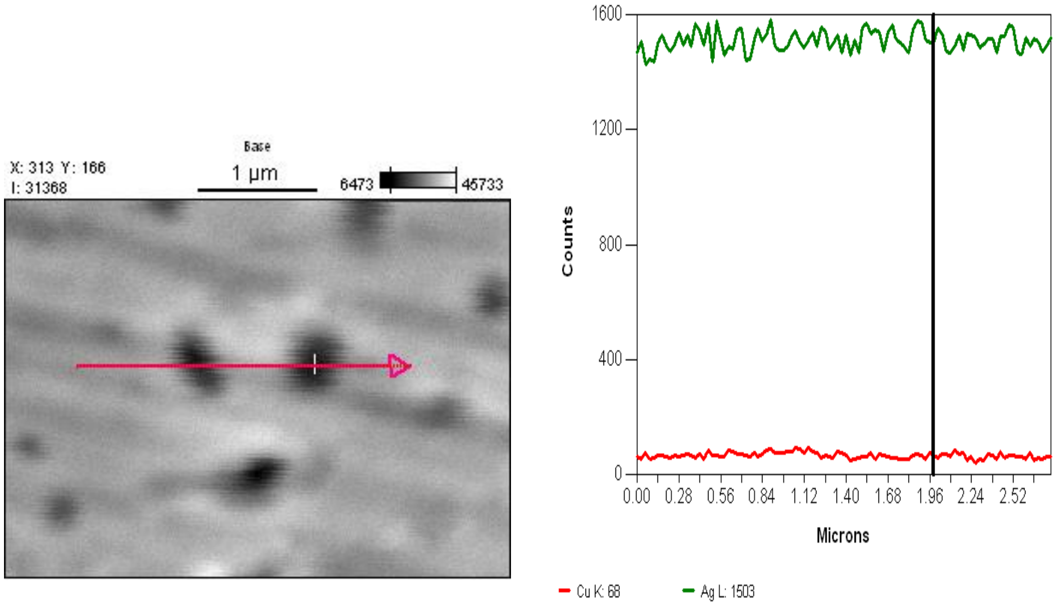


Figure 5.54**:** EDX spectrum for matrix of authentic Antoninus Pius silver coin (78-M173).

Application of SLEM on the authentic Antonius Pius silver coin (78-M173) is shown in Figure 5.55. As expected from the Ag and Cu values in black spots and matrix, as discussed above, there were no sharp concentration changes along the selected line. Although some other black points were also treated similarly using SLEM, it has not been possible to find a copper-rich black spot. This result is in agreement with the properties of an authentic coin.



a) **b)**

Figure 5.55**:** LSEM analysis of authentic silver coin of Antoninus Pius (78-M173) including black spots and matrix. a) SEM image and the line used for analysis, b) Variations of Ag and Cu concentrations along the selected line by EDX.

5.4.1.2 Authentic Vespasian Silver Coin (63-M154)

A selected Vespasian silver coin (63-M154) was subjected to SEM-EDX and LSEM-EDX analysis as discussed above. The SEM image of this coin is shown in Figure 5.56; there are similar black regions and carbon was also detected as shown in the EDX spectrum of the coin where a black spot (I) was chosen for EDX analysis (Figure 5.57). The EDX analysis of the black spot (I) yielded 96.64% Ag, 1.80% Cu and 1.56% Pb.

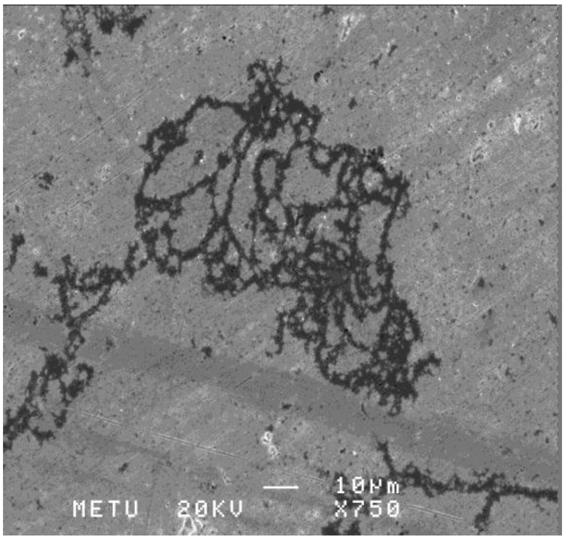


Figure 5.56: SEM image of authentic Vespasian silver coin (63-M154), selected region I.

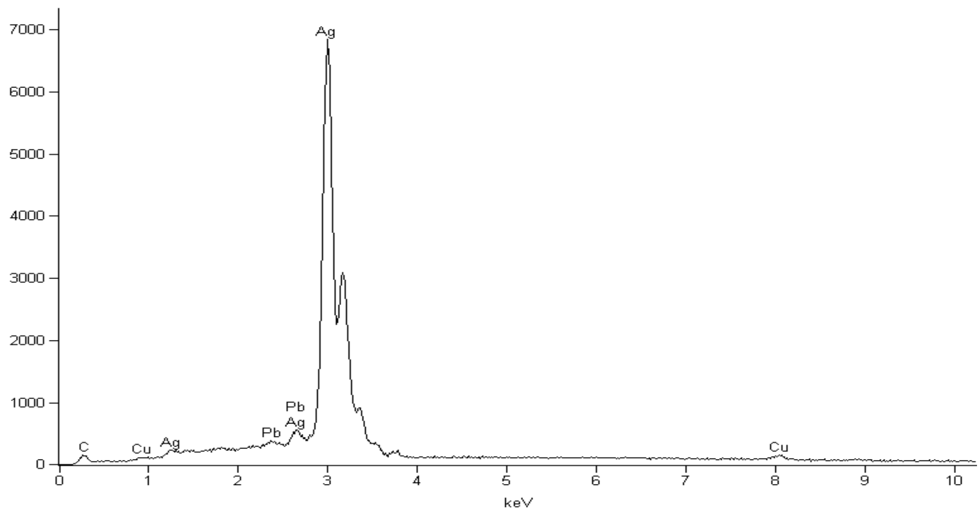


Figure 5.57: EDX spectrum of a black spot (I) on authentic Vespasian silver coin, 63-M154.

Using the same Vespasian coin, another section on the coin was selected and similar procedure was repeated. The results for the black spot (II) are shown in Figure 5.58 and the results from this spectrum were 94.82% Ag, 2.79% Cu and 2.39% Pb.

A third region selected in the same Vespasian silver coin was subjected to similar procedures; the SEM image and EDX spectrum are given in Figure 5.59 and Figure 5.60, respectively. Results of this analysis were 93.50% Ag, 4.94% Cu and 1.56% Pb.

Another examination on matrix excluding the black spots were carried out, the EDX spectrum in Figure 5.61 gave the results of 94.23% Ag, 4.08% Cu and 1.69% Pb. Since there are no large differences in concentrations obtained from black spots and matrix, it may be concluded that the spots were corrosion pits which are not rich in copper. In Figure 5.57 and Figure 5.58, it can be seen that carbon was also detectable. This is another indication that ancient technology of heating using wood and/or charcoal was probably used. Despite these results, two LSEM analyses on different selected areas were carried out, as shown in Figure 5.62 and Figure 5.63, respectively as expected from the previous analyses, there were no sharp changes at the interfaces between the black spots and matrix. These results support the suggestion that the Vespasian silver coin is authentic. As discussed above, the presence of carbon in some of the spectra is another support for authenticity. The lack of copper-rich spots may be a consequence of perfect natural diffusion in nearly 1950 years.

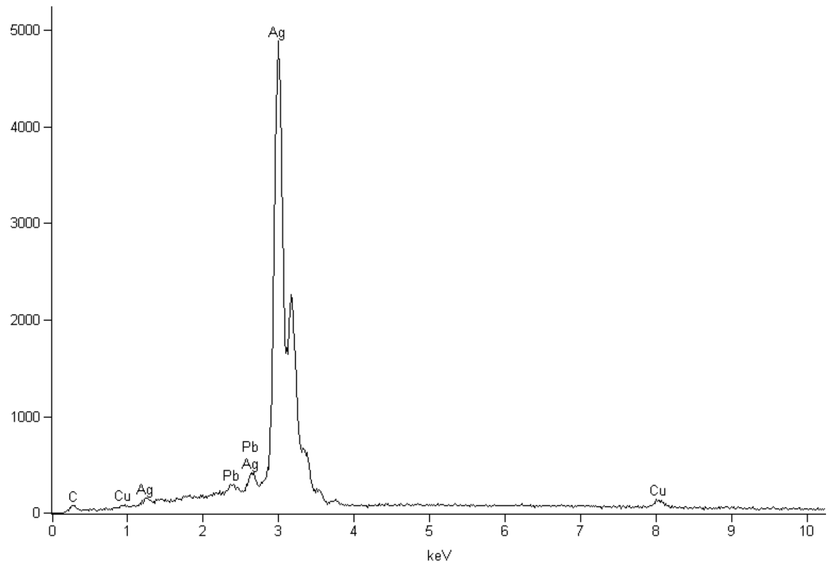


Figure 5.58: EDX spectrum of a black spot (II) on authentic Vespasian silver coin, 63-M154.

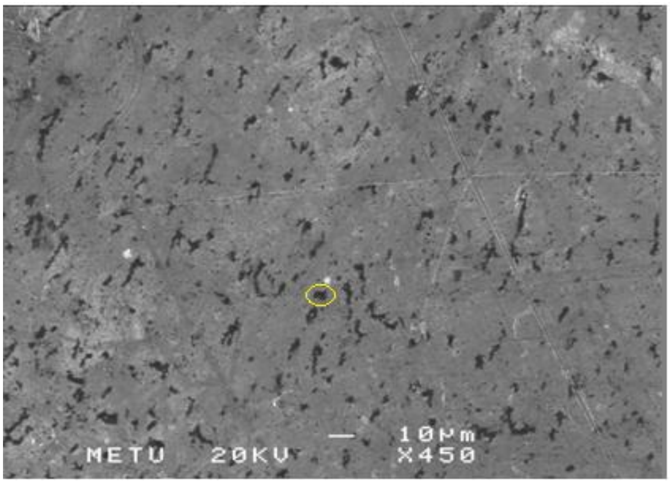


Figure 5.59: SEM image of authentic Vespasian silver coin (63-M154), selected region II.

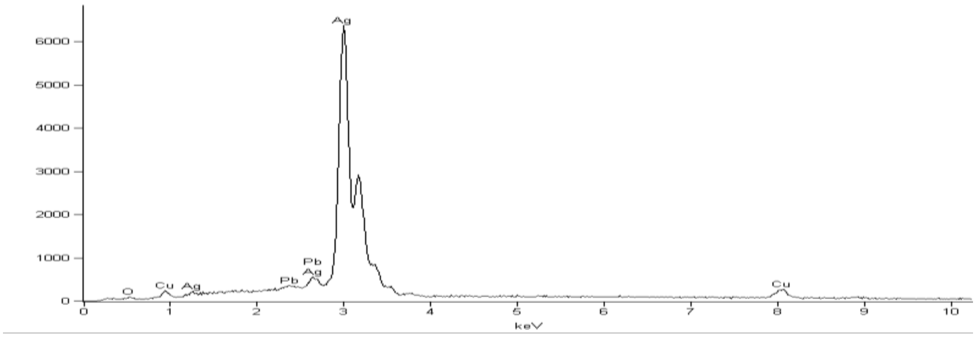


Figure 5.60: EDX spectrum of a black spot (III) on authentic Vespasian silver coin, 63-M154.

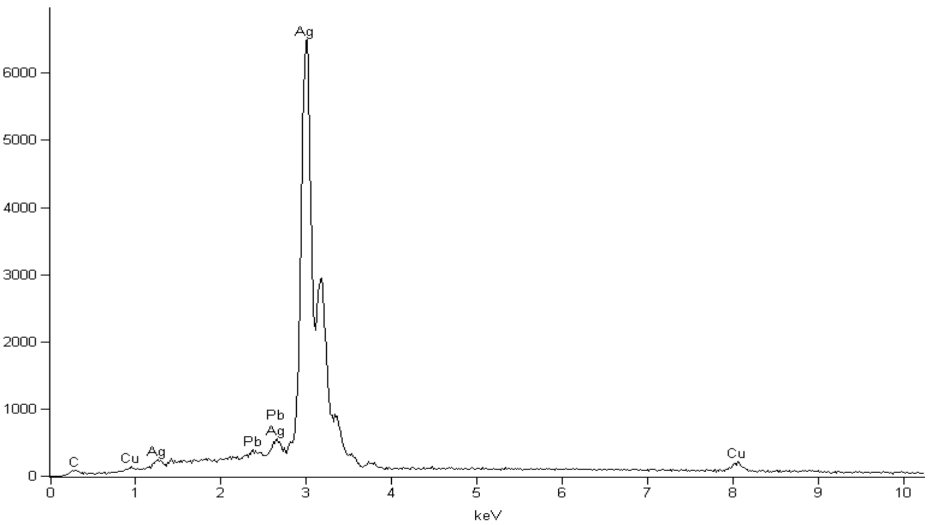
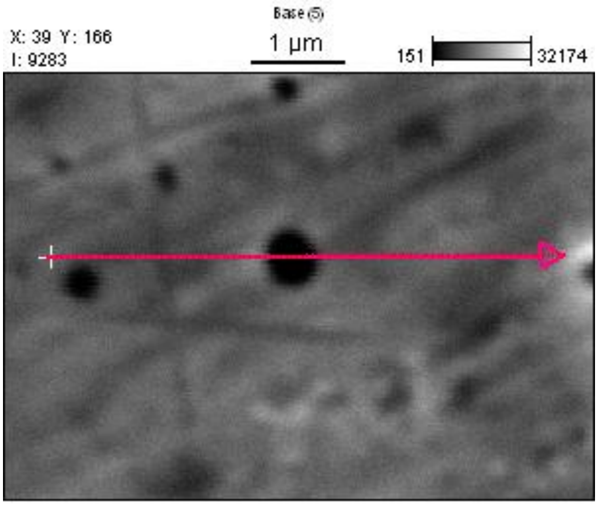
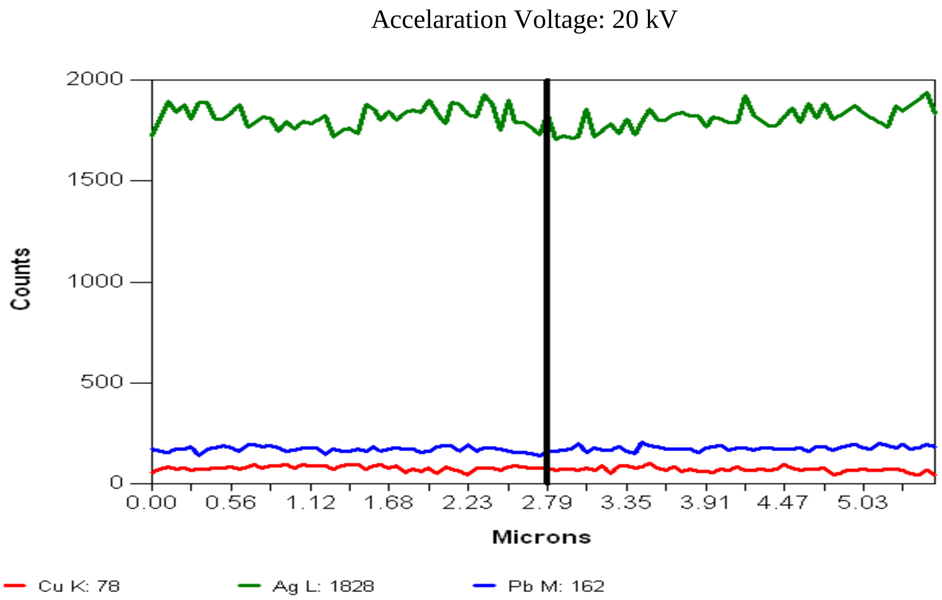


Figure 5.61: EDX spectrum for matrix of authentic Vespasian silver coin (63-M154).



a)



b)

Figure 5.62: LSEM analysis of authentic silver coin of Vespasian (63-M154), RUN I, including a black spot and matrix. a) SEM image and the line used for analysis, b) Variations of Ag, Cu and Pb concentrations along the selected line by EDX.

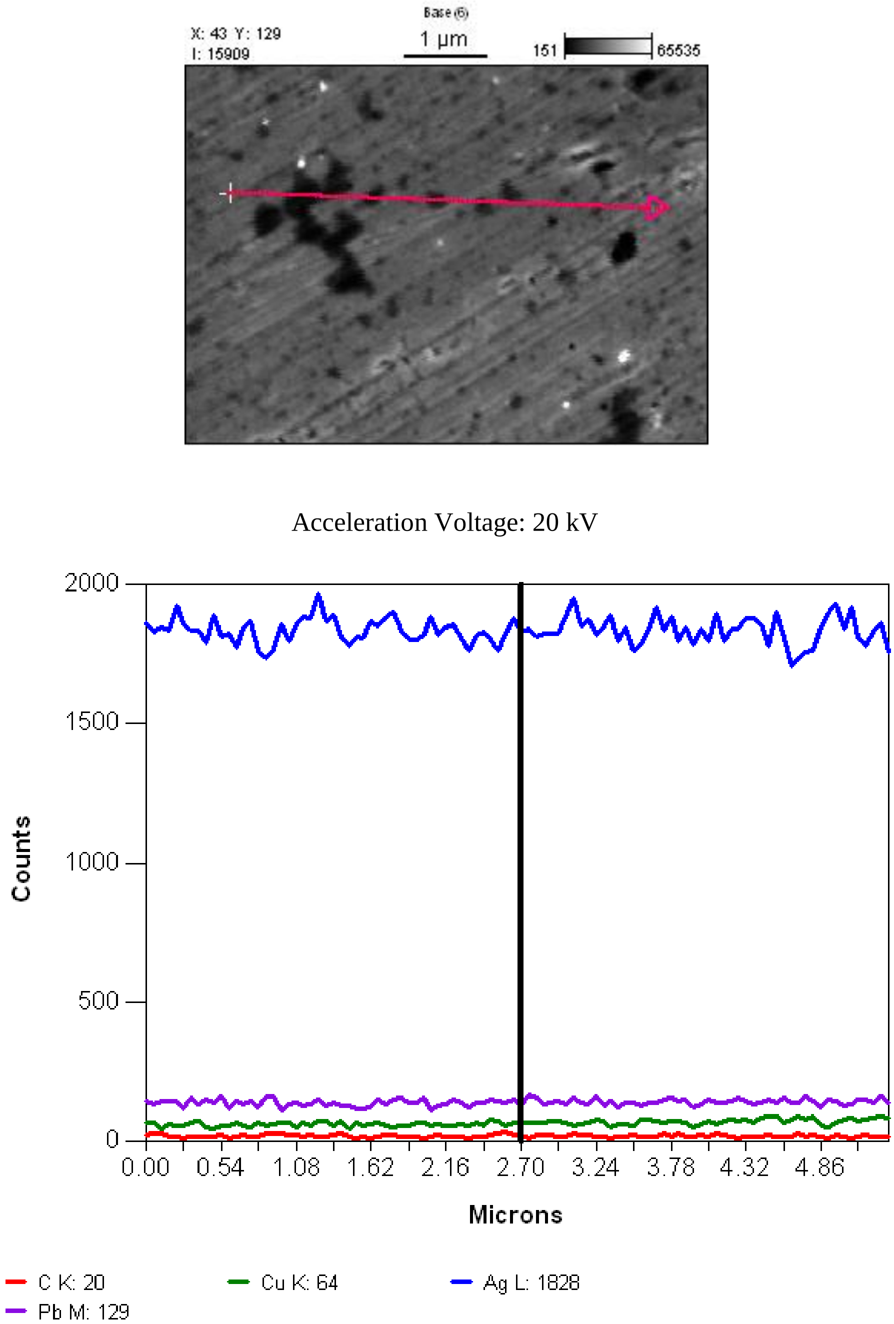


Figure 5.63: LSEM analysis of authentic silver coin of Vespasian (63-M154), RUN 2, including black spots and matrix. a) SEM image and the line used for analysis, b) Variations of C, Cu, Ag and Pb concentrations along the selected line by EDX.

5.4.1.3 Authentic Hadrian Silver Coin Coming from Juilopolis Excavation (37-M131)

The Hadrian silver coin selected had the inventory number of 37-M131. This coin was subjected to SEM-EDX and LSEM-EDX analysis as the others. The EDX spectra of the three black spots selected are given on the Figure 5.64, Figure 5.65 and Figure 5.66; these spectra yielded the results of 98.94% Ag, 1.06% Cu; 94.75% Ag, 2.64% Cu, 2.61% Al; and 97.17% Ag, 2.83% Cu, respectively. Although there is a variation in concentrations, this is due to the fact that in this mode of analysis, the focused area is rather limited, approximately the size of the black spot selected, at the order of 1.0 micrometer or less. Therefore, due to the heterogeneity, some differences in concentrations is expected. Nevertheless, the differences are not strikingly high to indicate that there is a copper-rich phase. The

Al signal in Figure 5.65 is probably due to the surface cleaning powder used, which was alumina. In all the spectra, carbon was detectable which is indicative of authenticity.

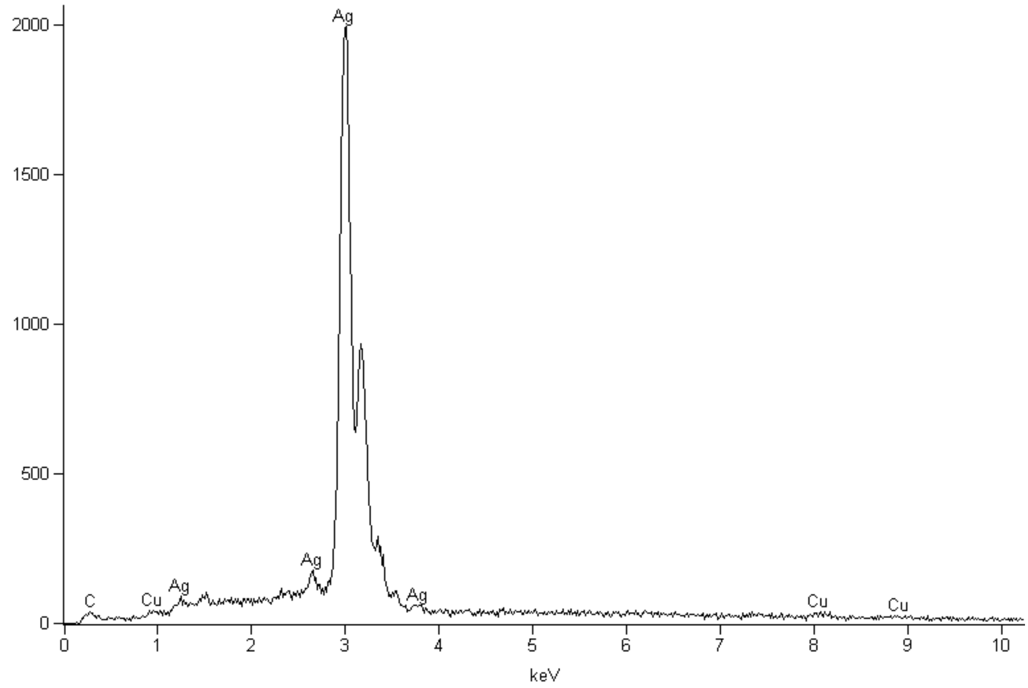


Figure 5.64: EDX spectrum of a black spot (I) on authentic Hadrian silver coin, 37-M131.

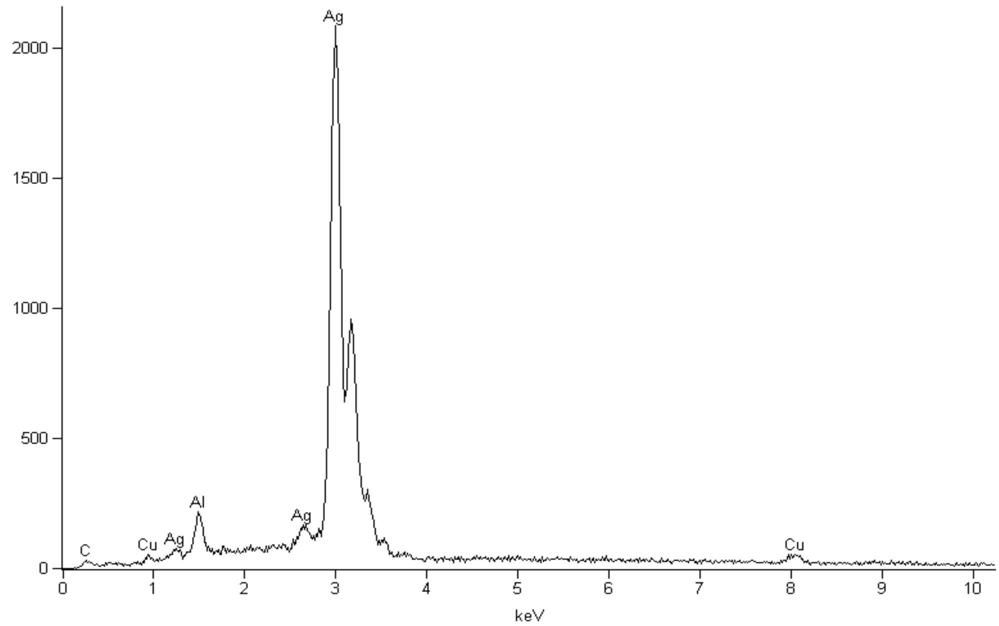


Figure 5.65: EDX spectrum of a black spot (II) on authentic Hadrian silver coin, 37-M131.

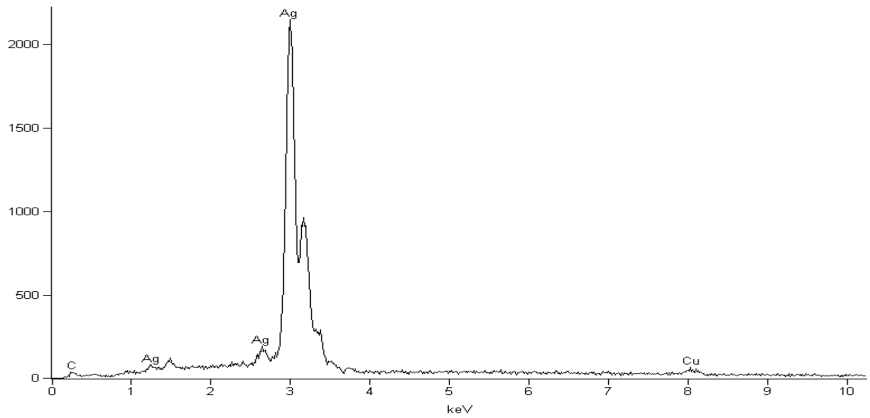
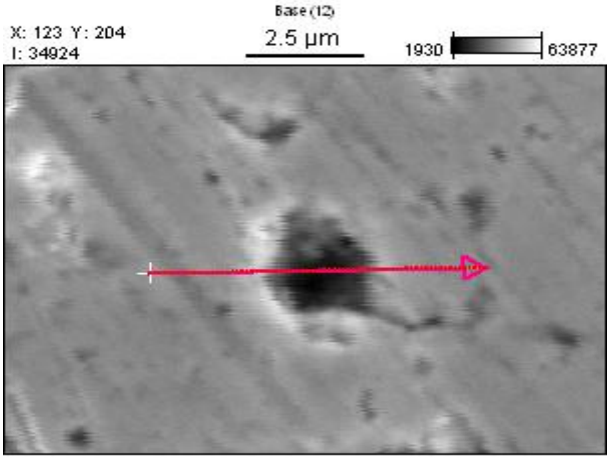


Figure 5.66: EDX spectrum of a black spot (III) on authentic Hadrian silver coin, 37-M131.

Although the results above indicated that it would be rather difficult to find a copper-rich phase on a black spot, LSEM analysis was performed on two different black spots, as shown in Figure 5.67 and Figure 5.68. The first black spot selected had a diameter of about 2 micrometer as shown in Figure 5.67. As the line was passing through the spot, there was a significant drop in Ag concentration; however, there was no other increasing concentration at this point, indicating that the spot corresponds to a pit rather than a copper-rich phase. For the second black spot (Figure 5.68), which was in an elongated configuration, there was no change in concentrations at the interfaces. Neither of the black points selected was a copper-rich phase.

As it is shown by the results above, in authentic silver coins, although there may have been copper-rich points at the time of solidification of the molten metal mixture, through the period of nearly 2000 years, diffusion must haveliminated the concentration differences a)



Acceleration Voltage: 20 kV

b)

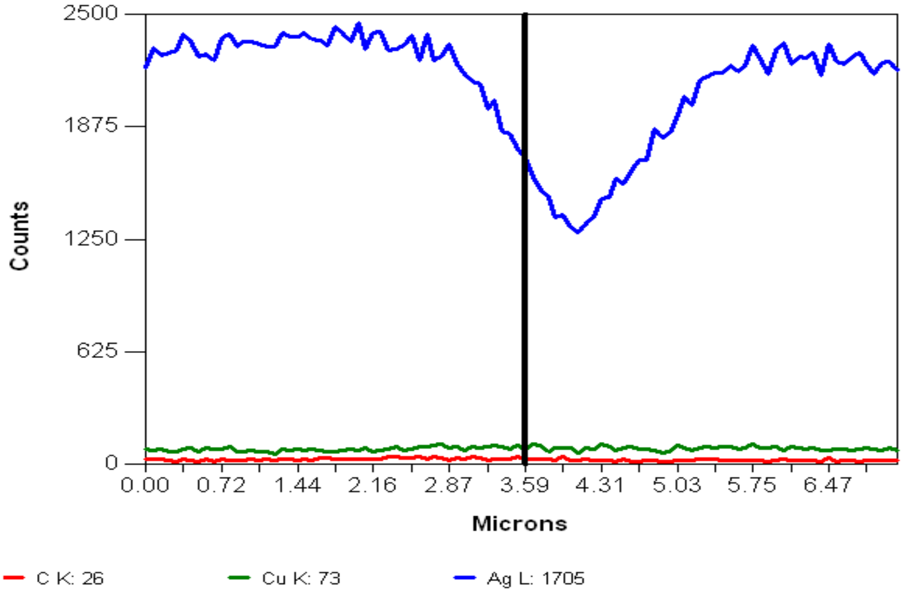
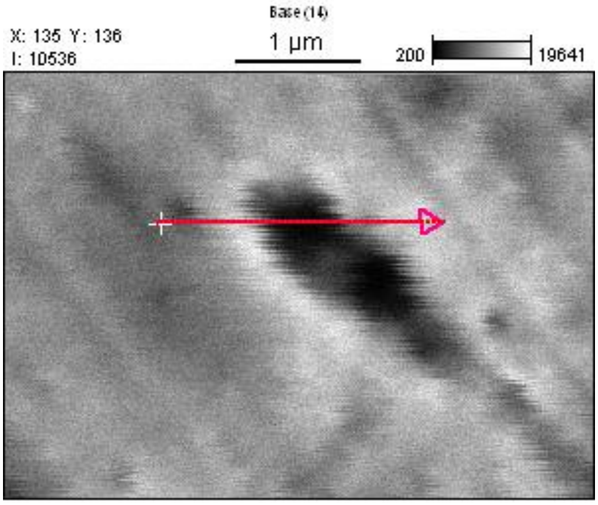
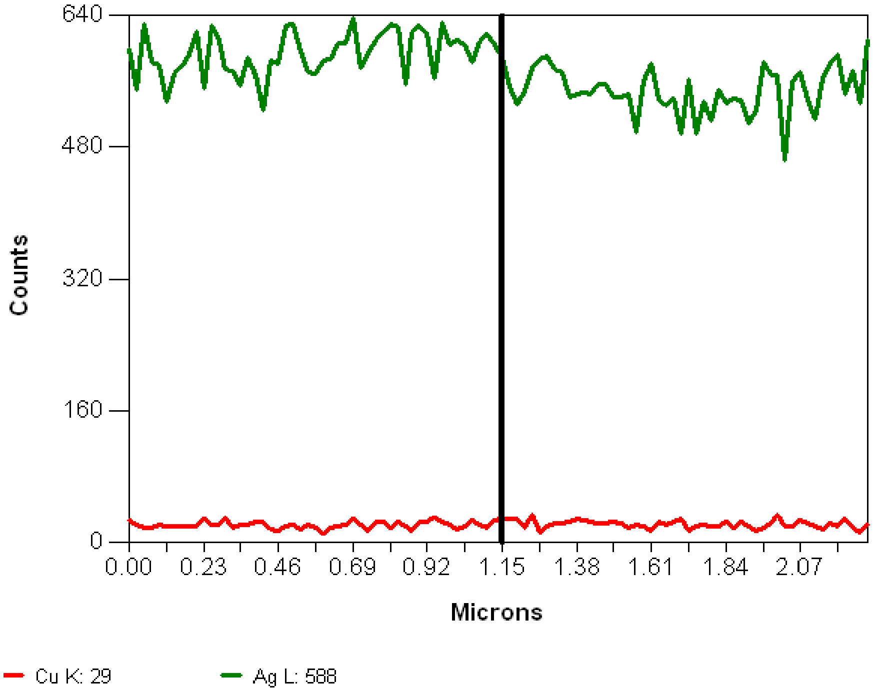


Figure 5.67: LSEM analysis of authentic silver coin of Hadrian (37-M131) including a black spot and matrix, RUN 1. a) SEM image and the line used for analysis, b) Variations of C, Cu and Ag concentrations along the selected line by EDX.



a) Acceleration Voltage: 20 kV



b)

Figure 5.68: LSEM analysis of authentic silver coin of Hadrian (37-M131) including a black spot and matrix, RUN 2. a) SEM image and the line used for analysis, b) Variations of Ag and Cu concentrations along the selected line by EDX.

5.4.2 Experiments on Fake Silver Coins

5.4.2.1 Fake Vespasian Silver Coin (U-5-3)

The SEM image of the selected fake Vespasian silver coin, U-5-3, is given in Figure 5.69. The black spot marked on the left hand side of the image was selected for EDX analysis; its spectrum is given on Figure 5.70. The beam was confined on the marked black spot that has a diameter below 1.0 micrometer. As it is evident from the EDX spectrum on Figure 5.70, Cu concentration is high, indicating that the spot may be a copper-rich phase. In addition carbon was not detected probably because no carbon based fuel such as wood or charcoal was used in the contemporary melting process. The EDX analysis gave 69.54% Ag and 30.46% Cu, showing that Cu is enriched on the spot selected. Authentic coins have Cu always below 5%.

LSEM analysis was carried out on the black spot selected as given in Figure 5.71. The drastic drop in Ag content is accompanied by an increase in Cu concentration on the spot. It is clear that the selected spot has a copper-rich phase, indicating that the alloy has been formed on a rather recent date; this evidence indicates that the sample handled is a fake coin.

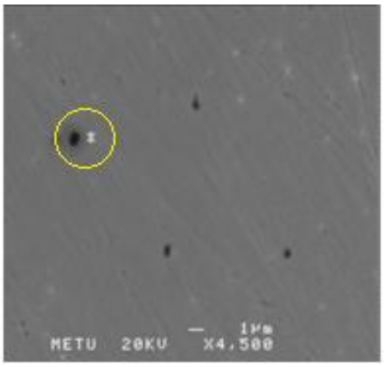


Figure 5.69: SEM image of copper rich phase of Fake Silver Vespasian coin (U-5-3).

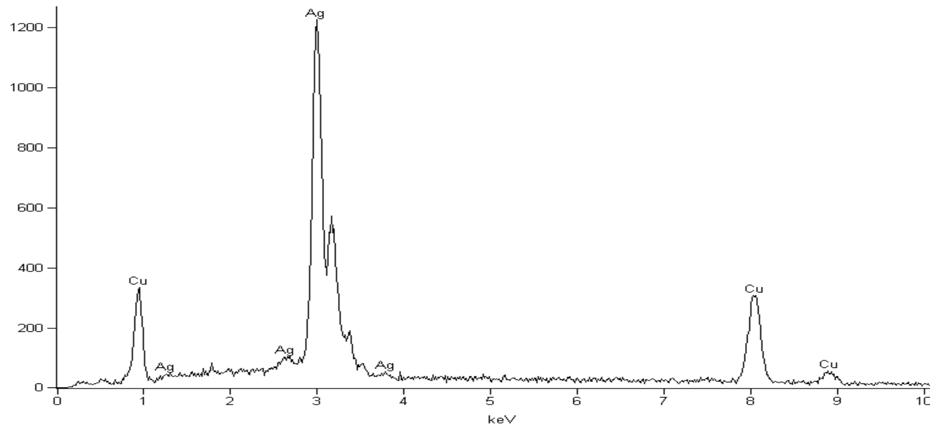
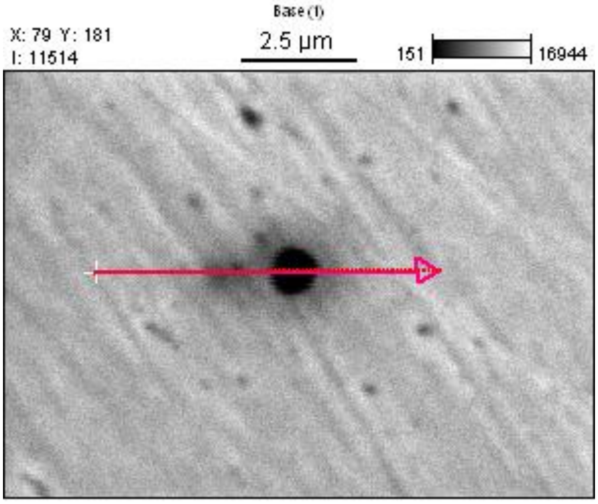
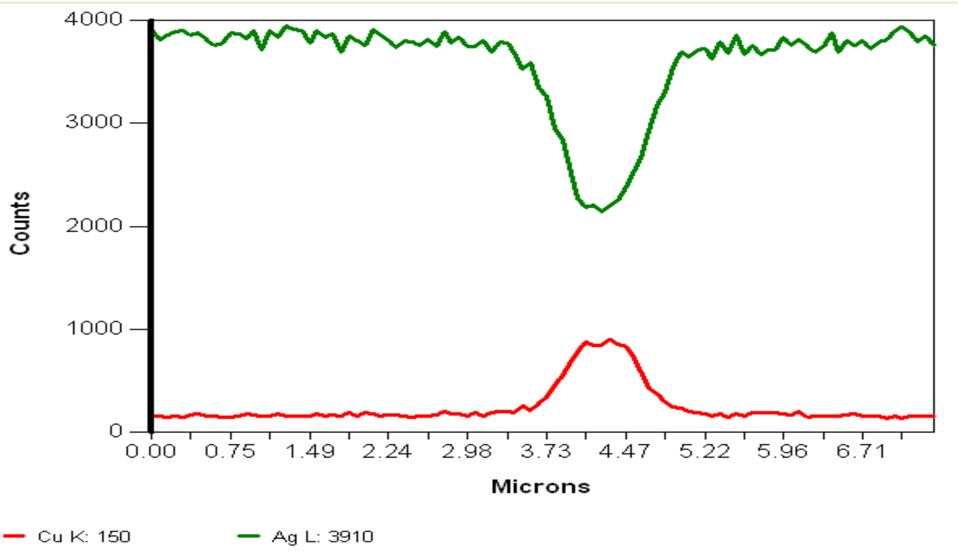


Figure 5.70: EDX spectrum of a black spot on fake Vespasian silver coin (U-5-3).



a) Acceleration Voltage: 20 kV



b)

Figure 5.71: LSEM analysis of fake silver coin of Vespasian (No. U-5-3) including a black spot and matrix. a) SEM image and the line used for analysis, b) Variations of Ag and Cu concentrations along the selected line by EDX.

5.4.2.2 Fake Hadrian Silver Coin (U-6-1)

Similar analyses were carried on a fake Hadrian silver coin selected (U-6-1); SEM images are shown in Figure 5.72. EDX spectra of the three black spots selected, namely I, II and II, are shown in Figure 5.73, Figure 5.74 and Figure 5.75, respectively. The Ag results from the black spots I, II and III were 66.38, 58.32 and 72.89%, respectively. The corresponding Cu concentrations for I, II and III were, 33.62, 41.68 and 27.11%, respectively. Relatively high Cu concentrations suggest that the selected black points contain a copper-rich phase. The EDX spectra taken on two points for gray looking matrix, namely RUN 1 and RUN 2 are shown in Figure 5.76 and Figure 5.87, respectively. The Cu results for RUN 1 and RUN 2 were 2.08 and 2.12%, while the Ag concentrations were 97.92 and 97.98%, respectively. It is evident that there is a significant concentration difference between the black points selected and the gray matrix, indicating that these locations have copper-rich phases.

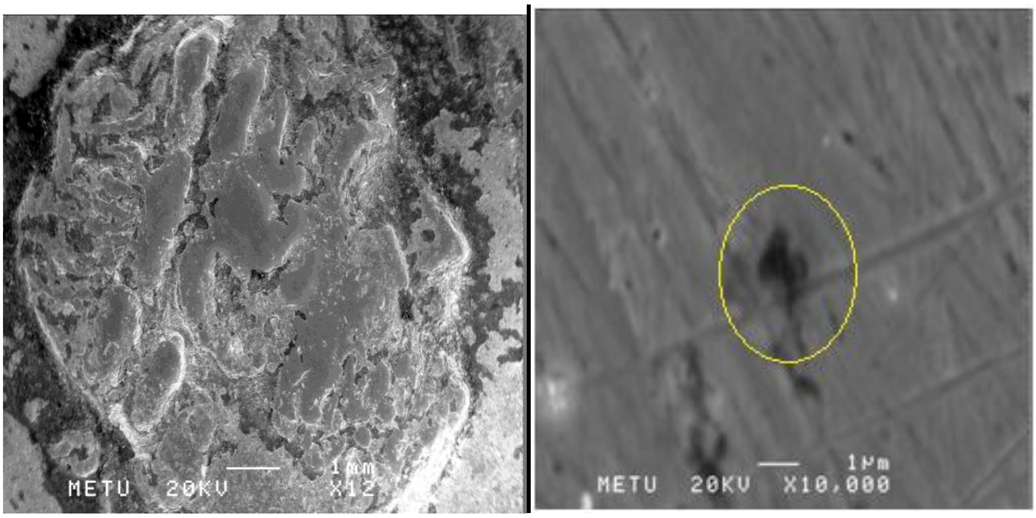


Figure 5.72: SEM images of fake Hadrian silver coin (U-6-17), a) Obverse side, b) Black spot selected. .

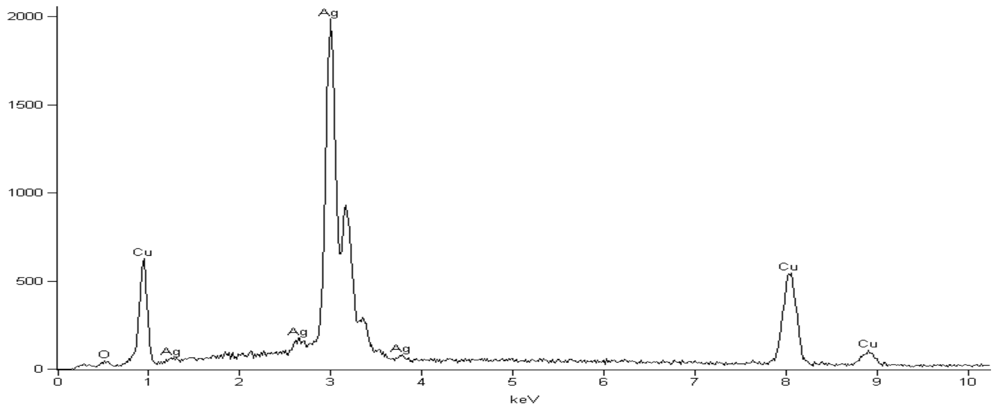


Figure 5.73: EDX spectrum of a black spot (I) on fake Hadrian silver coin (U-6-1).

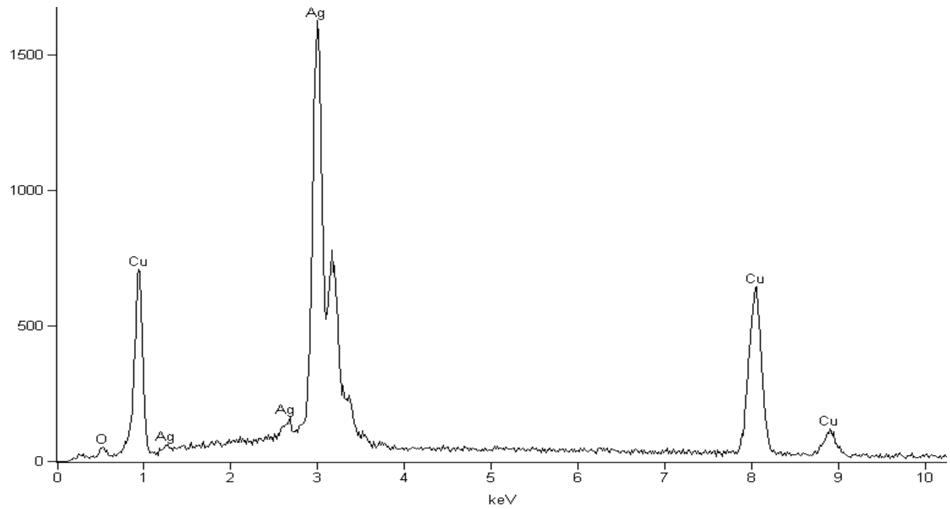


Figure 5.74: EDX spectrum of a black spot (II) on fake Hadrian silver coin (U-6-1).

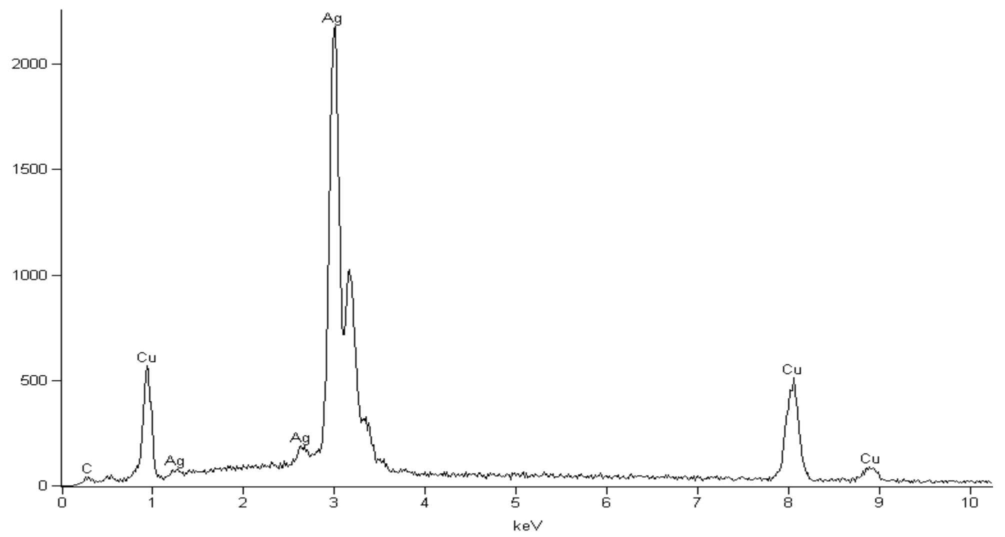


Figure 5.75: EDX spectrum of a black spot (III) on fake Hadrian silver coin (U-6-1).

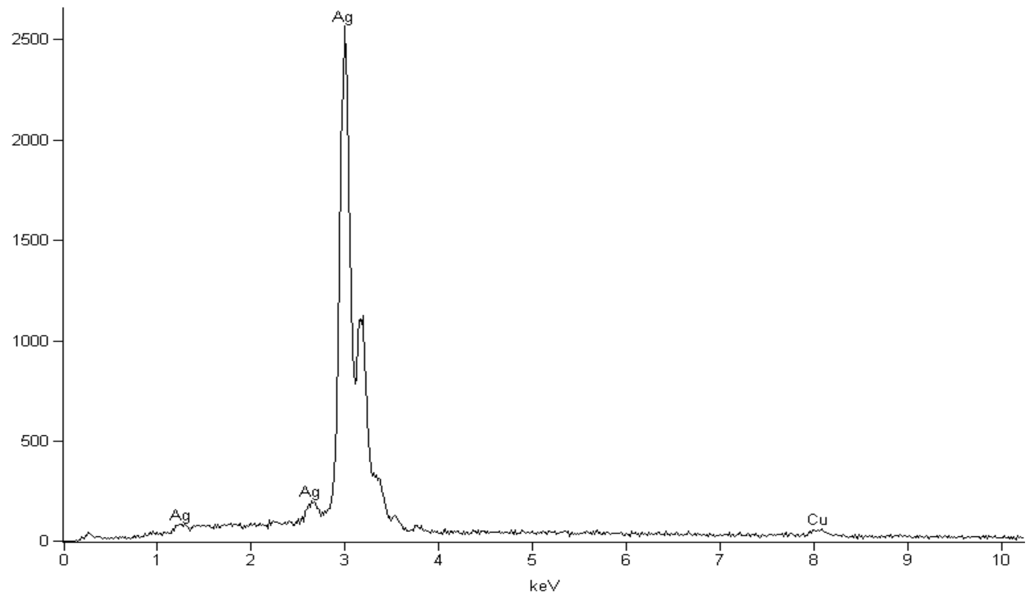


Figure 5.76: EDX spectrum from matrix of fake silver coin of Hadrian (U-6-1), RUN 1.

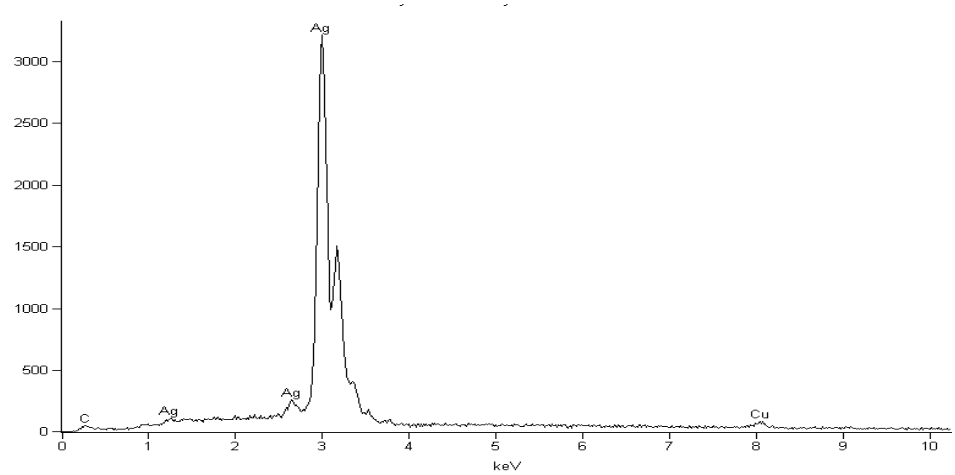
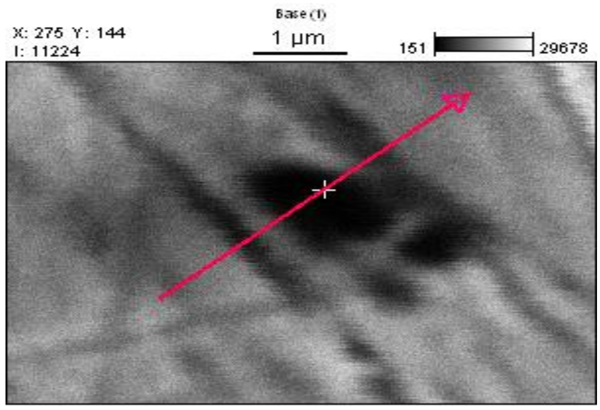


Figure 5.77: EDX spectrum from matrix of fake Hadrian silver coin (U-6-1), RUN 2.



Acceleration Voltage: 20 kV

a)

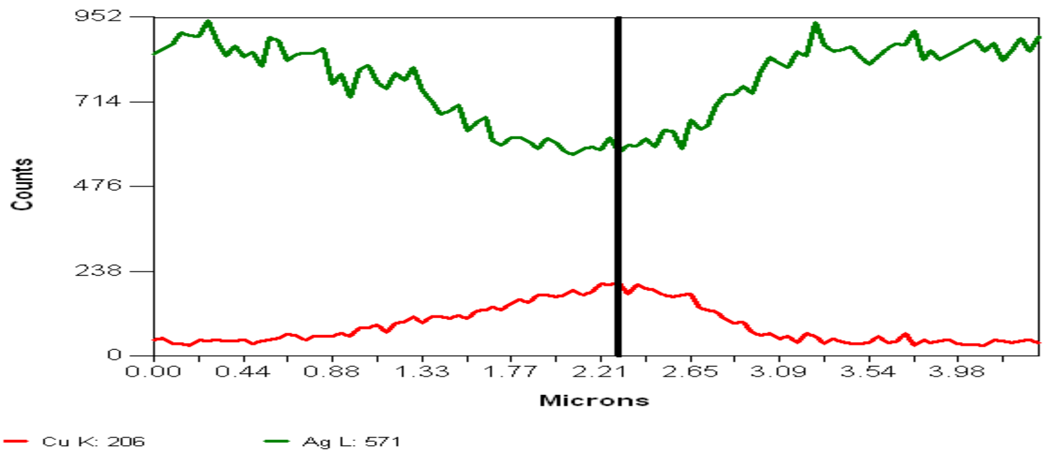


Figure 5.78: Analysis of fake silver coin of Hadrian (U-6-1) including the black spots and matrix. a) SEM image and the line used for analysis, b) Variations of Ag and Cu concentrations along the selected line by EDX.

5.4.2.3 Fake Athena Coins

In order to demonstrate the effectiveness of LSEM-EDX method, some Hellenistic silver coins were also used; these were two Athena coins, Ath Blg 1 and Ath Blg 2, known to be fake coins through previous experiences. The SEM image of the coin Ath Blg 1 is given in Figure 5.79 and the EDX spectra is shown in Figure 5.80. The EDX analysis gave the results of 63.65% Ag, 1.32% Fe, 6.13% Ni, 17.90% Cu, 2.55% Zn and 8.45% Sb. It is noteworthy that the Cu concentration is fairly high indicating a copper-rich phase and thus a fake coin. P-XRF analysis results of Ath Blg 2 were 91.77% Ag and 7.34% Cu.

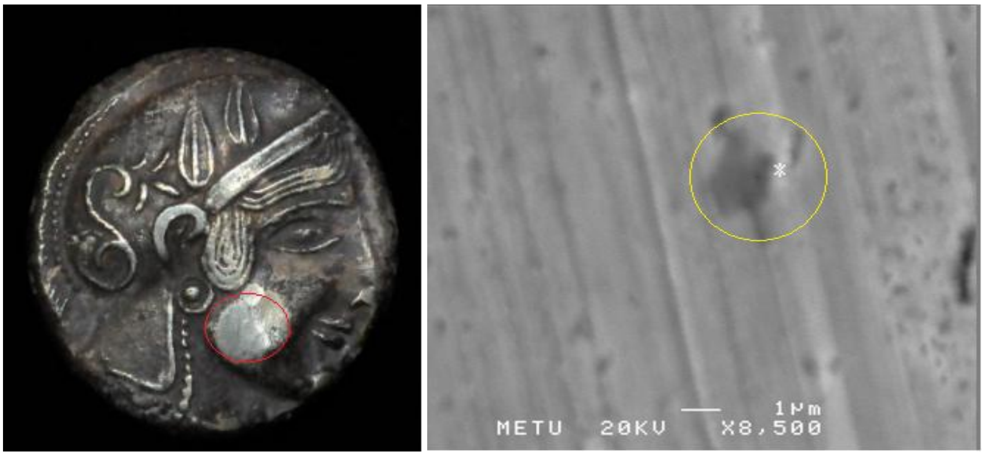


Figure 5.79: Obverse photo and SEM image of copper rich phase of fake silver coin of Athena

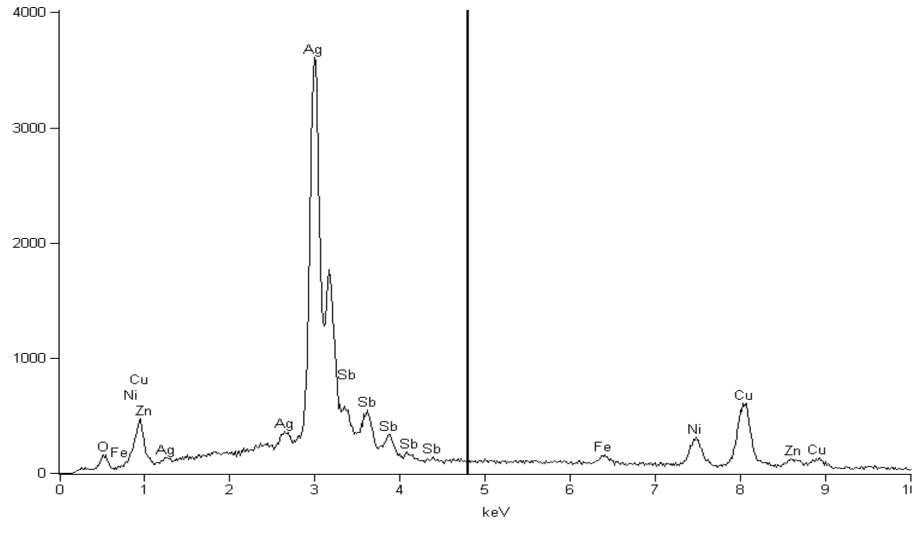


Figure 5.80: EDX analyze from copper rich phase of Fake Athena (Ath Blg 1) Silver coin.

Another Athena coin (Ath Blg 2) was also subjected to similar analysis procedure. EDX spectra for the two black spots selected, I and II, are shown in Figure 5.81 and Figure 5.82, respectively. The EDX analyses gave the results of 97.86% Ag, 2.14% Cu for the black spot I and 80.05% Ag, 19.95% Cu for the black spot II. It is likely that the black spot I is not a copper-rich phase while the black spot II is. This example demonstrates that even if the coin is a fake one, it may be difficult to spot a copper-rich phase in some cases. As many points as possible should be tested to show the coin is not authentic. P-XRF analysis results of Ath Blg 2 were 93.03% Ag and 5.30% Cu.

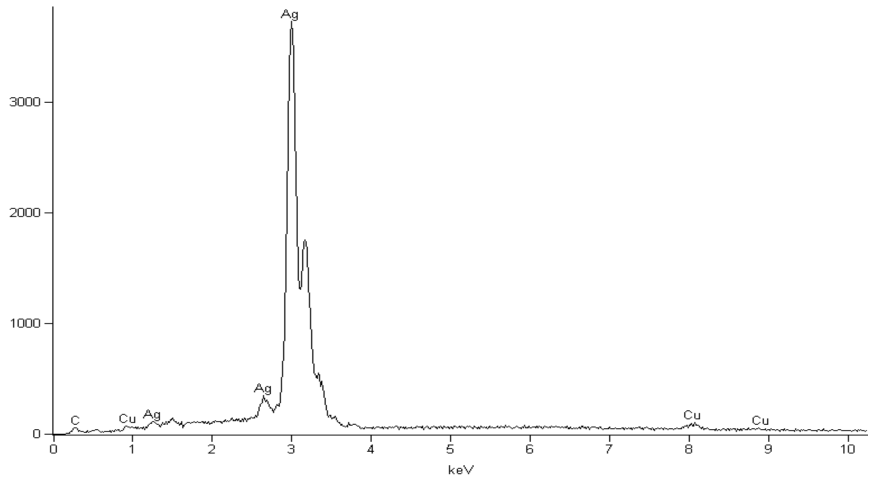


Figure 5.81: EDX spectrum of a black spot (I) on fake Athena silver coin II (Ath Blg 2).

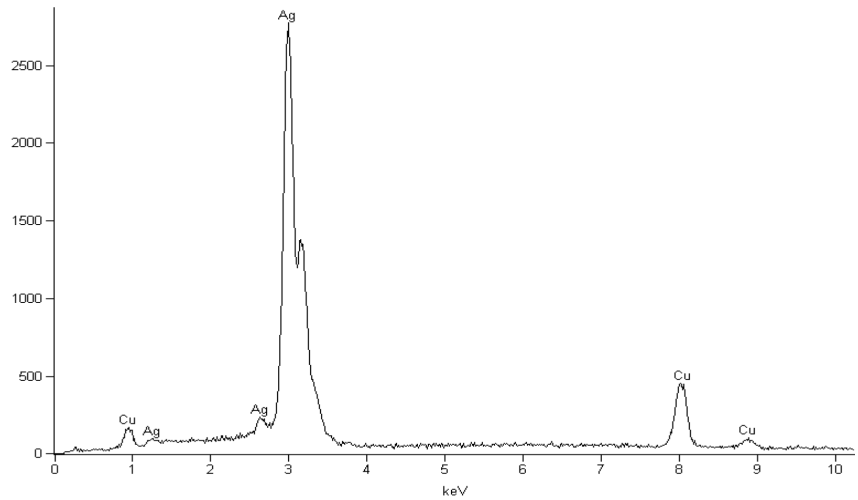
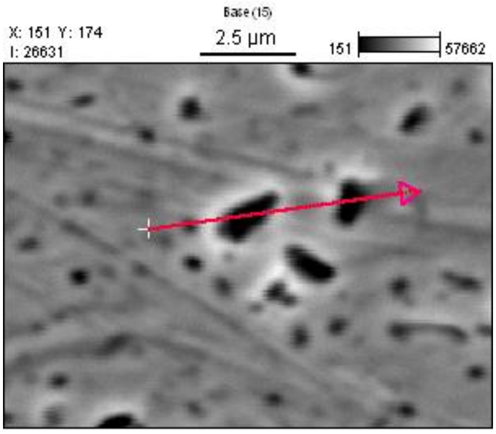
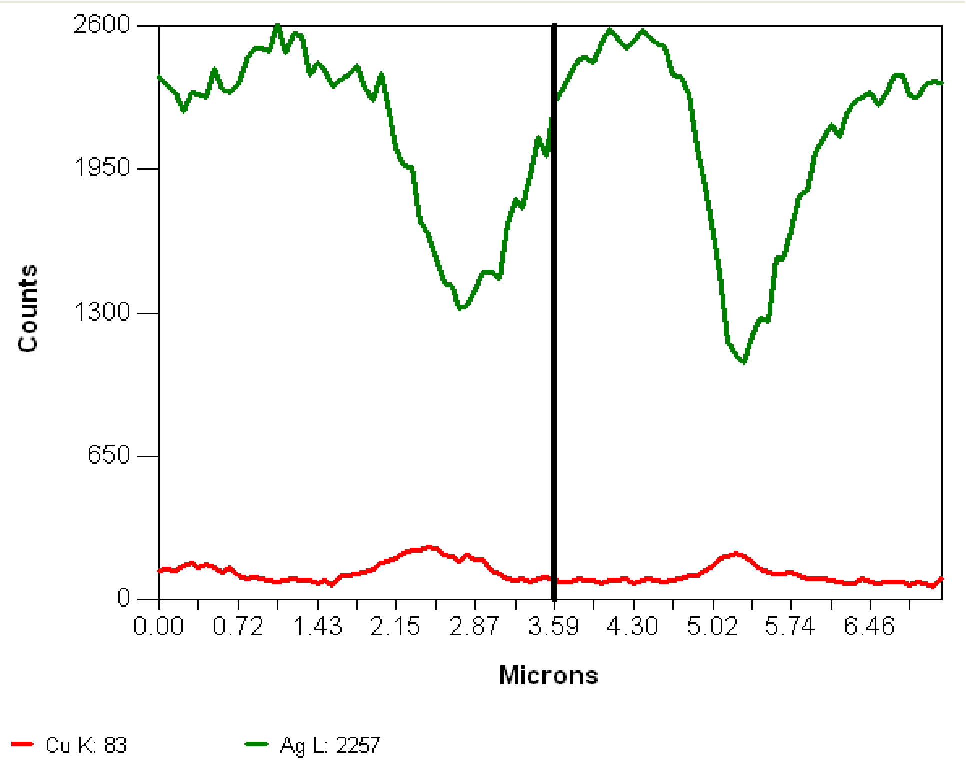


Figure 5.82: EDX spectrum of a black spot (II) on fake Athena silver coin II (Ath Blg 2).

LSEM analysis was carried out on the fake Athena silver coin (Ath Blg 2); the results are demonstrated in Figure 5.83. In this case, the selected line passes through two black spots and for the both of them there are significant variations in both Ag and Cu concentrations. This behavior is characteristic of fake coins as dicussed also in the preceding sections.



a) Acceleration Voltage: 20 kV



b)

Figure 5.83: LSEM analyze from matrix and copper rich phases of fake silver Athena coin (Ath Blg 2)

a) SEM image and the line used for analysis, b) Variations of Ag and Cu concentrations along the selected line by EDX.

LSEM analyzes obviously show how copper sharply increase and differ from the matrix in the new casted fake silver coin of Athena.

5. 4.2.4 Fake Vitellius and Pescennius Niger Silver Coins

In this section attempts by using LSEM-EDX were made on two fake silver coins, from the age of Vitellius (69 A.D.) and Pescennius Niger (193-194 A.D.) . In the first trial, EDX spectrum of a black spot selected on the Vitellius fake coin (U-4-14) was obtained, as shown in Figure 5.84. In this spectrum, the Ag sinal is large and apparent but the Cu is barely detectable. The results were 97.98% Ag and 2.02% Cu. The selected spot, therefore, does not represent a copper-rich phase although the coin is known to be a fake one. The situation was similar with the fake Pescennius silver coin (U-8-26); its EDX spectrum is given on Figure 5.85; the copper signal is not detectable at all.

These experiments, in addition to many other attempts made but not given here, demonstrate that finding copper-rich phases may not be easily found. Using LSEM-EDX, many analyses should be done to find copper-rich phases on silver coins. The black spots observed and located in SEM images may be corrosion pits, contaminations, sand particles etc. and they are not necessarily corresponding to copper-rich phases. However, in the case of fake coins it is usually possible to find black spots of copper-rich phase, if the search is carried out with suffient patience and care. Obviously, if the coin is a fake one, these points are not likely to be found. Analysis results have shown that the values of the Cu from matrix in the fake and authentic silver coins are very similar and 4% at maximum. On the other hand, copper-rich phases of fake silver coins can vary from 18 to 42% Cu in fake coins.

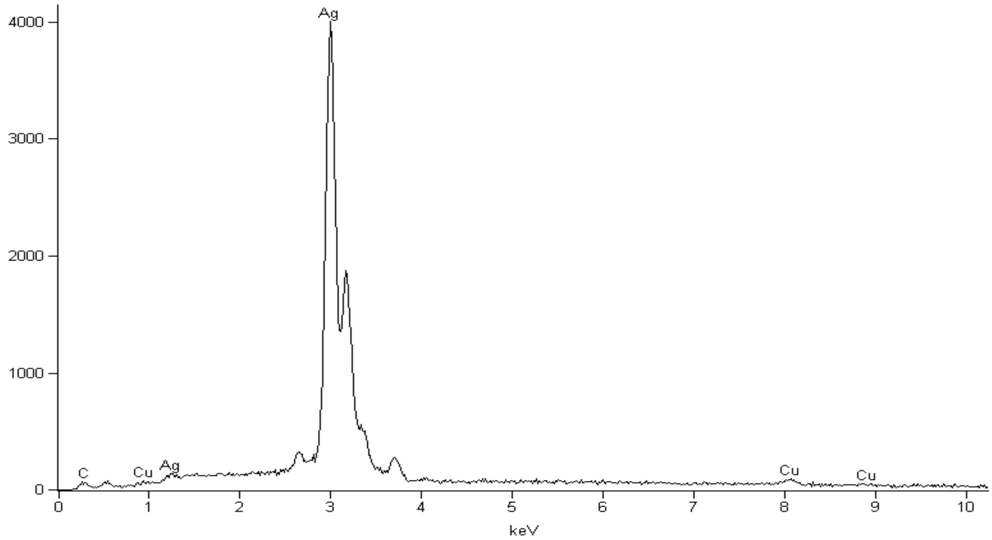


Figure 5.84: EDX spectrum of the fake coin of Vitellius (U-4-14).

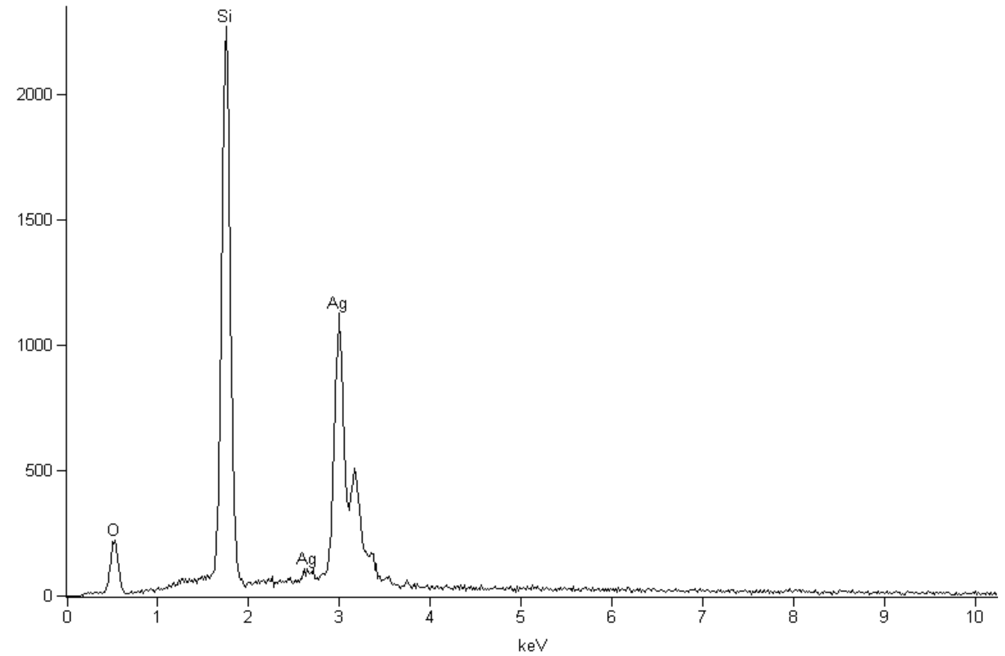


Figure 5.85: EDX spectrum of a black spot (I) on fake Pescennius Niger silver coin (U-8-26).

5.5 Accuracy of P-XRF Results

5.5.1 T Test of Certified Reference Materials (CRM)

In this study, t-test was used to determine the significance of the difference between the measured and certified values using Certified Reference Material BCR 691 (A and E) and Good Fellow pure Ag. P-XRF analyses results from CRM's; P-XRF was used for analysis. For the values assigned ND, not detected, limit of detection was used which is 0. 0010%.

X: Mean of P-XRF results
μ: CRM value
t: t value from t table (N-1 degrees of freedom with 0.05 level of significance)
s: Standard deviation of P-XRF results
N: Number of replicate analyses
If $X - \mu < \frac{t.s}{\sqrt{N}}$ it means the certified value and P-XRF results are same at 95% confidence level.

t-test for Zn, Sn, Pb and Ag Results

Table 5.37: Certified values for Zn and Sn in BCR 691 A Quaternary Bronze

CRM, European Commission Joint Research center Certified Reference Material BCR 691 A Quaternary Bronze				
	Certified Value		**Uncertainty**	
	(g/kg)	**%**	**(g/kg)**	**%**
Sn	71.6	7.16	2.1	0.21
Zn	60.2	6.02	2.2	0.22

Table 5.38: P-XRF results for Zn and Sn in BCR 691 A Quaternary Bronze

P-XRF Results for Zn and Sn in CRM BCR 691 A Quaternary Bronze, %				
The time of analyses and the direction	**Zn**	**Zn +/-**	**Sn**	**Sn +/-**
RefA12h 30 second	6.0111	0.0239	6.7829	0.0418
RefA13h 30 second	5.9421	0.0239	6.6115	0.0415
RefA14h 30 second	5.9509	0.0237	6.6608	0.0414
RefA15h 30 second	6.0095	0.0240	6.5915	0.0415
RefA16h 30 second	5.981	0.0240	6.6722	0.0418
RefA17h 30 second	5.922	0.0237	6.5818	0.0411
RefA18h 30 second	5.95	0.0238	6.5988	0.0412
RefA19h 30 second	6.0521	0.0243	6.5667	0.0418
RefA12h 60 second	6.0509	0.0170	6.5874	0.0293
RefA13h 60 second	5.9619	0.0169	6.5942	0.0292
RefA14h 60 second	5.9526	0.0197	6.5842	0.0343
RefA15h 60 second	6.005	0.0172	6.575	0.0297
RefA16h 60 second	5.9896	0.0172	6.5909	0.0296
RefA17h 60 second	5.9869	0.0171	6.5600	0.0295
RefA18h 60 second	5.9414	0.0169	6.6315	0.0294
RefA19h 60 second	6.0356	0.0170	6.5539	0.0293
RefA12h 30 second	6.0975	0.0242	6.6234	0.0415
RefA12h 60 second	6.0628	0.0173	6.5510	0.0296
RefA12h 120 second	6.0548	0.0121	6.5400	0.0208
RefA12h 180 second	6.0964	0.0100	6.5927	0.0172
X (Mean of P-XRF Results)	**6.0020**		**6.6020**	
s (Stand. Deviation of P-XRF Results)	**0.05357**		**0.054459**	
µ (Certified Value of CRM)	**6.02**		**7.16**	

Table 5.39: P-XRF results and certified value for Pb in BCR 691 E Quaternary Bronze

European Commission Joint Research center Certified Reference Material BCR 691 E Quaternary Bronze		
	Pb %	**Uncertainty %**
Certified Values of CRM	0.204	0.018
Trial Number of PXRF Analyses	**P-XRF Results of Pb CRM**	**Uncertainty of P-XRF**
1st	0.32	0.01
2nd	0.31	0.01
3rd	0.31	0.01
X (Mean of P-XRF Results)	**0.31**	
s (Stand. Deviation of P-XRF Results)	**0.006**	
µ (Certified Value of CRM)	**0.204**	

Table 5.40: P-XRF results and certified value in Good Fellow Metals Ag standard

CRM GOOD FELLOW METALS LTD England		
	Ag %	**Thickness (mm)**
Certified Values of CRM	99.97	0.025
Trial Number of PXRF Analyses	**P-XRF Results of Pb CRM**	**Uncertainty of P-XRF**
1st	99.45	0.12
2nd	99.98	0.12
3rd	99.98	0.12
4th	99.97	0.12
X (Mean of P-XRF Results)	99.84	
s (Stand. Deviation of P-XRF Results)	0.263	
µ (Certified Value of CRM)	99.97	

Table 5.41: t test results for Zn, Sn, Pb and Ag

t test results of Zn, Sn, Pb, Ag			
Element	$\frac{t.s}{\sqrt{N}}$	$\lvert X-\mu \rvert$	**95% Confidence interval**
Zn	0.024	0.0173	X and µ values of Zn are same at 95% CL
Sn	0.025	0.56	X and µ values of Sn are not same at 95% CL
Pb	0.012	0.304	X and µ values of Pb are not same at 95% CL
Ag	0.483	0.13	X and µ of Ag are same at 95% CL

As a result, P-XRF results and given CRM values were found to be same in terms of Ag and Zn at 95% confidence level (Table 5.41).

However, P-XRF values of Sn and Pb measured and CRM values, although close to each other, are not same, in other words there is a significant difference between them according to t-test. The reason of this should be the presence of As in CRM; since CRMs include As which was not among the assigned elements analyzed by P-XRF used, this value was added to Pb, causing a higher result..

5.6 Correlation Matrix

Correlation matrix was used to determine negative and positive correlations between the two variables. Correlation coefficient shows the degree of linear association between the two variables. When the correlation coefficient is +1, this means that there is a perfect positive correlation. A correlation number of -1 shows a perfect negative correlation. Correlation coefficient close to 0 indicates no linear association. In order to understand relationship between the elements, correlation matrix was prepared by using SPSS 16.0 software package.

In this study, the most related elements were determined using *Pearson's correlation coefficient*. Pearson's correlation coefficient whose absolute value was equal to or higher than +0.500 was evaluated as the presence of a strong correlation.

Pearson's correlation coefficient is described below.

Pearson correlation

N= Number of pair scores

$\sum xy$=Sum of the product of paired scores

$\sum x$=Sum of x scores

$\sum y$=Sum of y score

$\sum x^2$= Sum of squared x scores

$\sum y^2$=Sum of squared y scores

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

The results are given in Table 5.42. There are strong positive correlations between Cu-Zn, Cu-Mo and negative correlations between Cu-Ag, Mo-Ag and Zn-Ag in most of the groups (Table 5.42). These correlations can be explained by the ancient ore metallurgical processes and Roman Empire's economic changes. In case of economic problems, the Roman authorities decreased the silver percentage of the coins and compensated it with copper. These copper ores contain impurities such as Zn, Sb, and Mo. Therefore when Ag content was decreased, Cu content was increased, explaining the strong negative correlation for Cu-Ag. Depending on this correlation, Zn and Mo contents, as impurities, increased with Cu content which resulted in positive correlations for Cu-Zn, Cu-Mo and negative correlations for Mo-Ag and Zn-Ag (Craddock and Lang 2002).

These results cannot be used directly in authenticity studies because in recently used modern copper sources have also similar impurities as the ancient copper. Moreover, modern forgers also added Cu in the composition to mimic the Cu present in ancient coins.

Table 5.42: Correlation matrix of analysis.

	Correlations																			
Data	Fe-Zr	Fe-Pb	Cu-Mo	Cu-Zn	Cu-Ag	Cu-Pb	Mo-Ag	Mo-Sn	Ag-Sn	Ag-Pb	Ag-Bi	Sn-Pt	Sn-Pb	Sn-Zn	Sn-Bi	Zn-Ag	Zn-Bi	Zn-Mo	Zn-Pb	Sb-b
448 analyses results of P-XRF including fake coins	,675**	-,098*	,561**	179**	-,918**	,108*	-,519**	-,008	- ,422**	- ,487**	-,052	,592**	,949**	,008	-,038	-,175**	,003	,077	-,003	NA
408 analyses results of P-XRF only authentic coins results	-,027	-,048	,564**	,167**	-,913**	087	-,520**	-,011	-,420	- ,478**	018	,590**	,949**	,004	-,061	-,163**	-,021	,073	-,011	NA
Vespasian (25 analyses)	NA	NA	NA	NA	-,984**	-,183	NA	NA	NA	,096	,099	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trajan (28 analyses)	NA	NA	-,656**	,946**	-,999**	-,188	,660**	-,521*	- ,792**	,171	,574**	NA	-,152	803**	-,506**	-,948**	- ,509**	-,666**	-,228	NA
Marcus Aurelius (24 Analyses)	NA	-,081	,461*	,839**	-,999**	-,439	-,461*	-,155	,053	417*	,160	,296	,038	,100	-,263	-,840	-,164	,539**	-,477*	NA
Caracalla (37 Analyses)	NA	,185	NA	499**	-,990**	-,056	NA	NA	-,114	-,044	,068	-,165	,351*	,316	-,075	-,551**	,139	NA	,355*	-,012
Geta (29 Analyses)	NA	-,138	NA	765**	-,994*	,223	NA	NA	-,128	-,254	,251	,222	-,059	,102	,136	-,780**	-,153	NA	,410*	NA
Gordian III (21 analyses)	NA	-,514	,765**	,897**	-,994**	,000	-,770**	,260	-,304	-,101	,153	,062	,642**	,319	,483*	-,899**	-,274	,762**	-,003	868**
Augustus (77 Analyses)	-,101	-,238*	NA	NA	-,775**	,380**	NA	NA	-,042	- ,350**	,161	-,002	,048	NA	-,168	NA	NA	NA	NA	NA

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

*. Correlation is significant at the 0.05 level (2-tailed).
NA: Not Applicable, if one or the both elements are not detected.

5.7 Cluster Analysis and Dendrograms

We use cluster analysis to determine the elements that can successfully differentiate authentic and fake coins. We expect only Pb and Bi the most meaningful in terms of authenticity, to statistically differentiate between authentic and fake ones. We also want to explore whether other less significant elements (Cu, Zr, Ag, Sn, Pt) improve differentiation between authentic and fake coins when used along with Pb and Bi Therefore, in the following analyses, we used both (Pb,Bi) pair and (Pb,Bi,Cu,Zr,Ag,Sn,Pt). Hierarchical cluster algorithm is used. The results of the analysis are given as dendrograms. In clustering analyses not only both side analyses results used but also only one side analyses results were used to see if clustering of fake and authentic coins results will differ or not. In other words, it was tested whether there is a clear effect of using both or one side in analyses on clustering analyses of fake and authentic coins.

Using of Cluster analyses, Dendrogram, in determination authenticity of coins let us to cluster fake coins in one group. It is important to select correct methodology and correct elements which are meaningful in the clustering of fake and authentic coins.

Steps which were followed in order to build a dendrogram in SPSS 16.0 are given below.

1. Define Variables in the Variable view page (Type- numeric, width -8, Decimal -3 and Measurement selected -Scale)
2. Enter data in the *Data* view page,
3. Click *Analyze* from tool bar
4. From analyze click *Classify*

From opened window select *Hierarchical Cluster*

From opened screen move your variable to right

Later click on *Plot* and select dendrogram and click to continue,

from the same window, click to Methods. *Square Euclidian Distance* was the most suitable distance for our data to cluster; as the cluster method *Between-group Linkage* was selected after a few trials to find the best choice.

Click to *Continue* to close method window.

$$d^2(p,q) = (p_1 - q_1)^2 + (p_2 - q_2)^2 + \dots + (p_i - q_i)^2 + \dots + (p_n - q_n)^2.$$

Reader should refer to Deza and Deza (2009) for further details on Squared Euclidian Distance.

Finally click *OK*, the programme will create the dendrogram; a sample is given in Figure 5.86. In all the dendograms given in this section, the y-axis represents the Squared Euclidian Distance.

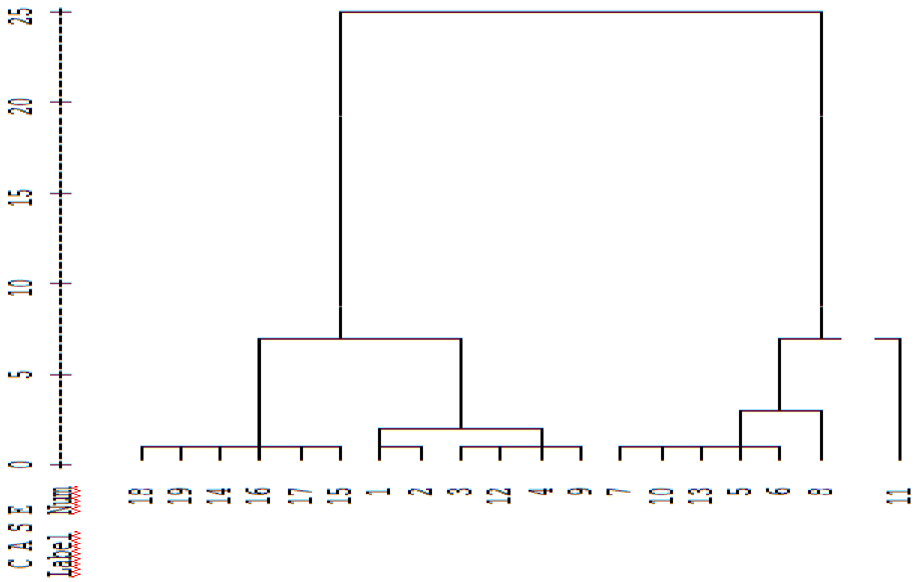


Figure 5.86: An example of dendrogram for Hadrian fake (14-19) and authentic silver coins (1-13). The selected elements are Cu Zr Ag Sn Bi Pb Pt.

If we cut the dendrogram in Figure 5.86 horizontally from the height of 1.5 we will have six different groups (Figure 5.87). Five of these groups correspond to authentic coins, one group including the numbers 14, 15, 16, 17, 18 and 19 represents the group of fake coins. Separation has been successful.

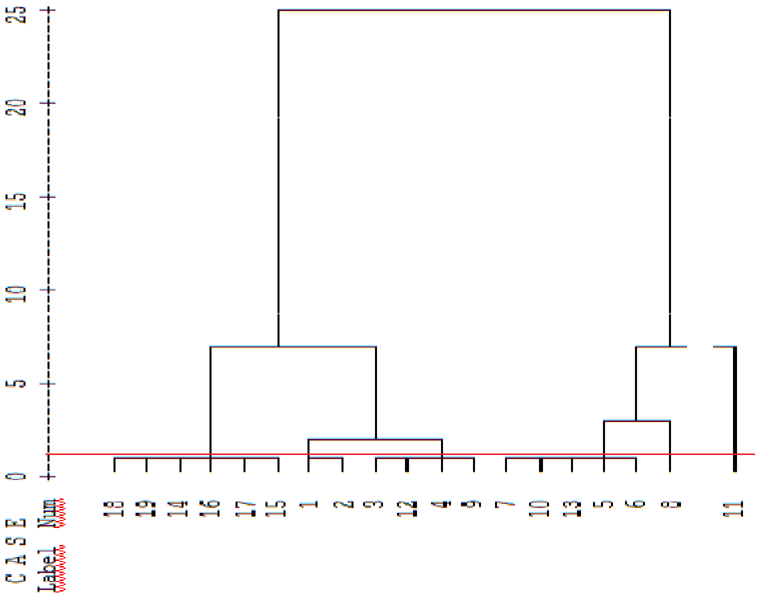


Figure 5.87: The dendrogram in Figure 5.86 cut from 1.5 forming 6 different groups. The selected elements are Cu, Zr, Ag, Pt, Pb, Bi.

Vespasian Silver Coins

The relations between the numbers used in dendograms and the inventory numbers of the coins are given in Table 5.43.

In this work, the analytical data obtained by only a single face of coins were used; the results were selected from the analyses of both sides, the higher result was selected in each case. Dendogram numbers 16-17 correspond to the fake coins. The fake coins could not be clustered in a separate group successfully by taking Cu, Zr, Ag, Pt, Pb, Bi elements in consideration, as shown in Figure 5.88.

Square Euclidian Distance was selected as distance and *Between-group Linkage* was selected as method.

Table 5.43: The list of numbers used in dendrogram

Dend. No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Inv . No	98-M189	63-M154	49-M139	3-M96	1223-28	1202-7/1	1202-7/2	1189-11	111-825-1	518-7	9-1529-4	9-1529-4/1	11-1869-52/47	11-1869-52/58	12-1873-476/41	U-5-2	U-5-3	5-1499-218

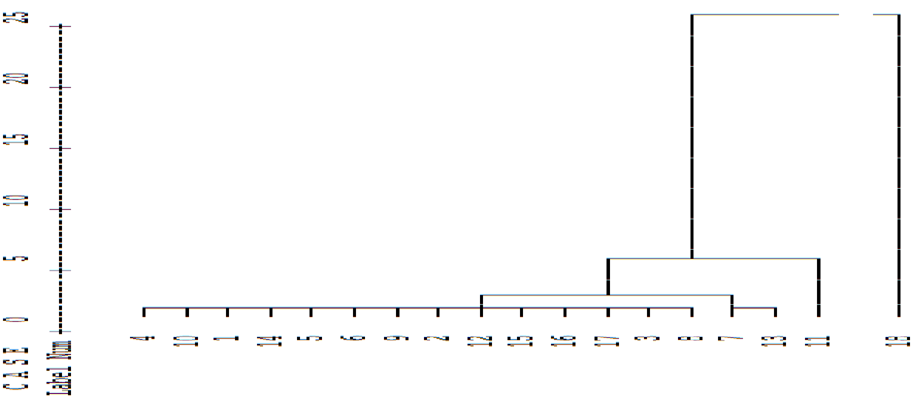


Figure 5.88: Dendrogram for P-XRF results of Vespasian silver coins. The selected elements are Cu, Zr, Ag, Pt, Pb, Bi; numbers 16-17 are fake coins.

However by keeping methodology same but only taking Bi and Pb elements in consideration, fakes (No 16-17) were clustered successfully in one group. It was understood that **Bi and Pb** are good indicators of authenticity for this case (Figure 5.89).

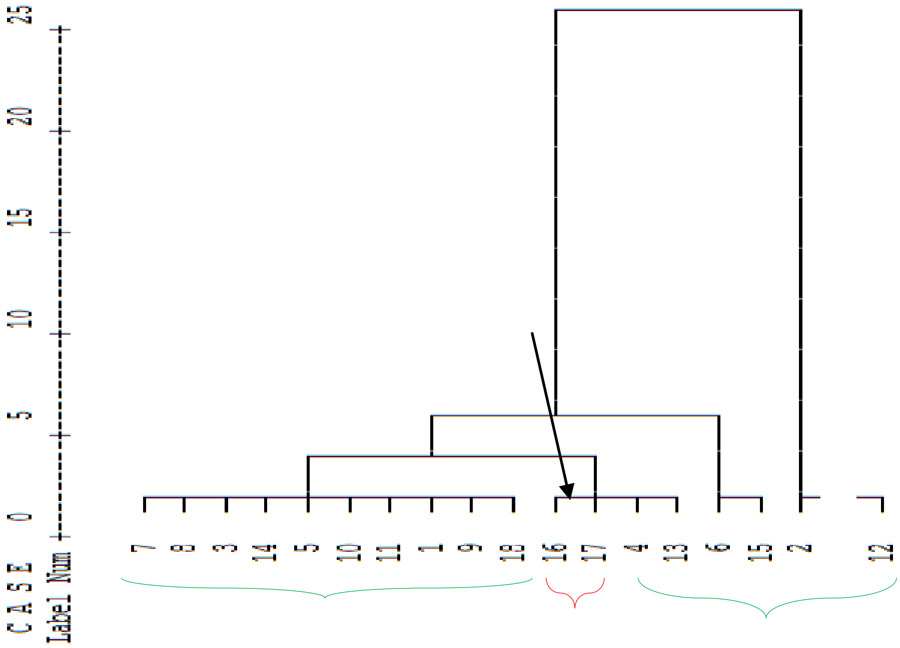


Figure 5.89: Dendrogram for P-XRF results of Vespasian silver coins. The selected elements are Pb, Bi; numbers 16-17 are measurements for the fake coin U-5-2, both sides.

Hadrian Silver Coins

The relations between the numbers used in dendograms and the inventory numbers of the coins are given in Table 5.44.

The data used for clustering include results from the analyses of both faces of coins. Numbers from 14 to 19 correspond to fake coins. Fake coins could not be clustered in a separate group successfully with the method used (*Euclidian Distance*) when elements of Cu, Zr, Ag, Sn, Bi, Pb, Pt) taken in consideration.

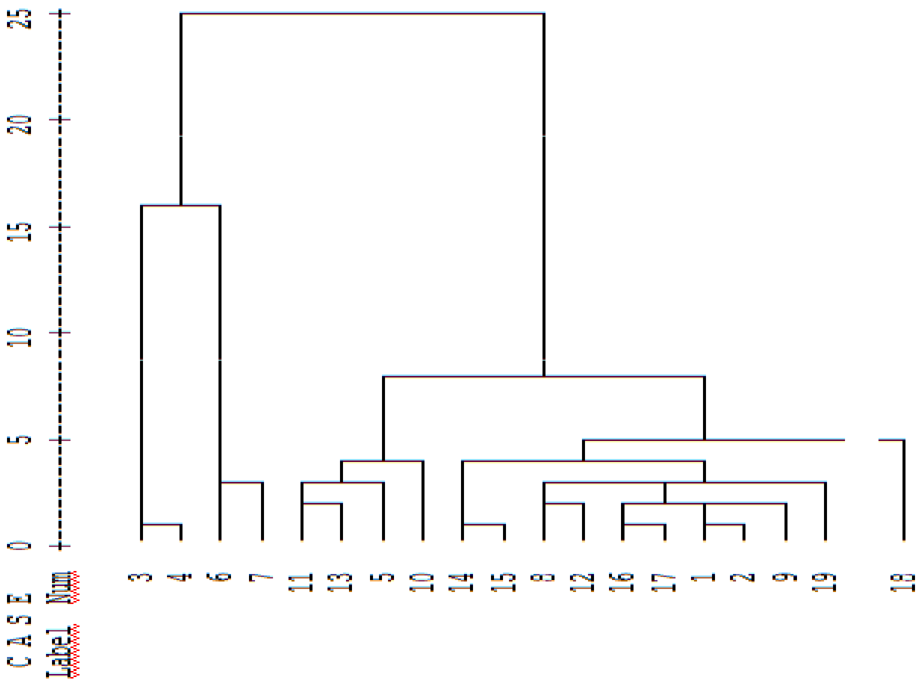


Figure 5.90: Dendrogram for P-XRF results of Hadrian silver coins. The selected elements are Cu, Zr, Ag, Sn, Pb, Bi; numbers 14-19 are fake coins.

Table 5.44: The list of numbers used in dendrogram.

Dend. No	1 & 2	3 & 4	5	6 & 7	8	9	10	11	12	13	14	15	16	17	18	19
Inv. No	100-M189	99-M189	83-M179	82-M177	70-M162	21-M120	37-M-131	20-M118	19-M118	14-M113	U-6-17	U-6-18	U-6-19	U-6-20	U-6-21	U-6-1

Because of fakes could not be clustered in a separate group in previous clustering study of Hadrian coins (Figure 5.90) by taking Cu, Zr, Ag, Sn, Bi, Pb and Pt results in consideration.

In the next clustering study example only Pb and Bi elements for Hadrian results are taken in consideration. The clustering interval was selected as *Square Euclidian Distance* and method selected was *Between-group Linkage* and as a result, fake coins (number 14, 15, 16, 17, 18) of Hadrian were clustered in one group successfully (Figure 5.91).

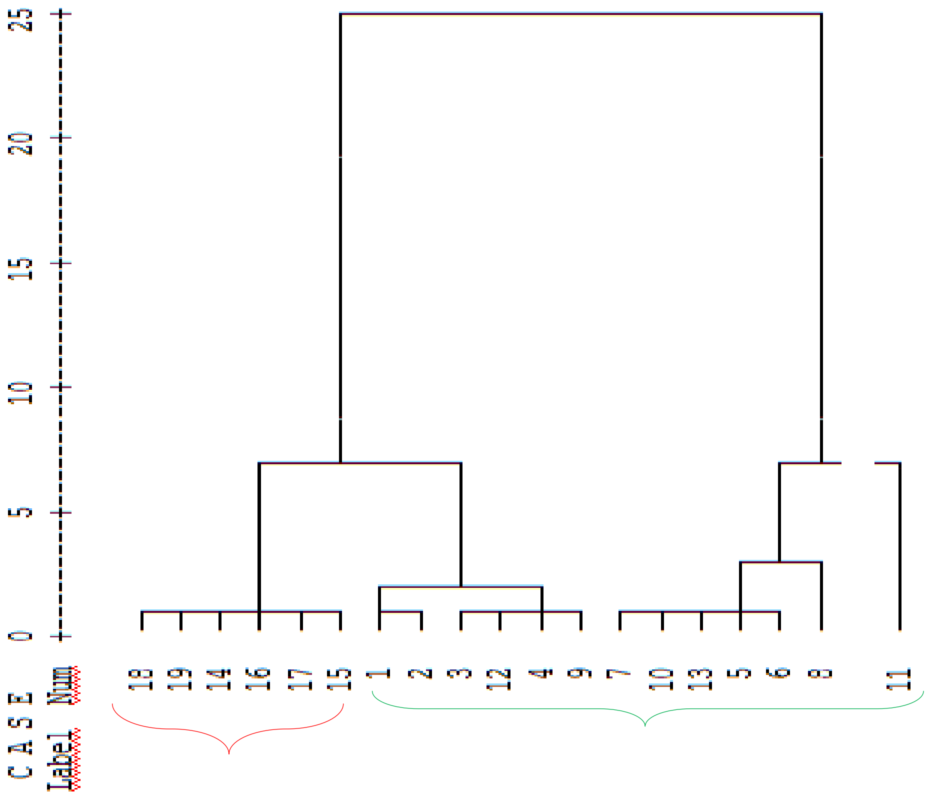


Figure 5.91: Dendrogram for P-XRF results of Hadrian silver coins. The selected elements are Pb, Bi; numbers 14-19 are fake coins.

Trajan Silver Coins

The list showing the numbers used in dendograms and the inventory numbers of the coins is given in Table 5.45.

Analyses taken in consideration in this cluster include not only obverse analyses results but also both sides of 9 coins. 27 results obtained on silver coins of Trajan and of whom both analyses made from one coin were suspicious (number 1 and 2) and could not be decided if they were fake or not (in the chapter five Trajan part) clustered in one group the other all coins clustered in another group big probably because of it is fake coin (Figure 5.92).

Square Euclidian Distance was selected as distance and *Between-group Linkage* was selected as method.

Table 5.45: The list of numbers used in dendrogram.

Dend . No	1 & 2	3	4	5	6	7 & 8	9 & 10	11 & 12	13 & 14	15 & 16	17 & 18	19	20	21	22 & 23	24 & 25	26	27
Inv No	1962-11-1571-16[illegible]	97-M190	58b-M148	48-M139	38-M132	609-1	576-1	1223-28	1188-11	1961 IX -1529-4	V-1499-218	1964 VII-1636-[illegible]	1962 12-1578-1	104-M180	1956 11-1405-9	1127-3	1947 XII-1212-17	9-1556-2-11

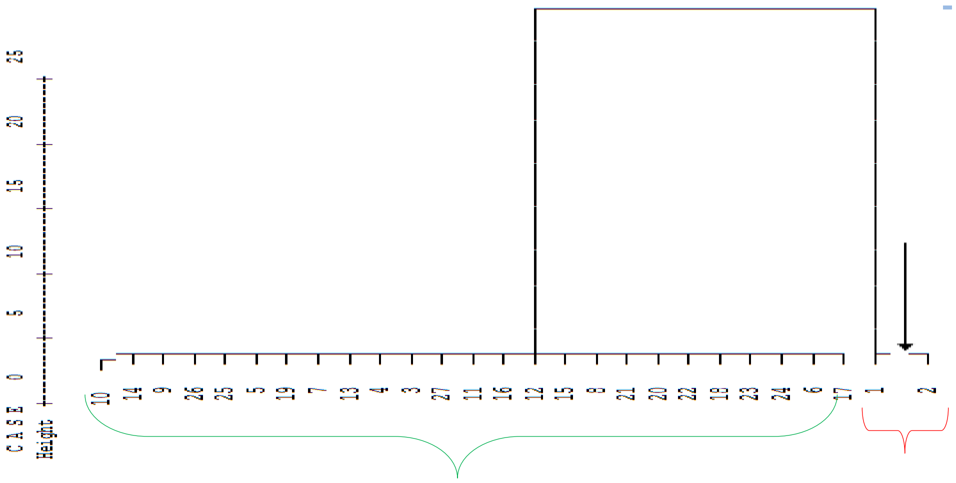


Figure 5.92: Dendrogram for P-XRF results of Trajan silver coins. The selected elements are Cu, Zn, Ag, Pt, Pb, Bi; numbers 1 and 2 are measurements on both sides of the fake coin 1962-11-1571-16/4.

Same clustering study above was repeated by taking only Pb and Bi elements in consideration. From these elements the fake coin 1962-11-1571-16/4 (No 1-2) could not be clustered as a separate group but they were in one group with some other authentic coins (Figure 5.93).

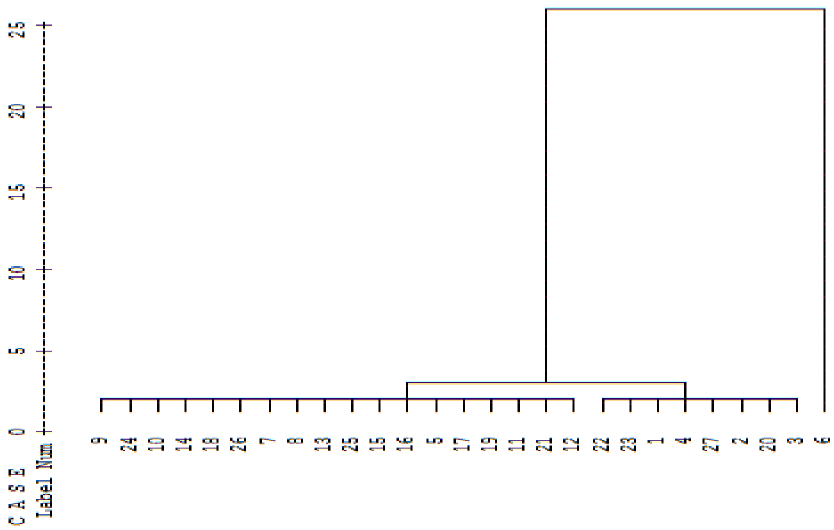


Figure 5.93: Dendrogram for P-XRF results of Trajan silver coins. The selected elements are Pb, Bi; numbers 1 and 2 are measurements on both sides of the fake coin 1962-11-1571-16/4.

Septimius Severus and His Wife Julia Domna Silver Coins

The numbers used in dendograms and the corresponding inventory numbers of the coins are given in Table 5.46. The data include a few two side analyses results of silver coins. Numbers from 12 to 18 correspond to measurements for 7 fake coins. The methodology was successful in this case; clustering interval selected as *Square Euclidian Distance* and method selected was *Between-group Linkage*. As a result, fake coins (number 12, 13, 14, 15, 16, 17, 18) of Julia Domna and Septimus Severus were clustered in one group successfully by using Cu, Zn, Zr, Ag, Pt, Sn, Pb and Bi as elements (Figure 5.94).

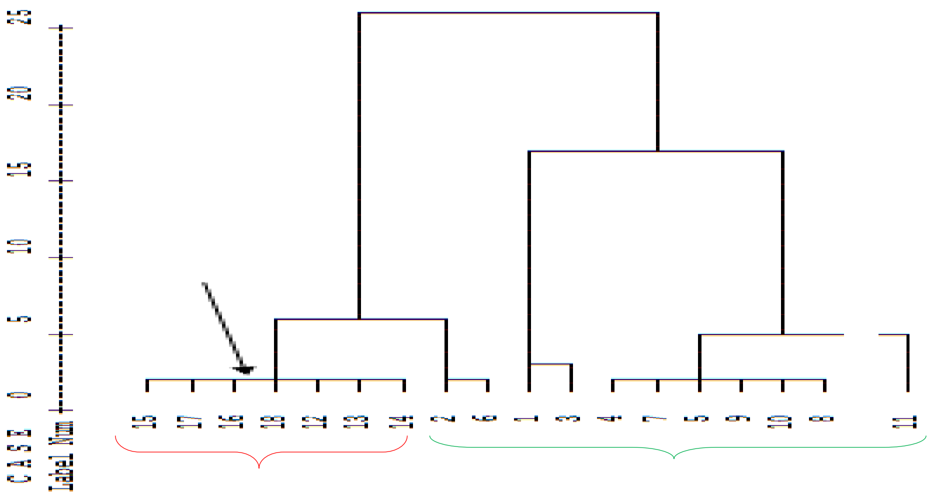


Figure 5.94: Dendrogram for P-XRF results of Septimius Severus and Julia Domna silver coins. The selected elements are Cu, Zn, Zr, Ag, Pt, Sn, Pb, Bi; numbers 12-18 are measurements for fake coins.

Table 5.46: The list of numbers used in dendrogram

Dend. No. for figure 5.95	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Inv No	64-M154	43-M138	12-M112	Z4	Z8	Z8 Rev.	Z16 obv.	Z16 obv.	Z17	Z17 Rev.	45-M138	U-9-27	U-9-28	U-9-28 Rev.	U-9-30	U-9-31 Rev.	U-9-32	U-9-33 Rev .
Dend. No. for Figure 5.96	1	2	3	4	5			6	7		8	9	10		11		12	

The statistical evaluation was repeated by taking P-XRF results for only the obverse sides of the fake and authentic coins (Figure 5.95). Numbers from 9 to 12 correspond to fake coins and the others are the authentic coins. In this cluster, same methodology was used as before. As a result, fake coins of Julia Domna and Septimus Severus clustered in one group successfully using Cu, Zn, Zr, Ag, Sn, Pt, Pb, Bi as elements (Figure 5.95).

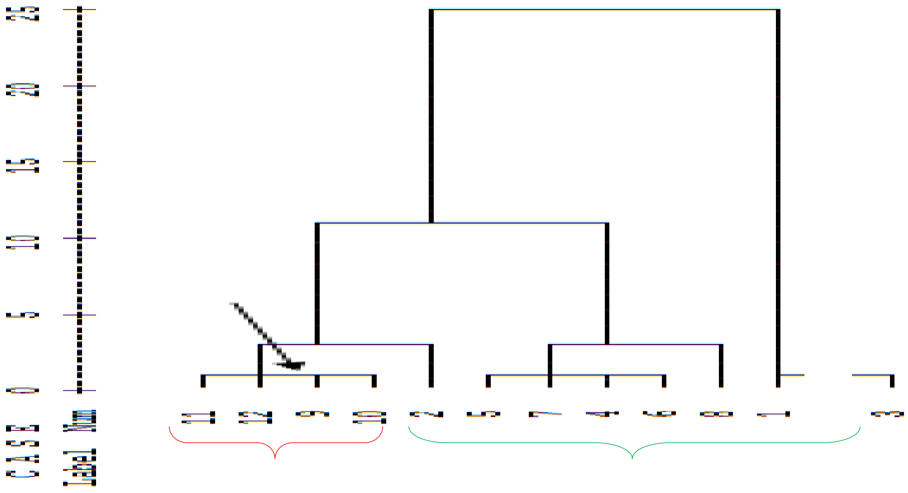


Figure 5.95: Dendrogram for P-XRF results of Septimius Severus and Julia Domna silver coins (Number s from 9 to12 are fakes group).

Geta Silver Coins

The numbers used in dendograms and the inventory numbers of the coins are given in Table 5. 47.

The data beside obverse analyses include a few both side analysis results of fake and authentic coins. Numbers 2 and 3 correspond to measurements on both sides of the fake coin U-10-34. The measurements No. 2 and 3 of Geta were clustered in one group by using Cu, Zn, Zr, Ag, Sn, Pt, Pb and Bi as elements as shown in Figure 5.96.

Square Euclidian Distance was selected as distance and *Between-group Linkage* was selected as method.

Table 5.47: The list of numbers used in dendrogram

Dend .No for figure 5.96	1	2 & 3 rev	4 & 5 rev	6 & 7 rev	8 & 9 rev	10 & 11 rev	12 & 13 rev	14 & 15 rev	16	17	18	19	20 & 21 rev	22	23	24	25 & 26rev	27 & 28rev
Inv No	73-M168	U-10-34	Z12	Z14	X-1861-243/128	X-1861-243/127	X-1861-243/126	X-1861-243/125	X-1861-243/124	X-1861-243/123	X-1861-243/122	X-1861-243/121	X-1861-243/136	X-1861-243/144	X-1861-243/142	X-1861-243/141	1176-41	1420-3-1956
Dend . No for figure 5.97		1	2	3	4	5	6			7			8				9	10

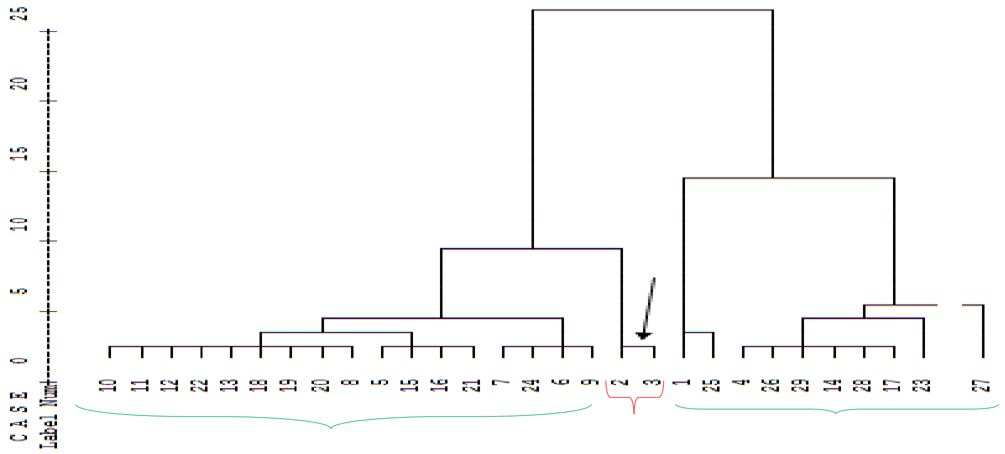


Figure 5.96: Dendrogram for P-XRF results of Geta silver coins. The selected elements are Cu, Zn, Zr, Ag, Sn, Pt, Pb and Bi; numbers 2 and 3 correspond to the fake coin U-10-34, analyzed on both sides.

In order to investigate whether there will be any difference in results when one side instead of both side of coins are used, in the new set only the reverse side results were used; the resulting dendogram is given in Figure 5.97. No. 1 is the fake coin, U-10-34. In this cluster, same methodology and same elements were used as before (Figure 5.92). As a result, the fake coin (No. 1) of Geta was separated successfully (Figure 5.97).

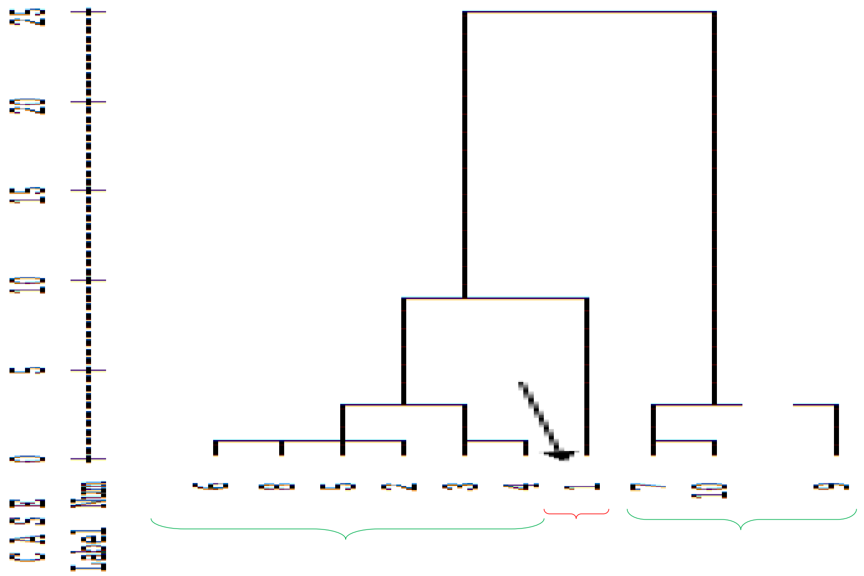


Figure 5.97: Dendrogram for P-XRF results of Geta silver coins. The selected elements are Cu, Zn, Zr, Ag, Sn, Pt, Pb and Bi; number 1 is a fake coin.

Macrinus and His Son Diadumenian Silver Coins

The numbers used in dendograms and the inventory numbers of the coins are given in Table 5. 48

In this cluster analysis, P-XRF results from obverse and reverse sides of three silver coins were taken in consideration. Numbers 1-6 correspond to measurements on both sides of fake coins. Hence they are expected to fall into the same group. In the cluster Cu, Zn, Zr, Ag, Sn, Pb and Bi were taken in consideration. The measurements for the fake coins (1-6) were clustered in one group by using hierarchical cluster analysis.

Square Euclidian Distance was selected as distance and *Between-group Linkage* was selected as method.

Table 5.48: The list of numbers used in dendrogram

Dend . No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Inv No	U-11-36	U-11-36 Rev.	U-11-38	U-11-38 Rev.	U-11-40	U-11-40 Rev.	X-1861-243/155	X-1861-243/154	X-1861-243/154 Rev.	X-1861-243/153	X-1861-243/153 Rev.	X-1861-243/152	X-1861-243/151	X-1861-243/151 Rev.	X-1861-243/150	X-1861-243/150 Rev.	V-1339-12	V-1339-12 Rev.

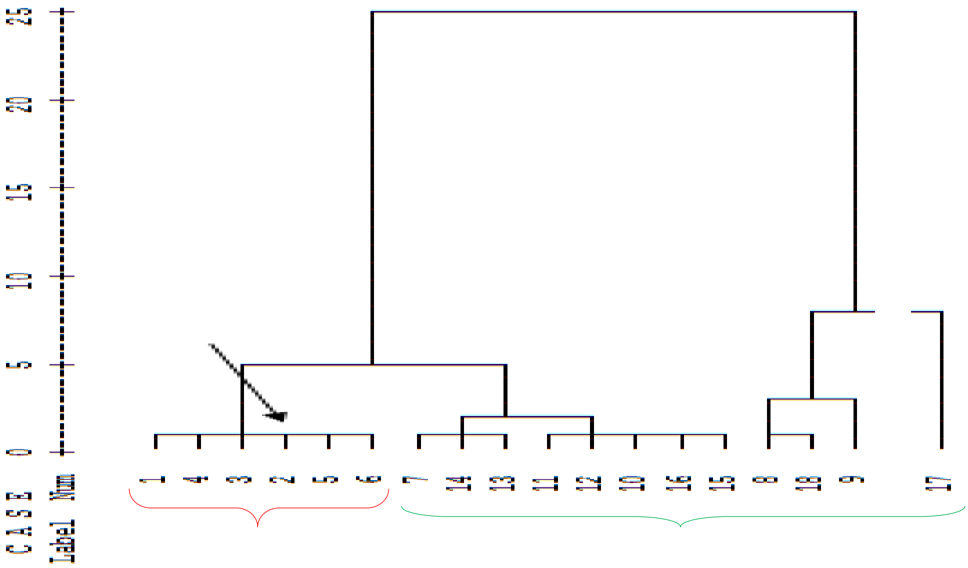


Figure 5.98: Dendrogram for P-XRF results of Macrinus and his son Diadumenian silver coins. The selected elements are Cu, Zn, Zr, Ag, Sn, Pt, Pb, Bi; numbers 1-6 are measurements for the fake coins.

5.7.1 T Tests for Dendrogram Results

In order to determine significance of the difference between the fake and authentic groups, data from dendrogram are used. The averages of the groups are statistically compared using two sample t test. SPSS 16.0 software package is employed to carry out the tests. For the results below that could not be detected (ND) the concentration value was taken as detection limit, 0.001%.

Firstly, Levene's test is used to test the equality of variances of the groups. For the groups with equal variances, two sample t test with pooled variance is used. For the groups with unequal variances, t test with unequal variance assumption is used. The p values for testing the hypothesis of equal averages over the groups are displayed in the following table. P value smaller than 0.10 indicate statistically significant difference between the two groups and these are highlighted in bold.

Table 5.49: T test table obtained from independent t test analyses

Emperor	Element	T test statistic	P value	Mean difference	Std. error difference	90% confidence interval	
						Lower	Upper
Vespasian	Cu	1.032	0.317	3.00	2.90	3.16	9.16
	Ag	-1.067	0.302	-3.05	2.85	-9.11	3.01
	Pb	**1.913**	**0.074**	**.817**	**.42**	**-.088**	**1.72**
	Bi	**1.758**	**0.098**	**.046**	**.026**	**-.009**	**103**
	Pt	**2.611**	**0.020**	**.030**	**011**	**.005**	**.056**
Hadrian	**Cu**	**2.797**	**0.016**	**2.04**	**.73**	**.45**	**3.63**
	Ag	**-2.843**	**0.012**	**-2.15**	**.75**	**-3.77**	**-.54**
	Zr	-1.455	0.219	-.014	.01	-.042	.01
	Pb	**7.747**	**0.000**	**.847**	**.10**	**.60**	**1.08**
	Bi	**5.814**	**0.000**	**.165**	**.02**	**.103**	**.22**
	Pt	.882	0.391	.008	.009	-.011	.02
Trajan	**Ag**	**14.020**	**0.000**	**22.36**	**1.59**	**19.07**	**25.64**
	Cu	**-14.558**	**0.000**	**-20.64**	**1.41**	**-23.55**	**-17.72**
	Zn	**-28.461**	**0.021**	**1.002**	**.035**	**-1.42**	**-.58**
	Pb	.399	0.693	.007	.0197	-.032	.048
	Bi	**3.024**	**0.006**	**.101**	**.033**	**.032**	**.171**
S.Severus& J.Domna	**Ag**	**-6.11**	**0.000**	**-17.57**	**2.87**	**-24.32**	**-10.82**
	Cu	**5.757**	**0.001**	**17.37**	**3.01**	**10.24**	**24.50**
	Bi	**4.782**	**0.002**	**.121**	**.025**	**.061**	**.181**
	Zr	**-2.570**	**0.082**	**-.011**	**.004**	**-.026**	**.002**
	Pb	**6.479**	**0.000**	**.817**	**.126**	**.536**	**1.098**
Geta	**Cu**	**8.835**	**0.000**	**13.04**	**1.54**	**9.86**	**16.22**
	Zn	**2.408**	**0.023**	**.059**	**.024**	**.008**	**.11**
	Ag	**-9.663**	**0.000**	**-14.77**	**1.52**	**-17.92**	**-11.63**
	Pb	**4.215**	**0.000**	**1.08**	**.256**	**.55**	**1.60**
	Bi	**10.776**	**0.000**	**.117**	**.010**	**.095**	**.14**
Macrinus & Diadumenian	**Ag**	**-5.469**	**0.000**	**-15.78**	**2.88**	**-22.10**	**-9.45**
	Cu	**5.629**	**0.000**	**15.32**	**2.72**	**9.33**	**21.31**
	Zn	**3.069**	**0.007**	**.045**	**.014**	**.014**	**.076**
	Bi	**4.979**	**0.000**	**.076**	**.015**	**.042**	**.110**
	Zr	**-2.964**	**0.031**	**-.011**	**.003**	**-.021**	**-.001**
	Pb	**2.661**	**0.017**	**.581**	**.218**	**.118**	**1.04**

From Table 5.49 t test for dendrogram these below results obtained
For Vespasian silver coins, equal mean rejected for Pt, Pb and Bi but equal mean assumed for Ag and Cu.
For Hadrian silver coins**, e**qual mean rejected for Ag, Cu, Pb, Bi and equal mean assumed for Zr and Pt.
For Trajan silver coins, equal mean rejected for Ag, Cu, Bi and Zn, but equal mean assumed for Pb.

For Septimius Severus and His wife Julia Domna silver coins, equal mean rejected for Ag, Cu, Pb, Bi and Zr
For Geta silver coins**,** equal mean rejected for Ag, Cu, Pb, Bi and Zn.
For Macrinus and his son Diadumenian silver, equal mean rejected for Ag, Cu, Pb, Bi, Zr and Zn.
As a result in most of elements equal mean were rejected by t test results.

5.8 Using Graphic for Cluster Analyses Results of Fake and Authentic Coins

A plot of analytical results has been prepared for 107 selected silver coins as shown in Figure 5.99. Both authentic and fake coins were used. Pb, Bi, Pt and Zr hierarchically are important in determination of authenticity. ND elements are given the concentration corresponding to detection limit value, 0.0010%.

The data given in Figure 5.99 are very helpful to let us see how good fakes and authentic coins are separated and clustered. Selecting the logarithmic scale is also important to see the results clearly. It is obvious that authentic coins contain high Pb, Bi and occasionally Pt and only one example had detectable Zr. On the other hand, fake coins contain lower levels of Pb comparing to authentic coins, none of the fake coins contain Bi and Pt while Zr was commonly detected in fakes.

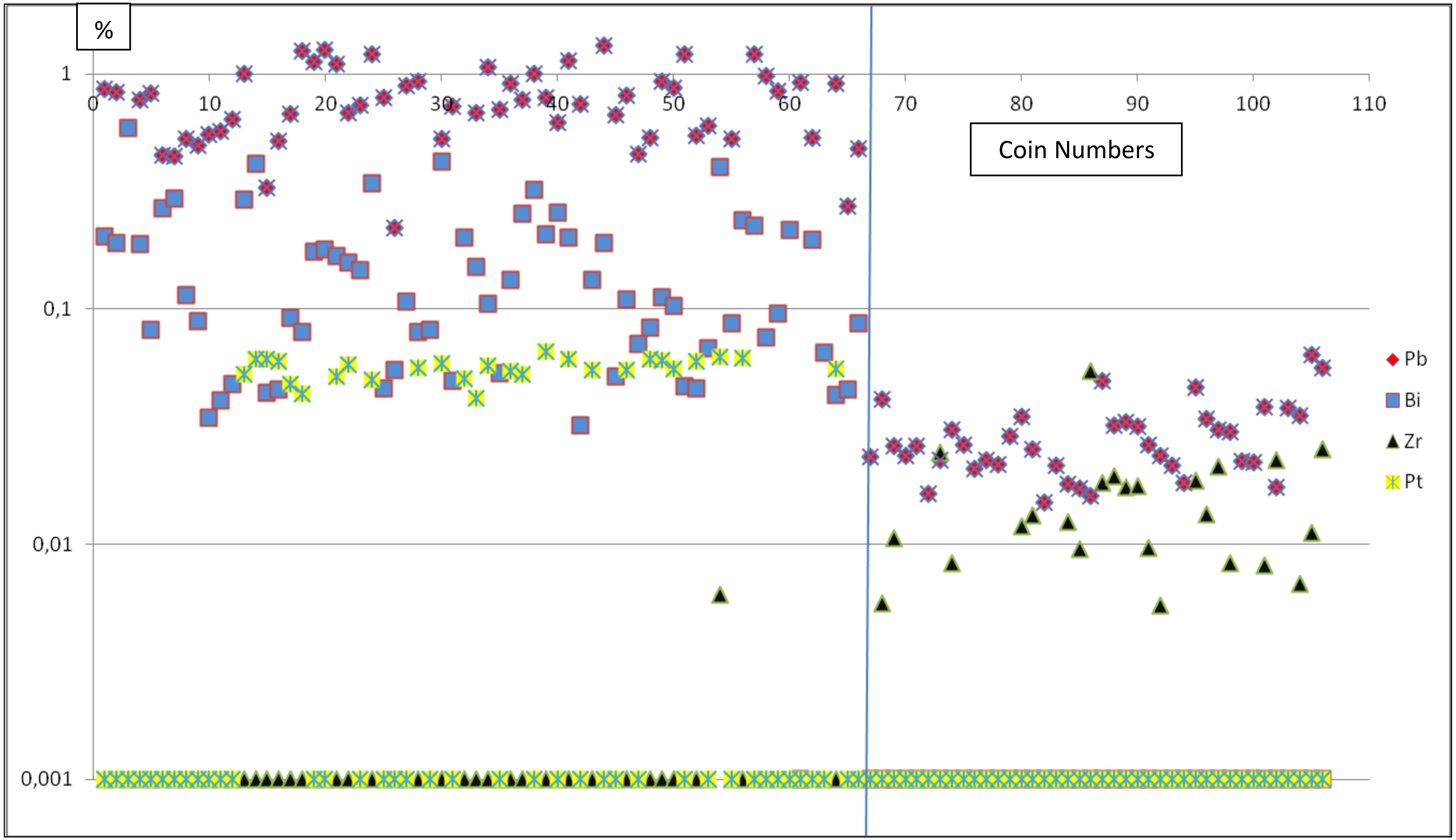


Figure 5.99: The plot showing the compositions of 107 selected coins, both fake and authentic. Elements are Zr, Pt, Pb and Bi. On left, samples from 1 to 68 are authentic; on right, from 68-107 are fakes).

CHAPTER 6

CONCLUSION

Authenticity of archaeological objects is a universal problem. It has also become one of the most important issues in Turkish Museums. Lack of modern archaeometric techniques in museums renders these valuable institutions an open market to national and international forgers. In addition to the museums certified collectors and private museums are in risk for similar reasons. A significant sum of payment is made to fake subjects brought to museums by individuals; in return, fake objects with very low artistic value and no historical importance may take their places in the collections. In this study, the problem of fake silver coins has been handled. The examination of these objects prior to acceptance by numismatists is a crucial step; a fake coin may be rejected after a proper visual examination by an expert. Nevertheless, some of the fake coins have the level of excellence that may deceive even an expert who is undertaking a task based on previous experience. In these cases, measurements of physical and chemical properties through archaeometric approaches gain importance. The differences between the chemical compositions may be found by several analytical techniques. For the obvious reasons, non-destructive analytical techniques are preferred so that the sample will be intact.

Silver coins, mostly denarius, from Roman Imperial Age, for the emperors from Augustus to Gordian III, were investigated by several archaeometric techniques such as Portable Energy Dispersive X-ray Fluorescence Spectrometry (P-XRF), Scanning Electron Microscopy-Energy Dispersive X-ray Fluorescence Spectrometry (SEM-EDX) and Line Scanning Electron Microscopy-EDX (LSEM-EDX). The purpose was to differentiate between the fake and authentic coins. The results were evaluated by statistical methods. Outcomes of the study have enabled us to classify silver coins by determining their chemical properties. The results of this investigation can be summarized as follows:

6.1 P-XRF Analyses of Silver Coins

In this study coins were selected as the problem: because more than half of the total objects of museums consist of coins. In the study the fake silver coins that are most difficult to differentiate from the authentic ones were analyzed by P-XRF; the decision about these coins could not be easily given using visual inspection. Using the P-XRF analysis, we can divide fake coins into two classes. The first one consists of the fake coins which are very easy to identify from their chemical compositions. These fake coins include those which are made from solder (Pb, Sn), German silver (Cu, Zn and Ni) and Lead (Pb) (Figure 5.100 and 5.101 a,b); they look like silver coins and it is very easy to determine their authenticity since the chemical composition is very different from silver coins. In Roman Imperial Age these metals were not used in production of coins as major elements. These elements were used as either minor elements or they exist as impurities in production of Roman Imperial Age silver coins (Denarius). The second class of fake coins has chemical compositions very close to authentic coins in terms of major elements Ag and Cu. This second group silver coins were mostly handled in this study (Figure 5.102 a, b).

Figure 5.100: Fake Roman coin made of solder with inventory number 15-216/1-75.

a) b)

Figure 5.101: Hellenistic and Lydian fake coins. a) Hellenistic coin made of German Silver, b) Lydian coin made of lead.

a) 

b)

 c)

Figure 5.102: Roman fake silver coins. a) Augustus (U-2-4), b) Claudius (U-3-11) and Trajan (1962-11-571-16/4

From the results of P-XRF experiments, the following conclusions were obtained regarding the importance of analyte elements.

Ag-Cu: These elements are the main constituents in silver coins. There are no significant differences between the fake and authentic coins regarding Ag content of silver coins which is between 90% and 99% from Augustus (27 B.C. to 14 A.D.) to Hadrian (117-138). However, the emperor Trajan decreased the Ag content in his silver coins to a level lower than 90% towards the end of his reign because of many wars that he was engaged. Ag content started to be present at values lower than 90% in Antoninus Pius age (Figure 5.103).

This value decreased to lower than 80% in Septimius Severus Age. The course of social events can also be followed from the chemical content of coins, since debasements were always affected by the social, economical and political events.

In order to preserve the appearance, physical properties and approximate weight of the coins, reduction in Ag content was compensated by the less expensive metal copper. Inflation of Roman

Imperial Age economy can be followed from the metal contents of silver coins. In other words, the ratio of the precious elements used in coins was a result of the wealth of societies.

Declining social and political situations were reflected in the composition to the metal of coins. We know from the ancient documents that Trajan and Septimius Severus were engaged in many wars within the Roman Empire and with the neighboring countries (Kaya 2008, Tekin 2008). The high costs of wars, including the salaries of the army and other expenses, resulted in decreasing of the silver content in coins. In the case of war, the size of the armies increased, causing further expenses. This meant that the authorities needed more silver coins which were the backbone of Roman Imperial payment. Therefore authorities used restricted silver sources more efficiently by decreasing silver content of the coin and increasing the Cu content of the silver coins.

In order to give the appearance of the high silver content, silver coins were sometimes silvered with tin (Sn). In Caracalla Age, they started to coat bronze coins with silver by using amalgamation technology. Amalgamation was done with liquid silver by using its mercury amalgam.

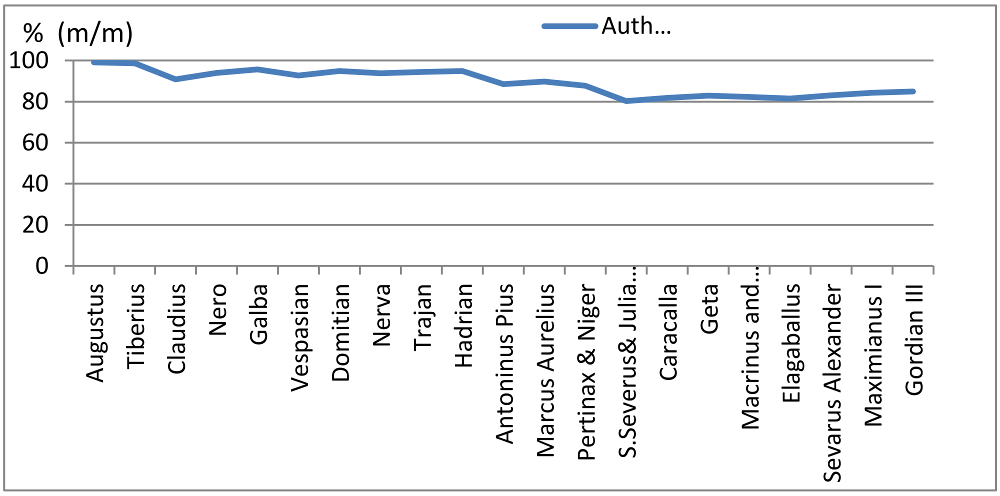


Figure 5.103: Ag value of Authentic Roman Imperial Age Denarii.

Minor Elements

Zirconium (Zr): Zirconium concentration is an important parameter when fake coins are produced with casting technology. Depending on the casting technology used, Zr was detected only in fake coins between 0.0055 and 0.0547%. If the fake coin was produced by hammering, as it was in ancient times, Zr was not detected. Therefore, while its presence is a strong indication of forgery, its absence is not a support for authenticity.

Tin (Sn): It could be detected especially in coins produced after decreasing of Ag percentage to 80% and even lower; such silver coins were silvered with Sn in order to give the sense of a high silver content coin. Tin content varied between 0.29 and 4.30% in real silver coins. In general, tin was not detected in fake silver coins. However, if the fake coin was made of solder, concentrations as high as 50% could be detected; such a case in this study was 15-216/1-75 of Nero (Table 5.4, Figure 5.100).

Platinum (Pt): Platinum content depends on the ore used in authentic silver coins. Pt is 50 times more expensive than Ag and it is completely separated from silver when modern technologies are used to obtain the latter. However, the melting point of Ag is 900 °C, while Pt melts at 1700 °C; therefore Pt could not be separated from silver when the ancient metallurgical process cupellation was used. Therefore Pt was detected in authentic silver coins with the values between 0.041and 0.42%. Pt was not detected in any of fake coins made of silver.

Lead (Pb): It is the most important element in determination of authenticity. Lead was detected in all the authentic and fake silver coins in different percentages. In the fake coins containing a high Ag content, at least 90%, Pb concentration is lower than 0.060%. Regarding the authentic coins obtained from a reliable source, Pb content was 0.20% or higher. Pb content depends also on the ore used to obtain the main element Ag. Silver purified from electrum, a natural Au-Ag alloy, contains less Pb than Ag purified from a Pb ore. Therefore, in some cases, where electrum was used as the source of silver, Pb concentration may be as low as 0.0826%; an example was found in case of Augustus silver coins, as shown in Table 5.1. In our study, it so happened that the authentic coins with lower Pb content came always from individuals. It should also be mentioned that most of the authentic coins bought from individuals contained Pb at a higher level, at least 0.20%. Several examples related to this discussion may be seen in Appendix B.

Bismuth (Bi): Second important element in determination authenticity of silver coins is Bi. Because Bi was detected in 360 of 419 of authentic coins between 0.0068 and 0.62 % and it was not detected in any of the fake coins. Therefore Bi is a good indicator of authenticity.

6.2 SEM-EDX and LSEM-EDX Analyses

During the formation of coins, firstly the amalgam with a desired composition is prepared. The liquefied mixture is poured into a mould. During the solidification, some segregation at the surface and in the bulk may take place, resulting in copper-rich phases. Therefore, during the surface analysis, copper concentration may show variations as reported in literature (Demortier 2003). In the SEM images, copper-rich phases may be seen as black spots. In order to understand whether the black spot selected is representing a copper-rich phase, SLEM-EDX analysis can be performed. In this analysis, EDX analysis is realized on a selected line showing the variations of selected analytes along this line. The presence of a sharp Ag and Cu concentration change near the black spot indicates that the amalgam was formed in a recent date; therefore the authenticity should be in doubt and it may be a fake coin. On the other hand in an authentic coin, it would not be possible to observe such changes near the black spots as the segregated copper-rich locations diffuse into the matrix by them so that the differences in Cu contents are diminished.

During this study, 16 SEM images, 17 SEM-EDX spectra and 13 sets of LSEM-EDX analyses were performed on the fake and authentic coins in order to see how the copper contents differ in these two groups. From the results of the SEM-EDX and LSEM-EDX experiments, the following conclusions were obtained.

Copper-rich phases may be found at black spots; however, the latter may also correspond to pits, corrosion defects, and other kinds of contaminations in the matrix of the coins. Hence in order to find copper-rich phases many analyses need to be done.

The black spots selected, supposedly copper-rich phases in authentic silver coins, contain copper in less than 5% while this value is approximately 2-4% in the matrix. Copper concentrations do not show important differences between the matrix and black spots selected.

In analyses made from copper-rich phases on fake coins Cu content varied in the range of 18 to 42%. In the matrix of the same fake coins copper concentration was around 2%. Regarding Cu content, there is a sharp difference between the matrix and the copper-rich phases.

Results of SEM-EDX and LSEM-EDX demonstrate that this approach can be useful in authenticity studies of silver coins.

6.3 Statistical Evaluation of P-XRF Results

A statistical evaluation of P-XRF results was done using dendograms in an effort to distinguish between the fake and authentic coins. The purpose is to collect the supposedly fake coins in one group.

6.3.1 Correlations

Correlations between element concentrations were calculated from P-XRF analysis results of silver coins minted under Roman Imperial Authority, by using SPSS 16.0 statistics program and Pearson Correlation.

There were strong positive correlations in few groups, namely Cu-Zn, Cu-Mo and negative correlation between Cu-Ag, Mo-Ag and Zn-Ag (Table 5.42). These correlations can be interpreted as results of ore metallurgy process and Roman Imperial Economic situation. Because Cu ores contain higher levels of impurities such as Zn, Sb and Mo. In cases of economic crisis, the Roman Authority decreased the silver percentage of the coins and replaced it with copper. Therefore when Ag content decreases, Cu content becomes higher; this results in a negative correlation between Ag-Cu. Consequently, there are positive correlations for Cu-Mo, Cu-Sb and Cu-Zn; and negative correlations for Mo-Ag and Zn-Ag (Craddock and Lang 2002).

These results are not directly helpful in authenticity studies; because when fake coins are used, Cu is also added and causes the similar impurities as in the authentic coins. Nevertheless, ancient copper is expected to have the mentioned impurities in higher levels as compared to copper used recently.

6.3.2 Use of Dendrograms

Dendrograms were prepared for P-XRF results of 6 emperors. The trials were done by selecting different groups of elements as well as the different methods of the statistics software used. In general, when a large group was selected, such as Cu, Zn, Zr, Ag, Sn, Bi, Pt, Pb, the attempts to separate the fake coins was sometimes successful and sometimes not. On the other hand, when Pb and Bi were taken, separations were more successful. It was mentioned before that both Pb and Bi are good indicators for authenticity. This property was also reflected in statistical studies.

6.4 Recommendations

In 21st century, protection of museum collections will necessitate the use of non-destructive archaeometric techniques in addition to traditional visual inspection.

Applications of non-destructive archaeometrical techniques should be improved and frequently employed in analysis and characterization of cultural artifacts. As compared to the destructive techniques such as ICP-OES, ICP-MS etc., the results obtained from non-destructive techniques are less reliable, since the latter usually refers to a surface technique that is not always representative of the bulk composition. On the other hand, the need for a non-destructive technique is obvious, since the archaeological samples should remain intact. However, if weaknesses of the non-destructive method is well-characterized, one could know what to expect; therefore the results should be interpreted with realistic error margins.

In this study the following suggestions for users can be made.

Several analyses from different parts of the same objects should be performed to show the variability. Results obtained using this approach will be more reliable.

It is always not possible to have a decision from analytical results; therefore visual inspections of experienced experts, numismatists, should be used in addition to non-destructive archaeometric techniques.

If P-XRF analysis cannot provide a definite result, SEM-EDX and LSEM-EDX may be used with the technique described in this thesis. However, it should be mentioned that this method is difficult, costly and slow.

In some cases, semi-destructive techniques may also be used, such as Laser Ablation (LA) ICP-MS. This approach is better than using a destructive technique. The samples will have small, sometimes invisible scars on their surfaces; otherwise they will be intact at the end of analysis.

In archaeometry, evaluation of analytical results is often supported by using statistical techniques. Proper techniques should be selected. Statistic programmes are also helpful in demonstrating the relations between the parameters chosen; this may not be always visible by ordinary inspection.

The subject of this thesis was the differentiation between the fake and authentic archaeological artifacts, namely silver coins. This operation could have been much easier, if the characteristics of the authentic objects were known. In this study, the silver coins originated from the reliable sources, such as Juliopolis Excavation, constituted the data for reliably authentic coins. This has been very helpful in building the relations and comparisons used for authenticity. It is therefore highly recommended to museums or entities keeping cultural heritage objects to obtain and record hard and soft copies of chemical compositions of these objects. Because changing real objects with fake ones or stealing objects is unfortunately a frequently encountered case. Whenever there is a suspicious case of replacing an authentic object with the fake one, it will be very easy to prove if the chemical/physical properties of the real object were recorded. A simple inspection will reveal if such a replacement has been done. Moreover, imitation of stolen objects is becoming a very common practice; several fake substitutes may be present for a single authentic artifact. A rapid chemical analysis may reveal the truth quite easily in such cases. As a conclusion, the related entities should archive the physical and chemical data for the authentic artifacts.

REFERENCES

- Arslan M., 1992, Roman Coins: Museum of Anatolian Civilizations, Kültür Bakanlığı, Ankara-Turkey.
- Aydın M., and Zoroğlu C., (2012), "Scientific techniques and risk management in museums" Umut Ajans, Ankara
- Beckhoff B., (2006) "Quantitation principles in X-ray fluorescence analysis", PowerPoint presentation for IAEA training course, "Implementation of portable X-ray fluorescence analysis and ion-beam methods in cultural heritage studies" Demokritos, Athens
- Beck L., Bosonnet S., Reveillon S., Eliot D., Pillon F., (2004), Silver surface enrichment of silver–copper alloys: a limitation for the analysis of ancient silver coins by surface techniques, Nuclear Instruments and Methods in Physics Research B 226, 2004, pp 153–162.
- Civici N., Gjongecaj S., Stamati F., Dilo T., Pavlidou E., Polychroniadis E. K., Smit Z., (2007), "Compositional study of III rd century BC silver coins from Kresphan Hoard (Albania) using EDXRF spectrometry" Nucl. Instr. Meth. B 258.
- Cope H. L., (1972), "Surface –silvered ancient coin"; Hall A.T. and Metcalf, D.M., Methods of chemical and metallurgical investigation of ancient coinage book, Special Publication No 8, Oxford University Press, London pp 261-278.
- Craddock P., (1995), "Early Mining and Production", Edinburgh University Press, Edinburgh.
- Craddock P., and Lang J., (2002), "Mining and Metal Production through the Ages", the British Museum Press, London.
- Demortier G., (2003), "PIXE and PIGE non destructive analysis of gold, silver and bronze coins" Numismatic & Technology: Questions and Answers symposium proceedings, SPV-Druck, Vienna, pp 37-49.
- Deza E., Deza M. M., (2009), "Encyclopedia of Distances", Springer, New York, page 94.
- Ercanlı L., (2012), Examination of Metal Working Technology in Kultepe in Assyrian Trade Colonies Period, Ph. D Thesis Middle East Technical University, Ankara, Turkey.
- Fulvio D, Romeo M, Salici A. (2009), Ancient coins and their modern fakes: an attempt of physico chemical unmasking, Mediterr Archaeol Ar, 9 (2), Greece.
- Hida M., Sato H., Sugawara H., Mitsui T., (2000), Classification of counterfeit coins using multivariate analysis with X-ray diffraction and X-ray Fluorescence methods, Forensic Sci Int 115.

- Fleming J. S., (1975), "Authenticity in art, the scientific detection of forgery", The Institute of Physics Press, London.

- Hodges H., (1981), "Artifacts: An introduction to primitive technology", Humanities Press, Newyork.

- Kaya M. A., (2008), "Romanın Afrikalı imparatoru Septimius Severus", Arkeoloji ve Sanat Yayınları, İstanbul .

- Kızılkaya Y., 1988, Türk Arkeoloji Dergisi Sayı XXVII, "Yatağan Definesi " pp. 141-173, Ankara-Turkey.

- Leute U., (1987), "Archaeometry, an introduction to physical methods in archaeology and the history art", VCH Publishers, Weinheim**.**

- Moioli P. and Seccaroni C., (2000), "Analysis of Art Objects Using a Portable X-ray florescence spectrometer", X-Ray Spectrom, special issue on cultural heritage, 29.

- Mezzasalma A. M., Mondio G., Serafino T., Fulvio G., Romeo M., Salici A., (2009), "Ancient coins and their modern fakes: An attempt of physico-chemical unmasking" Mediterr Archaeol Ar, 9(2).

- Moore M. D., Robert C., Reynolds J., (1997), "X-ray diffraction and the identification and analysis of clay minerals" Second edition, Oxford University Press, New York, p 69.

- Rojas R. I., Herrera A., Vazquez L. C., Apolo R., Hernandez J. G., Rodriguez M. E., (2003), "On the authenticity of eight real 1730 Mexican silver coins by X-ray diffraction and by energy dispersion spectroscopy techniques" Nuclear Instruments and Nucl. Instr. Meth. B Beam Interactions with Materials and Atoms, 215 (3-4).

- Romana F. P., (2010), "Non-destructive analyses of ancient metals by combined atomic and Ion-Beam methods" Power Poin presentation, CNR, Istituto per i Beni Archeologici e Monumentali, Catania and INFN, Laboratori Nazionali del Sud, Catania

- Rizzo F., Cirrone G. P., Cuttone G., Esposito A., Garraffo S., Pappalardo G., Pappalardo L., Romano, F. P, Russo S., (2010), "Non-destructive determination of the silver content in Roman coins (Nummi), Dated to 308-311 A.D., by the combined use of PIXE-alpha, XRF and DPAA techniques" Microchem J. 97.

- Rodrigues M., Cappa M., Schreiner M., Ferloni P., Radtke M., Reinholz U., Woytek B., Alram M., (2011) "Further metallurgical analyses on silver coins of Trajan (AD 98–117)" J. Anal. At. Spectrom, 26, 984.

- Sayles G. W., (2000), "Classical deception counterfeits, forgeries and reproduction of ancient coins" Krause Publication, USA.

- Skoog A. D., West D. M., Holler J. F., Crouch S. R., (2004), "Fundamentals of analytical chemistry", 8th Ed. pp 854, Brooks/Cole Publications, Canada.

- Solmon M. E., (1970), "A*n X-ray florescence method for micro-samples"*, IIc American Group Technical Papers from 1968 through 1970; IIc American Group: New York.

- Speir J., Kagan J., (2000), "Sir Charles Frederick and the forgery of ancient coins in eighteenth-century Rome" Journal of the History of Collections, New York.

- Suzuki M., (2008), "Development of a simple and non-destructive examination for counterfeit coins using acoustic characteristics" Forensic Sci Int, 177.

- Tansel İ., (2012), "Differentiation and classification of counterfeit and real coins by applying statistical methods" Master Thesis Middle East Technical University, Ankara, Turkey.

- Tekin, O., (2008), "Eski Yunan ve Roma tarihine giriş" İletişim yayınları, 2. Baskı, İstanbul, Turkey.

- Walker D. R., (1976) "The metrology of the Roman silver coinage part I, from Augustus to Domitian "BAR Publications, Supplementary Series 5, London,

- Walker D. R., (1977), "The metrology of the Roman silver coinage part II from Nerva to Commodus", BAR Publications, Supplementary Series 22, London.

- Walker D. R., (1978), "The metrology of the Roman silver coinage" part III, from Pertinax to Uranius Antoninus", BAR Publications, Supplementary Series 40, London

- Willard H. H., Merritt L. L., Dean J. A., Settle A.F., (1981), Instrumental Method of Analyses, Van Nostrand Reinhold Publisher, U.S.A.

- **Atomic absorption spectrometry (AAS)** (http://en.wikipedia.org/wiki/Atomic_absorption_spectroscopy, 23/12/2010)
- **Cast forgeries:**

(http://books.google.com.tr/books false, fakes, forgery 24/10/2010).

- **Die Struck Forgery: (**http://books.google.com.tr/books false, fakes, forgery, 24/10/2010)
- **Elektro Type Forgery:** (http://www.calgarycoin.com/reference/fakes/electro.htm, 24/10/2010)
- **Forgery:** (http://books.google.com.tr/books false, fakes, forgery).
- **Experimental principle of PIXE:** (http://www.ams.ethz.ch/research/material/iba/pixe/pixe.png&imgrefurl=http://www.ams.ethz.ch/research/material/iba/pixe&usg, 17/12/2010)
- **Inductively coupled plasma atomic emission spectroscopy (ICP-AES):** (http://en.wikipedia.org/wiki/Inductively_coupled_plasma_atomic_emission_spectroscopy , 23/12/2010).
- **Inductively Coupled Plasma Mass Spectrometry (ICPMS):**

(http://en.wikipedia.org/wiki/Inductively_coupled_plasma_mass_spectrometry, 23/12/2010)

- **Infrared spectroscopy (IR):** (http://webcache.googleusercontent.com/search?q=cache:1RJKLIt71ycJ:en.wikipedia.org/wiki/Infrared_spectroscopy+Infrared+Spectrometry 23/12/2010).

- **Laboratory Hand Book (2003):**

  The Metallographic Examination of Archaeological Artifacts Laboratory Manual MIT Summer Institute In Materials Science And Material Culture (http://ocw.mit.edu/courses/materials-science-and-engineering/3-094-materials-in-human-experience-spring-2004/laboratories/manual_suppl.pdf).

- **Microscopy** http://en.wikipedia.org/wiki/Microscopy 17/12/2010)
- **Ponting M. and Butcher K., (2005),** "Analysis of Roman Silver Coins, Augustus to Nero (27 BC - AD 69)" available in http://archaeologydataservice.ac.uk/ archives/view/coins_lt_2005/ 27.12.2011.

- **Proton-induced X-ray emission (PIXE):** (http://en.wikipedia.org/wiki/Particle-induced_X-ray_emission 21/12/2010).
- **Raman Spectroscopy**: (http://webcache.googleusercontent.com/search?q=cache:5vqoprN_wzwJ:en.wikipedia.org/wiki/Raman_spectroscopy+Raman+Spectrometry&cd=1&hl=tr&ct=clnk&gl=tr 23/12/2010).
- **Sand and clay mold casting:** (http://www.calgarycoin.com/reference/fakes/cast.htm. 24/10/2010)
- **Schematic representation of a FTIR Spectrometer**: (solidstate.physics.sunysb.edu/.. ./node111.html 23/12/2010)
- **Schematic diagram of a Raman spectrometer**: (www.chm.bris.ac.uk/.../stuthesis/chapter2 .htm 23/12/2010)

- **Scanning Electron Microscope:** (www.gmu.edu/depts/SRIF/tutorial/sem/sem_xs.gif 21/12/2010)
- **Schematic drawing of the ICP-MS System:** (www.gso.uri.edu/icpms/ICPMS-80-75.gif, 23/12/2010).
- **Schematic Drawing of AAS** (http://www.chemistry.nmsu.edu/Instrumentation/AAS_schematic.gif. 23/12/2010
- **Solder** (http://en.wikipedia.org/wiki/Solder 27.12.2011)
- **Transmission Electron Microscope:** (www.mauricewilkinscentre.org/.../2.jpg 21/12/2010)
- Yatağan Hoard (http://www.kulturvarliklari.gov.tr/sempozyum_pdf/turk_arkeoloji/27.turk.arkeoloji.pdf).

- **Zirkonyum:**(http://www.etoplum.com/zirkonyum-hafniyum-madeni-kullanim-alanlari-hakkinda-bilgi.html 09.06.2012)

- **X-ray florescence (XRF)** (http://www.karlloren.com, 10/12/2010).

APPENDIX A

PHOTOS OF JULIOPOLIS and ZURICH COINS

AUGUSTUS

1-M 375

VESPASIAN

49-M139

63-M154

49-M139

DOMITIAN

5-M110

22-M120

90-M196

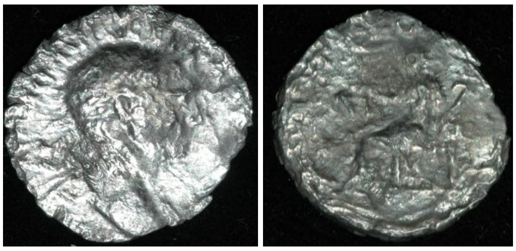
Z1

Z10

NERVA

Z6

TRAJAN



38-M132

48-M139

58b-M148

104-M180

97-M190

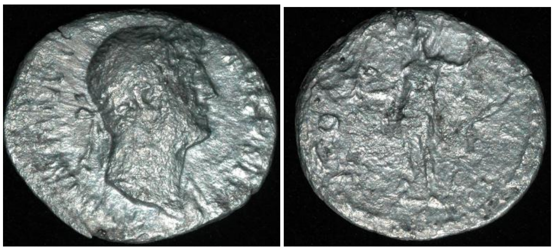
38-M132

101-M184

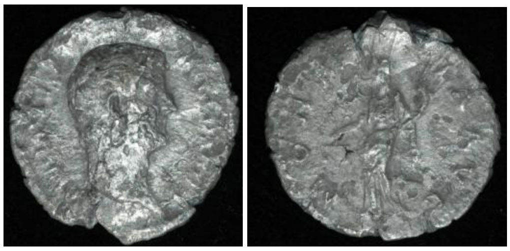
HADRIAN and SABINA

19-M118

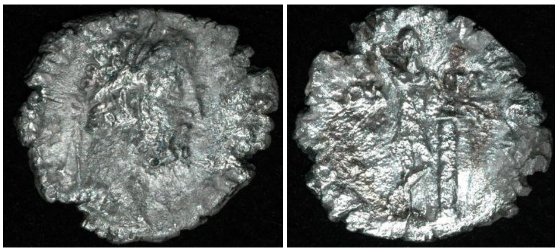
100-M189



99-M189



14-M113



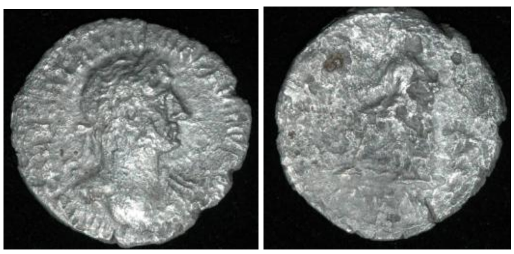
20-M118

21-M-120

83-M179

82-M177

37-M131



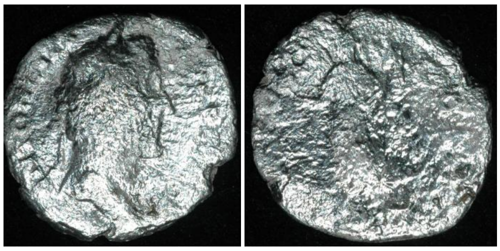
70-M162

ANTONINUS PIUS

103-M178

96-M190

92-M198



87-M195

81-M176

78-M173

76-M171

9-M112

54-M147

23-M120

Z20

MARCUS AURELIUS

2-M86

15-M114

41-M138

47-M139

55-M148

61-M151

SEPTIMIUS SEVERUS and JULIA DOMNA

45-M138

12-M112

43-M138

Z17

Z16

Z8

Z4

CARACALLA

Z21

79-M174

Z15

Z7

Z5

Z2

7-M112

71-M164

GETA

Z14

Z12

73-M168

ELAGABALUS

Z18

SEVERUS ALEXANDER

80-M174

GORDIAN III

11-M112

APPENDIX B

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
1-M 375	Juliopolis Exc.	2.94	Augustus	ND	ND	ND	ND	ND	ND	3.315	ND	ND	ND	ND	ND	95.81	ND	ND	ND	ND	ND	ND	ND	ND	0.798	0.081	A
77-1-77	Bought	3.61	Augustus	ND	ND	ND	ND	0.09	ND	0.435	ND	ND	ND	ND	ND	99.02	ND	ND	ND	ND	ND	ND	ND	ND	0.3953	0.058	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.14	ND	1.389	ND	ND	ND	ND	ND	98.38	ND	ND	ND	ND	ND	ND	ND	ND	0.0586	0.034	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	0.08	ND	0.141	ND	ND	ND	ND	ND	99.58	ND	ND	ND	ND	ND	ND	0.07	ND	0.0527	0.079	A
133-18/8-76	Bought	3.4	Augustus	ND	ND	ND	ND	0.29	ND	0.178	ND	ND	ND	ND	ND	99.42	ND	ND	ND	ND	ND	ND	ND	ND	0.1118	ND	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.23	ND	ND	ND	ND	ND	ND	ND	99.54	ND	ND	ND	ND	ND	ND	0.07	ND	0.0818	0.083	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND	ND	ND	98.75	ND	ND	0.38	ND	0.24	ND	0.11	ND	0.1142	0.162	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.29	ND	0.223	ND	ND	ND	ND	ND	99.17	ND	ND	ND	ND	ND	ND	0.09	ND	0.081	0.134	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	ND	ND	0.2	ND	0.08	ND	ND	ND	ND	ND	96.8	ND	ND	ND	ND	ND	ND	0.13	2.64	0.0789	0.077	A
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.44	ND	0.149	ND	ND	ND	ND	ND	99.22	ND	ND	ND	ND	ND	ND	ND	ND	0.1081	0.085	A
9-1856-749/8	Bought	3.21	Augustus	ND	ND	ND	ND	ND	ND	0.574	ND	ND	ND	ND	ND	99	ND	ND	ND	ND	ND	ND	ND	ND	0.3365	0.091	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.788	ND	ND	ND	ND	ND	99.04	ND	ND	ND	ND	ND	ND	0.06	ND	0.0683	0.046	A
12-1648-1	Bought	3.46	Augustus	ND	ND	ND	ND	0.24	ND	0.629	ND	ND	ND	ND	ND	98.79	ND	ND	ND	ND	ND	ND	ND	ND	0.3406	ND	A
916-1	Etnografya Mus. Bought	11.32	Augustus	ND	ND	ND	ND	0.05	ND	1.938	ND	ND	ND	ND	ND	97.48	ND	ND	ND	ND	ND	ND	ND	ND	0.4761	0.056	A
918-1	Bought	11.35	Augustus	ND	ND	ND	ND	ND	ND	2.711	ND	ND	ND	ND	ND	96.35	ND	ND	ND	ND	ND	ND	ND	ND	0.8905	0.044	A
2-1405-9	Bought	3.28	Augustus	ND	ND	ND	ND	0.07	ND	0.429	0.04	ND	ND	ND	ND	98.73	ND	ND	ND	ND	ND	ND	ND	ND	0.6037	0.134	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	0.14	ND	0.166	0.04	ND	ND	ND	ND	99.42	ND	ND	ND	ND	ND	ND	0.08	ND	0.0904	0.067	A
11-1571-16/2	Bought	3.41	Augustus	0.485	ND	ND	0.07	0.74	ND	5.309	0.04	ND	ND	ND	ND	93.04	ND	ND	ND	ND	ND	ND	ND	ND	0.2379	0.074	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.07	ND	1.246	ND	ND	ND	ND	ND	98.64	ND	ND	ND	ND	ND	ND	ND	ND	0.0418	ND	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	ND	ND	1.275	ND	ND	ND	ND	ND	98.69	ND	ND	ND	ND	ND	ND	ND	ND	0.0299	ND	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.08	ND	1.543	ND	ND	ND	ND	ND	98.34	ND	ND	ND	ND	ND	ND	ND	ND	0.0378	ND	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.15	ND	1.43	ND	ND	ND	ND	ND	97.97	0.38	ND	ND	ND	ND	ND	ND	ND	0.0429	0.034	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.1	ND	0.536	ND	ND	ND	ND	ND	98.82	0.46	ND	ND	ND	ND	ND	ND	ND	0.0525	0.033	A
150-870/14-76	Bought	3.52	Augustus	ND	ND	ND	ND	0.08	ND	0.372	ND	ND	ND	ND	ND	99.52	ND	ND	ND	ND	ND	ND	ND	ND	0.0335	ND	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	ND	ND	0.099	ND	ND	ND	ND	ND	99.78	ND	ND	ND	ND	ND	ND	ND	ND	0.0386	0.08	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	ND	ND	0.104	ND	ND	ND	ND	ND	99.79	ND	ND	ND	ND	ND	ND	ND	ND	0.0274	0.083	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	0.11	ND	0.195	ND	ND	ND	ND	ND	99.59	ND	ND	ND	ND	ND	ND	ND	ND	0.0247	0.081	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	0.15	ND	0.184	ND	ND	ND	ND	ND	99.56	ND	ND	ND	ND	ND	ND	ND	ND	0.0278	0.081	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	0.1	ND	0.173	ND	ND	ND	ND	ND	99.22	0.4	ND	ND	ND	ND	ND	ND	ND	0.0354	0.075	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	ND	ND	0.161	ND	ND	ND	ND	ND	99.32	0.4	ND	ND	ND	ND	ND	ND	ND	0.0388	0.08	A
150-870/13-76	Bought	3.57	Augustus	ND	ND	ND	ND	0.17	ND	0.306	ND	ND	ND	ND	ND	98.91	0.49	ND	ND	ND	ND	ND	ND	ND	0.0382	0.078	A
133-18/8-76	Bought	3.4	Augustus	ND	ND	ND	ND	0.55	ND	0.119	ND	ND	ND	ND	ND	99.24	ND	ND	ND	ND	ND	ND	ND	ND	0.0944	ND	A
133-18/8-76	Bought	3.4	Augustus	ND	ND	ND	ND	0.39	ND	0.097	ND	ND	ND	ND	ND	99.41	ND	ND	ND	ND	ND	ND	ND	ND	0.0968	ND	A
133-18/8-76	Bought	3.4	Augustus	ND	ND	ND	ND	0.13	ND	0.101	ND	ND	ND	ND	ND	99.67	ND	ND	ND	ND	ND	ND	ND	ND	0.0941	ND	A
133-18/8-76	Bought	3.4	Augustus	ND	ND	ND	ND	0.3	ND	0.162	ND	ND	ND	ND	ND	99.45	ND	ND	ND	ND	ND	ND	ND	ND	0.0891	ND	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.15	ND	ND	ND	ND	ND	ND	ND	99.71	ND	ND	ND	ND	ND	ND	ND	ND	0.0439	0.103	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.07	ND	ND	ND	ND	ND	ND	ND	99.79	ND	ND	ND	ND	ND	ND	ND	ND	0.0418	0.098	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.13	ND	ND	ND	ND	ND	ND	ND	99.75	ND	ND	ND	ND	ND	ND	ND	ND	0.0261	0.087	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.18	ND	ND	ND	ND	ND	ND	ND	99.69	ND	ND	ND	ND	ND	ND	ND	ND	0.0437	0.086	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.19	ND	ND	ND	ND	ND	ND	ND	99.67	ND	ND	ND	ND	ND	ND	ND	ND	0.0577	0.091	A
123-4/3-76	Bought	3.65	Augustus	ND	ND	ND	ND	0.19	ND	ND	ND	ND	ND	ND	ND	99.67	ND	ND	ND	ND	ND	ND	ND	ND	0.0577	0.091	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.16	ND	ND	ND	ND	ND	ND	ND	99.31	ND	ND	0.2	ND	0.15	ND	ND	ND	0.072	0.115	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.29	ND	ND	ND	ND	ND	ND	ND	99.05	ND	ND	0.26	ND	0.18	ND	ND	ND	0.0763	0.134	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND	99.69	ND	ND	ND	ND	ND	ND	ND	ND	0.0478	0.06	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND	ND	ND	99.63	ND	ND	ND	ND	ND	ND	ND	ND	0.0631	0.053	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.21	ND	ND	ND	ND	ND	ND	ND	98.53	0.42	ND	0.3	ND	0.23	ND	0.08	ND	0.0899	0.138	A
123-4/2-76	Bought	3.82	Augustus	ND	ND	ND	ND	0.27	ND	0.121	ND	ND	ND	ND	ND	95.71	0.42	ND	ND	ND	ND	ND	0.08	3.27	0.0719	0.059	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	ND	ND	0.164	ND	ND	ND	ND	ND	99.71	ND	ND	ND	ND	ND	ND	ND	ND	0.0266	0.096	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.12	ND	0.147	ND	ND	ND	ND	ND	99.58	ND	ND	ND	ND	ND	ND	ND	ND	0.0427	0.109	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.11	ND	0.138	ND	ND	ND	ND	ND	99.63	ND	ND	ND	ND	ND	ND	ND	ND	0.0272	0.092	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.08	ND	0.152	ND	ND	ND	ND	ND	99.64	ND	ND	ND	ND	ND	ND	ND	ND	0.0304	0.098	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.24	ND	0.208	ND	ND	ND	ND	ND	99.29	ND	ND	ND	ND	ND	ND	0.07	ND	0.0466	0.138	A
119-547/15-76	Bought	3.5	Augustus	ND	ND	ND	ND	0.13	ND	0.212	ND	ND	ND	ND	ND	99.5	ND	ND	ND	ND	ND	ND	ND	ND	0.052	0.109	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	ND	ND	0.14	ND	ND	ND	ND	ND	ND	ND	99.75	ND	ND	ND	ND	ND	ND	ND	ND	0.0489	0.066	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	ND	ND	0.1	ND	ND	ND	ND	ND	ND	ND	99.78	ND	ND	ND	ND	ND	ND	ND	ND	0.0484	0.067	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	ND	ND	0.13	ND	ND	ND	ND	ND	ND	ND	99.77	ND	ND	ND	ND	ND	ND	ND	ND	0.0331	0.076	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	0.1	ND	0.16	ND	0.08	0.03	ND	ND	ND	ND	96.35	0.43	ND	ND	ND	ND	ND	0.07	2.63	0.0637	0.067	A
5-2091-123/4	Confiscation	3.53	Augustus	ND	ND	ND	ND	0.17	ND	ND	ND	ND	ND	ND	ND	98.95	0.44	ND	0.09	ND	0.15	ND	0.08	ND	0.0512	0.072	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.34	ND	0.094	ND	ND	ND	ND	ND	99.41	ND	ND	ND	ND	ND	ND	ND	ND	0.071	0.083	A
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.37	ND	0.087	ND	ND	ND	ND	ND	99.37	ND	ND	ND	ND	ND	ND	ND	ND	0.0749	0.092	A
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.61	ND	0.115	ND	ND	ND	ND	ND	99.1	ND	ND	ND	ND	ND	ND	ND	ND	0.0802	0.092	A
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.41	ND	0.14	ND	ND	ND	ND	ND	98.92	0.38	ND	ND	ND	ND	ND	ND	ND	0.0838	0.072	A
6-2113-37/3	Bought	3.37	Augustus	ND	ND	ND	ND	0.66	ND	0.167	ND	ND	ND	ND	ND	99.03	ND	ND	ND	ND	ND	ND	ND	ND	0.0753	0.068	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.657	ND	ND	ND	ND	ND	99.29	ND	ND	ND	ND	ND	ND	ND	ND	0.0488	ND	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.672	ND	ND	ND	ND	ND	99.25	ND	ND	ND	ND	ND	ND	ND	ND	0.0427	0.035	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.345	ND	ND	ND	ND	ND	99.56	ND	ND	ND	ND	ND	ND	ND	ND	0.0506	0.041	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.336	ND	ND	ND	ND	ND	99.61	ND	ND	ND	ND	ND	ND	ND	ND	0.0492	ND	A
6-1780-297	Bought	3.69	Augustus	0.313	ND	ND	ND	ND	ND	1.084	0.03	ND	ND	ND	ND	98.49	ND	ND	ND	ND	ND	ND	ND	ND	0.0471	0.034	A
6-1780-297	Bought	3.69	Augustus	ND	ND	ND	ND	ND	ND	0.449	0.03	ND	ND	ND	ND	98.98	0.45	ND	ND	ND	ND	ND	ND	ND	0.0505	0.037	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	ND	ND	0.099	0.04	ND	ND	ND	ND	99.73	ND	ND	ND	ND	ND	ND	ND	ND	0.0623	0.062	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	ND	ND	0.091	ND	ND	ND	ND	ND	99.78	ND	ND	ND	ND	ND	ND	ND	ND	0.0709	0.062	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	0.06	ND	0.146	ND	ND	ND	ND	ND	99.64	ND	ND	ND	ND	ND	ND	ND	ND	0.0831	0.067	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	ND	ND	0.109	ND	ND	ND	ND	ND	99.75	ND	ND	ND	ND	ND	ND	ND	ND	0.0788	0.059	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	0.13	ND	0.166	ND	ND	ND	ND	ND	99.06	0.51	ND	ND	ND	ND	ND	ND	ND	0.0716	0.064	A
5-1499-218	Bought	3.51	Augustus	ND	ND	ND	ND	0.11	ND	0.192	ND	ND	ND	ND	ND	99.56	ND	ND	ND	ND	ND	ND	ND	ND	0.082	0.058	A
7-2124-208/13	Confiscation	3.57	Tiberius	ND	ND	ND	ND	0.21	ND	0.274	0.24	ND	ND	ND	ND	99.16	ND	ND	ND	ND	ND	ND	ND	ND	0.1156	ND	A
5-2019-22/6	Confiscation	3.67	Tiberius	ND	ND	ND	ND	0.43	ND	0.331	ND	ND	ND	ND	ND	98.99	ND	ND	ND	ND	ND	ND	ND	ND	0.1647	0.08	A
12-1706-6	Bought	3.66	Tiberius	ND	ND	ND	ND	0.08	ND	0.384	0.03	ND	ND	ND	ND	99.3	ND	ND	ND	ND	ND	ND	ND	ND	0.1728	0.033	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
1123-6	Bought	3.57	Tiberius	ND	ND	ND	0.06	0.46	ND	0.115	2.77	ND	ND	ND	ND	96.38	ND	ND	ND	ND	ND	ND	ND	ND	0.1177	0.107	A
496-1	Bought	3.66	Tiberius	ND	ND	ND	ND	ND	ND	0.233	ND	ND	ND	ND	ND	99.54	ND	ND	ND	ND	ND	ND	ND	ND	0.1814	0.044	A
1954/1-1	Bought	7.18	Claudius	ND	ND	ND	ND	ND	ND	3.875	ND	ND	ND	ND	ND	95.86	ND	ND	ND	ND	ND	ND	ND	ND	0.1835	0.081	A
150-870/15-76	Bought	1.65	Claudius	0.247	ND	ND	ND	0.59	ND	12.4	0.06	ND	ND	ND	ND	85.26	ND	ND	ND	ND	ND	ND	0.07	ND	1.2799	0.093	A
5-2020-52-10	Bought	1.55	Claudius	0.299	ND	ND	0.05	0.3	ND	6.931	0.05	ND	ND	ND	ND	91.18	ND	ND	ND	ND	ND	ND	0.06	ND	1.0546	0.076	A
10-1752-7/6	Bought	1.3	Claudius	0.341	ND	ND	ND	ND	ND	1.813	ND	ND	ND	ND	ND	96.77	ND	ND	ND	ND	ND	ND	0.06	ND	0.9535	0.069	A
12-1708-405/13	Bought	3.67	Claudius	ND	ND	0.14	ND	ND	ND	0.105	ND	ND	ND	ND	ND	99.49	ND	ND	ND	ND	ND	ND	ND	ND	0.1877	0.085	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.38	ND	11.57	ND	ND	ND	ND	ND	86.65	ND	ND	ND	ND	ND	ND	ND	ND	1.3027	0.094	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.28	ND	7.988	ND	ND	ND	ND	ND	90.28	ND	ND	ND	ND	ND	ND	ND	ND	1.3654	0.089	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.35	ND	11.37	ND	ND	ND	ND	ND	86.92	ND	ND	ND	ND	ND	ND	ND	ND	1.2693	0.087	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.41	ND	8.956	ND	ND	ND	ND	ND	89.25	ND	ND	ND	ND	ND	ND	ND	ND	1.2825	0.095	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	ND	ND	5.642	ND	ND	ND	ND	ND	92.95	ND	ND	ND	ND	ND	ND	ND	ND	1.3107	0.093	A
150-870/15-76	Bought	1.65	Claudius	0.239	ND	ND	0.05	0.38	ND	9.129	0.03	ND	ND	ND	ND	88.07	0.65	ND	ND	ND	ND	ND	0.05	ND	1.2888	0.102	A
150-870/15-76	Bought	1.65	Claudius	0.281	ND	ND	ND	0.71	ND	11.63	0.05	ND	ND	ND	ND	85.38	0.56	ND	ND	ND	ND	ND	0.05	ND	1.2391	0.09	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.23	ND	8.748	ND	ND	ND	ND	ND	89.58	ND	ND	ND	ND	ND	ND	ND	ND	1.341	0.098	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.25	ND	9.986	ND	ND	ND	ND	ND	88.26	ND	ND	ND	ND	ND	ND	ND	ND	1.4174	0.096	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.11	ND	6.44	ND	ND	ND	ND	ND	91.98	ND	ND	ND	ND	ND	ND	ND	ND	1.3608	0.101	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.51	ND	11.02	ND	ND	ND	ND	ND	87.17	ND	ND	ND	ND	ND	ND	ND	ND	1.2104	0.087	A
150-870/15-76	Bought	1.65	Claudius	ND	ND	ND	ND	0.34	ND	8.162	ND	ND	ND	ND	ND	90.16	ND	ND	ND	ND	ND	ND	ND	ND	1.2455	0.096	A
1574-16/4	Bought	3.41	Nero	ND	ND	ND	ND	ND	ND	3.554	ND	ND	ND	ND	ND	94.86	ND	ND	ND	ND	ND	ND	0.06	ND	1.4743	0.05	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
42-7/2-76	Bought	2.76	Galba	ND	ND	ND	ND	ND	ND	2.723	ND	ND	ND	ND	ND	96.77	ND	ND	ND	ND	ND	ND	ND	ND	0.5113	ND	A
7-2113-37/6	Bought	2.14	Galba	0.472	ND	ND	ND	0.34	ND	3.029	0.03	ND	ND	ND	ND	94.63	ND	ND	ND	ND	ND	ND	0.06	ND	1.3928	0.045	A
98-M189	Juliopolis Exc.	2.45	Vespasian	ND	ND	ND	ND	ND	ND	2.622	ND	ND	ND	ND	ND	96.79	ND	ND	ND	ND	ND	ND	ND	ND	0.5529	0.035	A
98-M189	Juliopolis Exc.	2.45	Vespasian	ND	ND	ND	ND	ND	ND	3.611	ND	ND	ND	ND	ND	95.78	ND	ND	ND	ND	ND	ND	ND	ND	0.5687	0.041	A
63-M154	Juliopolis Exc.	2.36	Vespasian	ND	ND	ND	ND	0.05	ND	1.842	ND	ND	ND	ND	ND	95.94	ND	ND	ND	ND	ND	ND	ND	ND	2.0807	0.082	A
49-M139	Juliopolis Exc.	2.22	Vespasian	ND	ND	ND	ND	ND	ND	2.316	ND	ND	ND	ND	ND	96.92	ND	ND	ND	ND	ND	ND	ND	ND	0.7095	0.053	A
3-M96	Juliopolis Exc.	3.09	Vespasian	ND	ND	ND	ND	ND	ND	3.363	ND	ND	ND	ND	ND	96.32	ND	ND	ND	ND	ND	ND	ND	ND	0.2752	0.045	A
1223-28	Bought	3.26	Vespasian	ND	ND	ND	0.06	0.05	ND	3.918	0.05	ND	ND	ND	ND	95.02	ND	ND	ND	ND	ND	ND	ND	ND	0.8566	0.046	A
1202-7/1	Bought	2.95	Vespasian	0.341	ND	ND	ND	ND	ND	3.821	0.05	ND	ND	ND	ND	94.66	ND	ND	ND	ND	ND	ND	ND	ND	1.0491	0.08	A
1202-7/2	Bought	2.71	Vespasian	ND	ND	ND	ND	ND	ND	6.228	0.05	ND	ND	ND	ND	92.95	ND	ND	ND	ND	ND	ND	ND	ND	0.6948	0.079	A
1189-11	Bought	2.99	Vespasian	ND	ND	ND	ND	ND	ND	2.681	ND	ND	ND	ND	ND	96.54	ND	ND	ND	ND	ND	ND	ND	ND	0.702	0.08	A
111-825-1	Bought	3.05	Vespasian	ND	ND	0.1	ND	ND	ND	4.766	0.04	ND	ND	ND	ND	94.56	ND	ND	ND	ND	ND	ND	ND	ND	0.5416	ND	A
518-7	Bought	2.88	Vespasian	ND	ND	ND	ND	ND	ND	3.446	ND	ND	ND	ND	ND	96.1	ND	ND	ND	ND	ND	ND	ND	ND	0.4565	ND	A
9-1529-4	Bought	2.86	Vespasian	0.338	ND	ND	ND	ND	ND	9.535	0.07	ND	ND	ND	ND	89.23	ND	ND	ND	0.33	ND	ND	ND	ND	0.4673	0.03	A
9-1529-4/1	Bought	2.72	Vespasian	ND	ND	ND	ND	0.05	ND	2.191	ND	ND	ND	ND	ND	95.33	ND	ND	ND	ND	ND	ND	0.08	ND	2.3519	ND	A
5-1499-218	Bought	3.26	Vespasian	ND	ND	ND	ND	0.07	ND	18.11	0.09	ND	ND	ND	ND	81.02	ND	ND	ND	ND	ND	ND	0.05	ND	0.6229	0.046	A
1-1677-50/5	Bought	13.78	Vespasian	ND	ND	ND	ND	ND	ND	13.28	0.06	ND	ND	ND	ND	86.11	ND	ND	ND	ND	ND	ND	ND	ND	0.504	0.039	A
11-1869-52/47	Gümüşhane Hoard	1.51	Vespasian	0.343	ND	ND	ND	0.07	ND	4.814	0.04	ND	ND	ND	ND	92.38	1.89	ND	ND	ND	ND	ND	0.06	ND	0.2845	0.126	A
11-1869-52/58	Gümüşhane Hoard	1.27	Vespasian	0.342	ND	ND	0.09	ND	ND	3.33	0.05	ND	ND	ND	ND	95.39	ND	ND	ND	ND	ND	ND	0.05	ND	0.7024	0.043	A
12-1873-476/41	Bought	2.37	Vespasian	ND	ND	0.11	ND	1.87	ND	2.308	0.03	ND	ND	ND	ND	94.41	ND	ND	ND	ND	ND	ND	0.07	ND	1.1994	ND	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	0.06	ND	9.989	ND	ND	ND	ND	ND	89.29	ND	ND	ND	ND	ND	ND	ND	ND	0.6604	ND	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	10.38	ND	ND	ND	ND	ND	88.97	ND	ND	ND	ND	ND	ND	ND	ND	0.6527	ND	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	7.438	ND	ND	ND	ND	ND	91.9	ND	ND	ND	ND	ND	ND	ND	ND	0.6652	ND	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	0.05	0.16	ND	11.38	0.05	ND	ND	ND	ND	87.26	0.42	ND	ND	ND	ND	ND	ND	ND	0.673	ND	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	0.08	ND	7.875	0.04	ND	ND	ND	ND	90.89	0.46	ND	ND	ND	ND	ND	ND	ND	0.6487	ND	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	16.51	ND	ND	ND	ND	ND	82.87	ND	ND	ND	ND	ND	ND	ND	ND	0.5873	0.037	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	19.08	ND	ND	ND	ND	ND	80.29	ND	ND	ND	ND	ND	ND	ND	ND	0.578	0.049	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	22.22	ND	ND	0.01	ND	ND	77.19	ND	ND	ND	ND	ND	ND	ND	ND	0.544	0.038	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	0.05	ND	18.16	0.07	ND	ND	ND	ND	81.08	ND	ND	ND	ND	ND	ND	ND	ND	0.5955	0.048	A
5-1499-218	Bought	3.54	Vespasian	ND	ND	ND	ND	ND	ND	16.23	ND	ND	ND	ND	ND	83.11	ND	ND	ND	ND	ND	ND	ND	ND	0.6188	0.042	A
90-M196	Juliopolis Exc.	1.47	Domitian	ND	ND	ND	ND	ND	ND	0.273	ND	ND	ND	ND	ND	99.29	ND	ND	ND	ND	ND	ND	0.06	ND	0.3287	0.044	A
90-M196	Juliopolis Exc.	1.47	Domitian	ND	ND	ND	ND	ND	ND	0.514	ND	ND	ND	ND	ND	98.86	ND	ND	ND	ND	ND	ND	0.06	ND	0.5214	0.046	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	0.04	ND	22.88	0.1	ND	ND	ND	ND	75.25	0.64	ND	ND	ND	ND	ND	0.06	ND	0.9268	0.112	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	0.04	ND	14.79	0.06	ND	ND	ND	ND	83.43	0.65	ND	ND	ND	ND	ND	0.06	ND	0.8727	0.103	A
22-M120	Juliopolis Exc.	2.64	Domitian	0.388	ND	ND	ND	ND	ND	1.585	ND	ND	ND	ND	ND	97.76	ND	ND	ND	ND	ND	ND	0.06	ND	0.5475	0.046	A
5-M110	Juliopolis Exc.	2.2	Domitian	ND	ND	ND	ND	ND	ND	2.104	ND	ND	ND	ND	ND	96.44	0.45	ND	ND	ND	ND	ND	0.06	ND	0.909	0.043	A
Z1	By Police From Zurich	3.52	Domitian	ND	ND	ND	ND	ND	ND	2.19	ND	ND	ND	ND	ND	96.65	0.6	ND	ND	ND	ND	ND	ND	ND	0.5187	0.048	A
Z10	By Police From Zurich	3.31	Domitian	ND	ND	ND	ND	ND	ND	2.963	ND	ND	ND	ND	ND	95.96	0.49	ND	ND	ND	ND	ND	ND	ND	0.5373	0.043	A
Z10	By Police From Zurich	3.31	Domitian	ND	ND	ND	ND	ND	ND	3.182	ND	ND	ND	ND	ND	95.75	0.42	ND	ND	ND	ND	ND	ND	ND	0.6088	0.047	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	20.99	ND	ND	ND	ND	ND	77.38	0.61	ND	ND	ND	ND	ND	ND	ND	0.9125	0.108	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	9.049	ND	ND	ND	ND	ND	89.19	0.73	ND	ND	ND	ND	ND	ND	ND	0.9186	0.118	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	8.987	ND	ND	ND	ND	ND	89.42	0.61	ND	ND	ND	ND	ND	ND	ND	0.8708	0.114	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	22.84	0.08	ND	0.01	ND	ND	74.78	0.84	0.41	ND	ND	ND	ND	0.05	ND	0.8722	0.114	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	16	0.06	ND	ND	ND	ND	82.1	0.76	ND	ND	ND	ND	ND	0.06	ND	0.9016	0.114	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	20.52	ND	ND	ND	ND	ND	78.37	ND	ND	ND	ND	ND	ND	ND	ND	0.991	0.114	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	22.65	ND	ND	ND	ND	ND	76.31	ND	ND	ND	ND	ND	ND	ND	ND	0.9276	0.112	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	11.27	ND	ND	0.01	ND	ND	87.11	0.61	ND	ND	ND	ND	ND	ND	ND	0.8952	0.106	A
25-M122	Juliopolis Exc.	1.51	Domitian	ND	ND	ND	ND	ND	ND	16.67	ND	ND	ND	ND	ND	82.3	ND	ND	ND	ND	ND	ND	ND	ND	0.9194	0.108	A
Z6	By Police From Zurich	3.25	Nerva	ND	ND	ND	ND	0.05	ND	1.537	ND	ND	ND	ND	ND	97.79	0.46	ND	ND	ND	ND	ND	ND	ND	0.1606	ND	A
Z6	By Police From Zurich	3.25	Nerva	ND	ND	ND	ND	ND	ND	1.868	ND	ND	ND	ND	ND	97.62	0.43	ND	ND	ND	ND	ND	ND	ND	0.0826	ND	A
Z6	By Police From Zurich	3.25	Nerva	ND	ND	ND	ND	ND	ND	1.883	ND	ND	ND	ND	ND	98.03	ND	ND	ND	ND	ND	ND	ND	ND	0.0895	ND	A
1373-16	Bought	3.45	Nerva	ND	ND	ND	ND	ND	ND	2.868	ND	ND	ND	ND	ND	96.64	ND	ND	ND	ND	ND	ND	ND	ND	0.4624	0.031	A
1373-16	Bought	3.45	Nerva	ND	ND	ND	ND	ND	ND	3.155	ND	ND	ND	ND	ND	96.45	ND	ND	ND	ND	ND	ND	ND	ND	0.3976	ND	A
1969-IV-1826-17/4	Bought	6.38	Nerva	ND	ND	ND	ND	ND	ND	31.93	0.09	ND	0.01	ND	ND	67.42	ND	ND	ND	ND	ND	0.12	ND	ND	0.4225	ND	A
1969-IV-1826-17/4	Bought	6.38	Nerva	ND	ND	ND	ND	ND	ND	23.33	0.08	ND	ND	ND	ND	76.13	ND	ND	ND	ND	ND	ND	ND	ND	0.4578	ND	A
104-M180	Juliopolis Exc.	2.33	Trajan	ND	ND	ND	ND	ND	ND	2.557	ND	ND	ND	ND	ND	96.37	ND	ND	ND	ND	ND	ND	ND	ND	0.8664	0.203	A
104-M180	Juliopolis Exc.	2.33	Trajan	ND	ND	ND	ND	ND	ND	3.229	ND	ND	ND	ND	ND	95.74	ND	ND	ND	ND	ND	ND	ND	ND	0.8399	0.192	A
97-M190	Juliopolis Exc.	2.38	Trajan	ND	ND	ND	ND	ND	ND	2.164	ND	ND	ND	ND	ND	97.14	ND	ND	ND	ND	ND	ND	ND	ND	0.644	0.048	A
58b-M148	Juliopolis Exc.	1.6	Trajan	ND	ND	0.02	ND	0.05	ND	3.828	0.03	ND	ND	ND	ND	95.02	ND	ND	ND	ND	ND	ND	ND	ND	0.7257	0.05	A
48-M139	Juliopolis Exc.	2.44	Trajan	ND	ND	ND	ND	ND	ND	3.466	ND	ND	ND	ND	ND	95.43	ND	ND	ND	ND	ND	ND	0.05	ND	0.9146	0.134	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
38-M132	Juliopolis Exc.	2.17	Trajan	ND	ND	ND	ND	0.06	ND	5.623	0.04	ND	ND	ND	ND	92.36	ND	ND	ND	ND	ND	ND	0.06	ND	1.7297	0.133	A
609-1	Bought	3.27	Trajan	ND	ND	ND	ND	0.05	ND	3.867	0.03	ND	ND	ND	ND	94.66	0.38	ND	ND	ND	ND	ND	ND	ND	0.9374	0.068	A
609-1	Bought	3.27	Trajan	ND	ND	ND	ND	ND	ND	3.205	0.07	ND	ND	ND	ND	95.73	ND	ND	ND	ND	ND	ND	ND	ND	0.9246	0.071	A
576-1	Bought	2.64	Trajan	ND	ND	ND	ND	ND	ND	4.5	0.03	ND	ND	ND	ND	94.43	ND	ND	ND	ND	ND	ND	ND	ND	0.9674	0.076	A
576-1	Bought	2.64	Trajan	ND	ND	ND	ND	ND	ND	4.386	0.05	ND	ND	ND	ND	94.47	ND	ND	ND	ND	ND	ND	ND	ND	0.9991	0.091	A
1223-28	Bought	3.2	Trajan	ND	ND	ND	ND	0.1	ND	2.081	0.03	ND	ND	ND	ND	96.65	ND	ND	ND	ND	ND	ND	0.05	ND	0.8791	0.205	A
1223-28	Bought	3.2	Trajan	ND	ND	ND	ND	0.1	ND	2.328	0.03	ND	ND	ND	ND	96.53	ND	ND	ND	ND	ND	ND	ND	ND	0.8137	0.195	A
1188-11	Bought	3.04	Trajan	ND	ND	ND	ND	0.06	ND	3.923	ND	ND	ND	ND	ND	95.01	ND	ND	ND	ND	ND	ND	ND	ND	0.9281	0.082	A
1188-11	Bought	3.04	Trajan	ND	ND	ND	ND	0.06	ND	4.368	0.03	ND	ND	ND	ND	94.45	ND	ND	ND	ND	ND	ND	ND	ND	0.9952	0.09	A
1961 IX -1529-4	Bought	2.58	Trajan	ND	ND	ND	ND	ND	ND	2.263	ND	ND	ND	ND	ND	96.69	ND	ND	ND	ND	ND	ND	ND	ND	0.9129	0.131	A
1961 IX -1529-4	Bought	2.58	Trajan	ND	ND	ND	ND	ND	ND	2.143	0.03	ND	ND	ND	ND	96.8	ND	ND	ND	ND	ND	ND	ND	ND	0.9032	0.13	A
V-1499-218	Bought	3.1	Trajan	ND	ND	ND	ND	ND	ND	6.099	0.03	ND	ND	ND	ND	92.89	ND	ND	ND	ND	ND	ND	ND	ND	0.8827	0.1	A
V-1499-218	Bought	3.1	Trajan	ND	ND	ND	ND	ND	ND	6.765	0.03	ND	ND	ND	ND	92.13	ND	ND	ND	ND	ND	ND	ND	ND	0.9693	0.1	A
1964 VII-1636-7/1	Bought	2.95	Trajan	ND	ND	ND	ND	0.57	ND	3.281	ND	ND	ND	ND	ND	95.1	ND	ND	ND	ND	ND	ND	ND	ND	0.9387	0.11	A
1962 12-1578-1	Bought	3.59	Trajan	0.259	ND	0.08	ND	1.04	ND	7.632	0.04	ND	ND	ND	ND	90.14	ND	ND	ND	ND	ND	ND	ND	ND	0.6846	0.113	A
1956 11-1405-9	Bought	3.16	Trajan	ND	ND	ND	ND	ND	ND	8.932	ND	ND	ND	ND	ND	90.21	ND	ND	ND	ND	ND	ND	ND	ND	0.8072	0.048	A
1956 11-1405-9	Bought	3.16	Trajan	ND	ND	ND	ND	0.04	ND	7.237	ND	ND	ND	ND	ND	91.85	ND	ND	ND	ND	ND	ND	ND	ND	0.8239	0.05	A
1127-3	From Financial Ministery	2.77	Trajan	ND	ND	ND	ND	0.08	0.06	7.303	0.05	ND	ND	ND	ND	91.07	0.37	ND	ND	ND	ND	ND	ND	ND	0.9914	0.077	A
1127-3	From Financial	2.77	Trajan	ND	ND	ND	ND	0.49	0.09	4.199	0.03	ND	ND	ND	ND	94.16	ND	ND	ND	ND	ND	ND	ND	ND	0.9425	0.09	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
	Ministery																										
1947 XII-1212-17	Bought	3.31	Trajan	ND	ND	ND	ND	ND	ND	4.533	ND	ND	ND	ND	ND	94.29	ND	ND	ND	ND	ND	ND	ND	ND	1.0459	0.129	A
9-1556-2-1	Bought	2.97	Trajan	ND	ND	ND	ND	0.29	0.03	2.289	ND	ND	ND	ND	ND	96.66	ND	ND	ND	ND	ND	ND	ND	ND	0.6743	0.047	A
101-M184	Juliopolis Exc.	2.63	Trajan	ND	ND	ND	ND	ND	ND	3.864	0.03	ND	ND	ND	ND	95.2	ND	ND	ND	ND	ND	ND	ND	ND	0.8265	0.082	A
100-M189	Juliopolis Exc.	2.22	Hadrian	ND	ND	ND	ND	ND	ND	2.07	ND	ND	ND	ND	ND	97.21	ND	ND	ND	ND	ND	ND	ND	ND	0.4531	0.268	A
100-M189	Juliopolis Exc.	2.22	Hadrian	ND	ND	ND	ND	ND	ND	2.272	ND	ND	ND	ND	ND	96.99	ND	ND	ND	ND	ND	ND	ND	ND	0.4485	0.294	A
99-M189	Juliopolis Exc.	2.71	Hadrian	ND	ND	0.1	ND	ND	ND	9.185	0.05	ND	ND	ND	ND	90.12	ND	ND	ND	ND	ND	ND	ND	ND	0.5325	0.115	A
99-M189	Juliopolis Exc.	2.71	Hadrian	ND	ND	ND	ND	ND	ND	8.953	0.04	ND	ND	ND	ND	90.32	ND	ND	ND	ND	ND	ND	ND	ND	0.4953	0.089	A
83-M179	Juliopolis Exc.	2.5	Hadrian	ND	ND	ND	ND	ND	ND	2.565	ND	ND	ND	ND	ND	96.06	ND	ND	ND	ND	ND	ND	0.04	ND	1.2554	0.08	A
82-M177	Juliopolis Exc.	2.37	Hadrian	ND	ND	ND	ND	ND	ND	5.193	0.03	ND	ND	ND	ND	93.48	ND	ND	ND	ND	ND	ND	ND	ND	1.1265	0.176	A
82-M177	Juliopolis Exc.	2.37	Hadrian	0.297	ND	ND	ND	ND	ND	5.81	0.03	ND	ND	ND	ND	92.71	ND	ND	ND	ND	ND	ND	ND	ND	1.2646	0.18	A
70-M162	Juliopolis Exc.	2.06	Hadrian	ND	ND	ND	ND	ND	ND	1.763	ND	ND	ND	ND	ND	97.24	ND	ND	ND	ND	ND	ND	ND	ND	0.8935	0.108	A
21-M-120	Juliopolis Exc.	2.62	Hadrian	ND	ND	ND	ND	ND	ND	2.3	ND	ND	ND	ND	ND	96.65	ND	ND	ND	ND	ND	ND	ND	ND	0.6	0.007	A
37-M131	Juliopolis Exc.	2.22	Hadrian	ND	ND	ND	ND	ND	ND	3.346	ND	ND	ND	ND	ND	95.13	ND	ND	ND	ND	ND	ND	ND	ND	1.3273	0.192	A
20-M118	Juliopolis Exc.	2.1	Hadrian	ND	ND	ND	ND	ND	ND	2.448	ND	0.01	ND	ND	ND	95.46	ND	ND	ND	ND	ND	ND	0.06	ND	1.6261	0.401	A
19-M118	Juliopolis Exc.	2.66	Sabina	ND	ND	ND	ND	ND	ND	1.667	ND	ND	ND	ND	ND	97.26	0.45	ND	ND	ND	ND	ND	ND	ND	0.5312	0.087	A
14-M113	Juliopolis Exc.	2.47	Hadrian	0.226	ND	0.07	ND	0.05	ND	2.706	ND	ND	ND	ND	ND	95.3	0.5	ND	ND	ND	ND	ND	ND	ND	1.2203	0.227	A
103-M178	Juliopolis Exc.	3.36	Antoninus Pius	ND	ND	ND	ND	0.04	ND	6.053	0.04	ND	ND	ND	ND	91.31	ND	ND	ND	ND	ND	ND	ND	ND	1.9634	0.592	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	15.92	0.07	ND	ND	ND	ND	82.25	0.41	ND	ND	ND	ND	ND	0.05	ND	1.0019	0.293	A
92-M198	Juliopolis Exc.	3.12	Antoninus Pius	ND	ND	ND	ND	ND	ND	7.364	0.03	ND	ND	ND	ND	90.25	ND	ND	ND	ND	ND	ND	0.06	ND	1.8809	0.414	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
87-M195	Juliopolis Exc.	2.14	Antoninus Pius	ND	0.06	ND	ND	ND	ND	1.865	ND	ND	ND	ND	ND	96.88	0.44	ND	ND	ND	ND	ND	0.05	ND	0.6802	0.092	A
81-M176	Juliopolis Exc.	2.84	Antoninus Pius	ND	ND	ND	ND	0.2	ND	9.831	0.05	ND	ND	ND	ND	87.92	0.38	ND	ND	ND	ND	ND	0.05	ND	1.1015	0.168	A
78-M173	Juliopolis Exc.	2.3	Antoninus Pius	ND	ND	ND	ND	0.06	ND	2.905	ND	ND	ND	ND	ND	96.15	ND	ND	ND	ND	ND	ND	ND	ND	0.7384	0.147	A
76-M171	Juliopolis Exc.	2.56	Faustina I	ND	ND	ND	ND	0.05	ND	5.444	0.03	ND	ND	ND	ND	92.88	ND	ND	ND	ND	ND	ND	0.05	ND	1.2084	0.341	A
54-M147	Juliopolis Exc.	2.58	Antoninus Pius	ND	ND	ND	ND	0.06	ND	2.837	0.03	ND	ND	ND	ND	96.2	ND	ND	ND	ND	ND	ND	0.04	ND	0.681	0.151	A
23-M120	Juliopolis Exc.	3.17	Antoninus Pius	ND	ND	ND	ND	0.15	0.02	63.28	0.14	ND	0.01	ND	ND	35.16	ND	ND	ND	ND	ND	ND	ND	ND	1.2095	0.047	A
9-M112	Juliopolis Exc.	2.66	Faustina I	ND	ND	ND	ND	0.08	ND	17.96	0.06	ND	ND	ND	ND	80.79	0.37	ND	ND	ND	ND	ND	ND	ND	0.5379	0.197	A
Z3	By Police From Zurich	3.5	Antoninus Pius	ND	ND	ND	ND	ND	ND	14.27	0.05	ND	ND	ND	ND	83.68	1	ND	ND	ND	ND	ND	ND	ND	0.9188	0.085	A
Z20	By Police From Zurich	3.45	Antoninus Pius	ND	ND	ND	ND	ND	ND	10.79	0.05	ND	ND	ND	ND	88.15	ND	ND	ND	ND	ND	ND	0.05	ND	0.8503	0.111	A
Z20	By Police From Zurich	3.45	Antoninus Pius	ND	ND	ND	ND	ND	ND	18.31	0.06	ND	ND	ND	ND	80.36	ND	ND	ND	ND	ND	ND	0.06	ND	1.062	0.144	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	15.09	ND	ND	ND	ND	ND	83.55	ND	ND	ND	ND	ND	ND	ND	ND	1.0597	0.304	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	15.19	ND	ND	ND	ND	ND	82.9	0.49	ND	ND	ND	ND	ND	ND	ND	1.1239	0.301	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	35.33	ND	ND	0.01	ND	ND	63.4	ND	ND	ND	ND	ND	ND	ND	ND	0.9585	0.301	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	31.7	ND	ND	ND	ND	ND	66.61	0.42	ND	ND	ND	ND	ND	ND	ND	0.9532	0.313	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.05	ND	15.35	0.06	ND	ND	ND	ND	82.62	0.61	ND	ND	ND	ND	ND	0.06	ND	0.9568	0.295	A
96-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	28.21	0.09	ND	ND	ND	ND	69.65	0.48	ND	ND	ND	ND	ND	0.08	ND	1.1486	0.347	A
95-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	15.94	ND	ND	ND	ND	ND	82.69	ND	ND	ND	ND	ND	ND	ND	ND	1.059	0.308	A
95-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	16.01	ND	ND	ND	ND	ND	82.56	ND	ND	ND	ND	ND	ND	ND	ND	1.1146	0.314	A
95-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	22.2	ND	ND	ND	ND	ND	76.35	ND	ND	ND	ND	ND	ND	ND	ND	1.1007	0.35	A
95-M190	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	ND	ND	15.51	ND	ND	ND	ND	ND	83	ND	ND	ND	ND	ND	ND	ND	ND	1.1539	0.334	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
9-M112	Juliopolis Exc.	2.66	Faustina I	ND	ND	ND	ND	ND	ND	19.33	ND	ND	ND	ND	ND	79.94	ND	ND	ND	ND	ND	ND	ND	ND	0.5617	0.174	A
9-M112	Juliopolis Exc.	2.66	Faustina I	ND	ND	ND	ND	ND	ND	15.9	ND	ND	ND	ND	ND	83.42	ND	ND	ND	ND	ND	ND	ND	ND	0.5232	0.156	A
9-M112	Juliopolis Exc.	2.66	Faustina I	ND	ND	ND	ND	ND	ND	7.735	ND	ND	ND	ND	ND	91.55	ND	ND	ND	ND	ND	ND	ND	ND	0.5558	0.161	A
23-M120	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.09	ND	68.55	ND	ND	0.01	ND	ND	30.37	ND	ND	ND	ND	ND	ND	ND	ND	0.9769	ND	A
23-M120	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.08	ND	64.26	ND	ND	0.02	ND	ND	34.38	ND	ND	ND	ND	ND	ND	ND	ND	1.203	0.056	A
23-M120	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.04	ND	58.79	ND	ND	0.01	ND	ND	39.79	ND	ND	ND	ND	ND	ND	ND	ND	1.3114	0.053	A
23-M120	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.09	ND	55.97	ND	ND	0.02	ND	ND	42.36	ND	ND	ND	ND	ND	ND	ND	ND	1.4967	0.06	A
23-M120	Juliopolis Exc.	2.98	Antoninus Pius	ND	ND	ND	ND	0.34	ND	60.9	ND	ND	0.02	ND	ND	37.7	ND	ND	ND	ND	ND	ND	ND	ND	1.0067	0.042	A
61-M151	Juliopolis Exc.	3.39	Marcus Aurelius	0.074	ND	ND	ND	0.08	ND	26.01	0.11	ND	ND	ND	ND	72.6	ND	ND	ND	ND	ND	ND	0.06	ND	0.5276	0.425	A
55-M148	Juliopolis Exc.	2.68	Marcus Aurelius	ND	ND	ND	ND	0.06	ND	5.562	0.03	ND	ND	ND	ND	91.91	ND	ND	ND	ND	ND	ND	0.05	ND	2.0797	0.202	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	39.04	0.15	ND	0.01	ND	ND	59.72	ND	ND	ND	ND	ND	ND	0.05	ND	0.7772	0.256	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	13.74	0.06	ND	ND	ND	ND	84.89	ND	ND	ND	ND	ND	ND	ND	ND	0.9984	0.322	A
41-M138	Juliopolis Exc.	2.4	Marcus Aurelius	ND	ND	ND	ND	0.08	ND	0.905	0.03	ND	ND	ND	ND	97.1	0.48	ND	ND	ND	ND	ND	0.06	ND	1.1348	0.203	A
15-M114	Juliopolis Exc.	2.13	Marcus Aurelius	0.057	ND	ND	ND	ND	ND	2.444	0.03	ND	ND	ND	ND	94.67	0.53	ND	ND	ND	ND	ND	0.06	ND	1.7425	0.239	A
2-M86	Juliopolis Exc.	3.35	Marcus Aurelius	ND	ND	ND	ND	0.03	ND	55.96	0.13	ND	ND	ND	ND	43.01	0.3	ND	ND	ND	ND	ND	ND	ND	0.4835	0.087	A
1936 1-218-1	Bought	2.7	Marcus Aurelius	ND	ND	ND	ND	ND	ND	6.013	0.05	ND	ND	ND	ND	91.57	0.7	ND	ND	ND	ND	ND	0.05	ND	1.5253	0.099	A
1936 1-218-1	Bought	2.7	Marcus Aurelius	0.27	ND	ND	ND	0.11	ND	17.51	0.09	ND	ND	ND	ND	79.91	0.62	ND	ND	ND	ND	ND	0.07	ND	1.3282	0.093	A
611-1	Bought	3.06	Marcus Aurelius	ND	ND	ND	ND	0.06	ND	2.55	0.05	ND	ND	ND	ND	95.62	0.4	ND	ND	0.69	ND	ND	ND	ND	0.3533	0.267	A
611-1	Bought	3.06	Marcus Aurelius	ND	ND	ND	ND	ND	ND	4.32	ND	ND	ND	ND	ND	93.46	ND	ND	ND	0.7	ND	ND	0.07	ND	0.8211	0.625	A
638-1	Bought	3.28	Marcus Aurelius	ND	ND	ND	ND	ND	ND	4.381	ND	ND	ND	ND	ND	93.69	ND	ND	ND	ND	ND	ND	ND	ND	1.6814	0.244	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
638-1	Bought	3.28	Marcus Aurelius	ND	ND	ND	ND	ND	ND	5.781	0.03	ND	ND	ND	ND	91.95	ND	ND	ND	ND	ND	ND	ND	ND	1.9446	0.295	A
1023-1	Bought	2.85	Marcus Aurelius	ND	ND	ND	ND	ND	ND	4.062	ND	ND	ND	ND	ND	94.88	ND	ND	ND	ND	ND	ND	ND	ND	0.8923	0.162	A
1128-67	Bought	2.79	Marcus Aurelius	ND	ND	ND	ND	0.07	ND	10.26	0.05	ND	ND	ND	ND	88.52	ND	ND	ND	ND	ND	ND	ND	ND	0.8798	0.22	A
1128-67	Bought	2.79	Marcus Aurelius	ND	ND	ND	ND	ND	ND	11.74	0.05	ND	ND	ND	ND	87	ND	ND	ND	ND	ND	ND	ND	ND	0.9715	0.236	A
1969 X-1861-243/3	Yatagan Hoard	3.15	Marcus Aurelius	ND	ND	ND	ND	ND	ND	5.503	ND	ND	ND	ND	ND	92.93	ND	ND	ND	ND	ND	ND	ND	ND	1.3636	0.204	A
1969 X-1861-243/3	Yatagan Hoard	3.15	Marcus Aurelius	ND	ND	ND	ND	0.08	ND	4.898	0.03	ND	ND	ND	ND	93.37	ND	ND	ND	ND	ND	ND	ND	ND	1.4141	0.21	A
1960 XII-1512-1	Bought	3.55	Marcus Aurelius	ND	ND	ND	ND	0.06	ND	7.09	0.06	ND	ND	ND	ND	91.28	0.42	ND	ND	ND	ND	ND	ND	ND	0.998	0.093	A
133-118-76	Bought	3.28	Marcus Aurelius	ND	ND	ND	ND	ND	ND	8.561	0.05	ND	ND	ND	ND	89.57	0.55	ND	ND	ND	ND	ND	ND	ND	0.8971	0.368	A
133-118-76	Bought	3.28	Marcus Aurelius	ND	ND	ND	ND	ND	ND	9.572	0.05	ND	ND	ND	ND	88.55	0.48	ND	ND	ND	ND	ND	ND	ND	0.9634	0.386	A
98-407/21-76	Bought	3.43	Marcus Aurelius	ND	ND	ND	ND	ND	ND	10.47	0.06	ND	ND	ND	ND	88.65	ND	ND	ND	ND	ND	ND	ND	ND	0.6213	0.206	A
98-407/20-76	Bought	3	Marcus Aurelius	ND	ND	ND	ND	0.07	ND	7.555	0.08	ND	ND	ND	ND	91.07	ND	ND	ND	ND	ND	ND	ND	ND	0.9374	0.294	A
788-23	Bought	3.48	Marcus Aurelius	ND	ND	ND	ND	0.19	ND	16.89	0.06	ND	ND	ND	ND	81.6	ND	ND	ND	ND	ND	ND	0.05	ND	1.0348	0.167	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	35.38	ND	ND	ND	ND	ND	63.44	ND	ND	ND	ND	ND	ND	ND	ND	0.8983	0.286	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	36.14	ND	ND	ND	ND	ND	62.82	ND	ND	ND	ND	ND	ND	ND	ND	0.8111	0.235	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	7.242	ND	ND	ND	ND	ND	91.44	ND	ND	ND	ND	ND	ND	ND	ND	1.002	0.315	A
47-M139	Juliopolis Exc.	2.45	Marcus Aurelius	ND	ND	ND	ND	ND	ND	24.84	ND	ND	ND	ND	ND	73.89	ND	ND	ND	ND	ND	ND	ND	ND	0.9475	0.322	A
27-M123	Juliopolis Exc.	2.44	Pescennius Niger	0.243	ND	ND	ND	ND	ND	12.06	0.06	ND	ND	ND	ND	86.94	0.4	ND	ND	ND	ND	ND	ND	ND	0.459	0.071	A
27-M123	Juliopolis Exc.	2.44	Pescennius Niger	ND	ND	ND	ND	ND	ND	10.28	0.05	ND	ND	ND	ND	88.4	0.35	ND	ND	ND	ND	ND	0.06	ND	0.5353	0.083	A
64-M154	Juliopolis Exc.	3.4	Julia Domna	ND	ND	ND	ND	ND	ND	28.59	0.11	ND	ND	ND	ND	69.77	0.45	ND	ND	ND	ND	ND	0.06	ND	0.9343	0.08	A
45-M138	Juliopolis Exc.	2.6	Septimius Severus	ND	ND	ND	0.04	ND	ND	22.71	0.1	ND	ND	ND	ND	75.59	0.32	ND	ND	ND	ND	ND	0.07	ND	0.7975	0.209	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
43-M138	Juliopolis Exc.	1.77	Julia Domna	ND	ND	ND	ND	0.12	ND	7.185	0.04	ND	ND	ND	ND	88.94	2.84	ND	ND	ND	ND	ND	ND	ND	0.6222	0.257	A
12-M112	Juliopolis Exc.	2.31	Julia Domna	ND	ND	ND	ND	0.04	ND	33.09	0.09	ND	ND	ND	ND	65.45	0.39	ND	ND	ND	ND	ND	ND	ND	0.8442	0.096	A
Z4	By Police From Zurich	2.99	Julia Domna	ND	ND	ND	ND	ND	ND	14.29	0.07	ND	ND	ND	ND	83.9	0.57	ND	ND	ND	ND	ND	ND	ND	1.0734	0.094	A
Z8	By Police From Zurich	2.96	Julia Domna	ND	ND	ND	ND	ND	ND	16.77	0.05	ND	0.01	ND	ND	81.68	0.55	ND	ND	ND	ND	ND	ND	ND	0.8746	0.062	A
Z8	By Police From Zurich	2.96	Julia Domna	ND	ND	ND	ND	ND	ND	9.739	0.04	ND	ND	ND	ND	88.67	0.61	ND	ND	ND	ND	ND	ND	ND	0.8609	0.078	A
Z16	By Police From Zurich	3.32	Julia Domna	ND	ND	ND	ND	ND	ND	13.68	0.06	ND	ND	ND	ND	84.96	ND	ND	ND	ND	ND	ND	ND	ND	1.217	0.084	A
Z16	By Police From Zurich	3.32	Julia Domna	ND	ND	ND	ND	ND	ND	18.62	0.07	ND	ND	ND	ND	80.04	ND	ND	ND	ND	ND	ND	ND	ND	1.1785	0.095	A
Z17	By Police From Zurich	3	Julia Domna	0.325	ND	ND	ND	ND	0.04	17.06	0.08	ND	ND	ND	ND	81.91	ND	ND	ND	ND	ND	ND	0.06	ND	0.4306	0.095	A
Z17	By Police From Zurich	3	Julia Domna	ND	ND	ND	ND	ND	0.03	16.42	0.08	ND	ND	ND	ND	82.46	0.45	ND	ND	ND	ND	ND	ND	ND	0.4438	0.108	A
79-M174	Juliopolis Exc.	1.63	Caracalla	ND	ND	ND	ND	ND	ND	21.19	0.08	ND	ND	ND	ND	77.4	0.43	ND	ND	ND	ND	ND	0.06	ND	0.6873	0.158	A
71-M164	Juliopolis Exc.	2.35	Caracalla	ND	ND	ND	ND	ND	ND	22.13	0.08	ND	ND	ND	ND	77.51	ND	ND	ND	ND	ND	ND	ND	ND	0.2215	0.055	A
7-M112	Juliopolis Exc.	2.54	Caracalla	ND	ND	ND	ND	0.09	ND	19.4	0.25	ND	ND	ND	ND	74.21	4.31	ND	ND	ND	ND	ND	ND	ND	1.6827	0.065	A
10-1861-243/95	Yatağan Hoard	2.77	Caracalla	ND	ND	ND	ND	0.24	ND	20.25	0.12	ND	ND	ND	ND	76.87	0.74	0.4	ND	ND	ND	ND	ND	ND	1.2542	0.131	A
10-1861-243/95	Yatağan Hoard	2.77	Caracalla	ND	ND	ND	ND	0.08	ND	9.616	0.08	ND	ND	ND	ND	88.05	0.62	ND	ND	ND	ND	ND	ND	ND	1.4256	0.134	A
10-1861-243/96	Yatağan Hoard	2.98	Caracalla	ND	ND	ND	ND	0.19	ND	11.42	0.07	ND	ND	ND	ND	84.75	1.21	ND	ND	ND	ND	ND	ND	ND	2.1945	0.182	A
10-1861-243/97	Yatağan Hoard	2.38	Caracalla	ND	ND	ND	ND	0.07	ND	12.51	0.08	ND	ND	ND	ND	85.91	0.42	ND	ND	ND	ND	ND	ND	ND	0.9096	0.094	A
10-1861-243/98	Yatağan Hoard	3.69	Caracalla	ND	ND	ND	ND	0.08	ND	13.24	0.08	ND	ND	ND	ND	84.96	0.47	ND	ND	ND	ND	ND	ND	ND	1.0504	0.127	A
10-1861-243/100	Yatağan Hoard	3.42	Caracalla	ND	ND	ND	ND	0.08	ND	11.58	0.08	ND	ND	ND	ND	86.42	0.51	ND	ND	ND	ND	ND	ND	ND	1.0752	0.248	A
10-1861-243/100	Yatağan Hoard	3.42	Caracalla	ND	ND	ND	ND	0.1	ND	13.57	0.09	ND	ND	ND	ND	83.85	0.66	0.54	ND	ND	ND	ND	ND	ND	0.9561	0.237	A
10-1861-243/101	Yatağan Hoard	2.84	Caracalla	ND	ND	ND	ND	0.14	ND	17.09	0.09	ND	ND	ND	ND	80.5	0.46	0.43	ND	ND	ND	ND	ND	ND	1.1107	0.177	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
10-1861-243/102	Yatağan Hoard	3.03	Caracalla	ND	ND	ND	ND	0.05	ND	19.78	0.13	ND	ND	ND	ND	78.39	0.34	ND	ND	ND	ND	ND	ND	ND	1.1982	0.107	A
10-1861-243/102	Yatağan Hoard	3.03	Caracalla	ND	ND	ND	ND	0.54	0.02	30.55	0.11	ND	ND	ND	ND	67.03	0.48	ND	ND	ND	ND	ND	ND	ND	1.1644	0.101	A
10-1861-243/103	Yatağan Hoard	2.96	Caracalla	ND	ND	ND	ND	0.16	ND	20.55	0.08	ND	ND	ND	ND	77.44	0.44	ND	ND	ND	ND	ND	ND	ND	1.1903	0.124	A
10-1861-243/104	Yatağan Hoard	3.06	Caracalla	ND	ND	ND	ND	0.16	ND	17.17	0.08	ND	ND	ND	ND	80.69	0.57	ND	ND	ND	ND	ND	ND	ND	1.1147	0.235	A
10-1861-243/104	Yatağan Hoard	3.06	Caracalla	ND	ND	ND	ND	0.14	ND	18.87	0.06	ND	ND	ND	ND	79.01	0.54	ND	ND	ND	ND	ND	ND	ND	1.1479	0.227	A
10-1861-243/85	Yatağan Hoard	3	Caracalla	ND	ND	ND	ND	0.17	ND	10.6	0.05	ND	ND	ND	ND	87.87	0.57	ND	ND	ND	ND	ND	ND	ND	0.6601	0.065	A
10-1861-243/86	Yatağan Hoard	3.14	Caracalla	ND	ND	ND	ND	0.15	ND	5.807	0.04	ND	ND	ND	ND	92.87	0.44	ND	ND	ND	ND	ND	ND	ND	0.6197	0.079	A
10-1861-243/87	Yatağan Hoard	2.85	Caracalla	ND	ND	ND	ND	0.07	ND	13.56	0.06	ND	ND	ND	ND	85.25	0.38	ND	ND	ND	ND	ND	ND	ND	0.5473	0.14	A
10-1861-243/88	Yatağan Hoard	3.24	Caracalla	ND	ND	ND	ND	0.13	ND	5.049	0.04	ND	ND	ND	ND	93.42	ND	ND	ND	ND	ND	ND	ND	ND	1.299	0.065	A
10-1861-243/89	Yatağan Hoard	3.16	Caracalla	ND	ND	ND	ND	0.08	ND	14.32	0.07	ND	ND	ND	ND	84.01	0.41	ND	ND	ND	ND	ND	ND	ND	0.9609	0.152	A
601-1	Bought	3.02	Caracalla	ND	ND	ND	ND	0.05	ND	15.07	0.11	ND	ND	ND	ND	83.11	0.42	ND	ND	ND	ND	ND	ND	ND	1.1239	0.121	A
601-1	Bought	3.02	Caracalla	ND	ND	ND	ND	ND	ND	14.95	0.13	ND	ND	ND	ND	83.2	0.51	ND	ND	ND	ND	ND	ND	ND	1.1012	0.109	A
1223-28	Bought	3	Caracalla	ND	ND	ND	ND	0.06	ND	39.81	0.13	ND	0.01	ND	ND	58.48	0.49	ND	ND	ND	ND	ND	0.06	ND	0.9042	0.05	A
1223-28	Bought	3	Caracalla	ND	ND	ND	ND	0.07	ND	26.76	0.09	ND	0.01	ND	ND	71.1	0.63	0.39	ND	ND	ND	ND	ND	ND	0.8942	0.05	A
1772-186	Museums Gen. Mng	2.98	Caracalla	ND	ND	ND	ND	ND	ND	6.704	0.05	ND	ND	ND	ND	90.08	1.51	ND	ND	ND	ND	ND	ND	ND	1.6068	0.054	A
Z2	By Police From Zurich	3.51	Caracalla	ND	ND	ND	ND	ND	0.02	27.69	0.08	ND	ND	ND	ND	70.46	0.88	ND	ND	ND	ND	ND	ND	ND	0.7177	0.155	A
Z2	By Police From Zurich	3.51	Caracalla	ND	ND	ND	ND	ND	0.04	16.18	0.06	ND	ND	ND	ND	82.01	0.91	ND	ND	ND	ND	ND	ND	ND	0.668	0.137	A
Z5	By Police From Zurich	2.97	Caracalla	0.341	ND	ND	ND	ND	0.03	9.966	0.05	ND	ND	ND	ND	87.89	0.98	ND	ND	ND	ND	ND	ND	ND	0.645	0.098	A
Z7	By Police From Zurich	3.05	Caracalla	ND	ND	ND	ND	ND	ND	9.716	0.06	ND	ND	ND	ND	87.37	1.82	ND	ND	ND	ND	ND	ND	ND	0.9546	0.082	A
Z7	By Police From Zurich	3.05	Caracalla	ND	ND	ND	ND	ND	ND	17.56	0.09	ND	ND	ND	ND	79.66	1.68	ND	ND	ND	ND	ND	ND	ND	0.9354	0.08	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
Z15	By Police From Zurich	3.29	Caracalla	ND	ND	ND	ND	ND	0.02	14.12	0.07	ND	ND	ND	ND	84.87	ND	ND	ND	ND	ND	ND	ND	ND	0.8607	0.059	A
Z15	By Police From Zurich	3.29	Caracalla	ND	ND	ND	ND	ND	ND	7.334	0.04	ND	ND	ND	ND	91.69	ND	ND	ND	ND	ND	ND	0.05	ND	0.8383	0.047	A
Z18	By Police From Zurich	3.17	Elagabalus	ND	ND	ND	ND	ND	ND	27.75	0.09	ND	ND	ND	ND	70.68	0.6	ND	ND	ND	ND	ND	ND	ND	0.8883	ND	A
Z18	By Police From Zurich	3.17	Elagabalus	ND	ND	ND	ND	ND	ND	11.34	0.05	ND	ND	ND	ND	86.91	0.63	ND	ND	ND	ND	ND	ND	ND	1.0732	ND	A
Z21	By Police From Zurich	3.17	Caracalla	ND	ND	ND	ND	ND	0.02	21.02	0.16	ND	ND	ND	ND	76.18	0.62	ND	ND	ND	ND	ND	ND	ND	1.8957	0.104	A
Z21	By Police From Zurich	3.17	Caracalla	ND	ND	ND	ND	ND	0.04	24.83	0.18	ND	ND	ND	ND	72.71	0.5	ND	ND	ND	ND	ND	ND	ND	1.6467	0.09	A
73-M168	Juliopolis Exc.	2.84	Geta	ND	ND	ND	ND	ND	ND	36.48	0.11	ND	ND	ND	ND	62.15	0.42	ND	ND	ND	ND	ND	ND	ND	0.7938	0.046	A
Z12	By Police From Zurich	4.19	Geta	ND	ND	ND	ND	ND	ND	23.28	0.07	ND	ND	ND	ND	74.98	0.5	ND	ND	ND	ND	ND	ND	ND	1.0988	0.069	A
Z12	By Police From Zurich	4.19	Geta	ND	ND	ND	ND	ND	ND	13.54	0.05	ND	ND	ND	ND	84.66	0.57	ND	ND	ND	ND	ND	ND	ND	1.0997	0.079	A
Z14	By Police From Zurich	2.91	Geta	ND	ND	ND	ND	ND	ND	4.766	0.05	ND	ND	ND	ND	93.07	0.56	ND	ND	ND	ND	ND	0.06	ND	1.3878	0.107	A
Z14	By Police From Zurich	2.91	Geta	ND	ND	ND	ND	ND	ND	6.51	0.07	ND	ND	ND	ND	91.48	0.41	ND	ND	ND	ND	ND	ND	ND	1.4298	0.1	A
X-1861-243/128	Yatagan Hoard	3.1	Geta	ND	ND	ND	ND	0.11	ND	9.317	0.05	ND	ND	ND	ND	86.18	3.31	ND	ND	ND	ND	ND	ND	ND	0.823	0.206	A
X-1861-243/128	Yatagan Hoard	3.1	Geta	ND	ND	ND	ND	0.11	ND	6.009	0.04	ND	ND	ND	ND	89.22	3.62	ND	ND	ND	ND	ND	ND	ND	0.7987	0.202	A
X-1861-243/127	Yatagan Hoard	2.77	Geta	ND	ND	ND	ND	0.1	ND	9.761	0.05	ND	ND	ND	ND	89.15	0.41	ND	ND	ND	ND	ND	ND	ND	0.3319	0.205	A
X-1861-243/127	Yatagan Hoard	2.77	Geta	ND	ND	ND	ND	0.06	ND	9.888	0.05	ND	ND	ND	ND	89	0.42	ND	ND	ND	ND	ND	ND	ND	0.3361	0.246	A
X-1861-243/126	Yatagan Hoard	3.15	Geta	ND	ND	ND	ND	0.16	ND	10.37	0.06	ND	ND	ND	ND	88.09	ND	ND	ND	ND	ND	ND	ND	ND	1.1556	0.155	A
X-1861-243/126	Yatagan Hoard	3.15	Geta	ND	ND	ND	ND	0.04	ND	10.55	0.06	ND	ND	ND	ND	87.42	0.46	ND	ND	ND	ND	ND	ND	ND	1.3082	0.162	A
X-1861-243/125	Yatagan Hoard	3.24	Geta	ND	ND	ND	ND	ND	ND	21.21	0.08	ND	ND	ND	ND	77.49	ND	ND	ND	ND	ND	ND	ND	ND	1.0684	0.147	A
X-1861-243/124	Yatagan Hoard	2.82	Geta	ND	ND	ND	ND	0.08	ND	14.02	0.06	ND	ND	ND	ND	84.54	ND	ND	ND	ND	ND	ND	ND	ND	1.0912	0.217	A
X-1861-243/123	Yatagan Hoard	2.80	Geta	ND	ND	ND	ND	0.11	ND	12	0.06	ND	ND	ND	ND	86.43	ND	ND	ND	ND	ND	ND	ND	ND	1.2593	0.144	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
X-1861-243/123	Yatagan Hoard	2.80	Geta	ND	ND	ND	ND	0.16	ND	21.56	0.07	ND	ND	ND	ND	76.73	ND	ND	ND	ND	ND	ND	ND	ND	1.3267	0.147	A
X-1861-243/122	Yatagan Hoard	3.70	Geta	ND	ND	ND	ND	0.12	ND	11.06	0.05	ND	ND	ND	ND	87.64	ND	ND	ND	ND	ND	ND	ND	ND	1.0308	0.093	A
X-1861-243/121	Yatagan Hoard	3.35	Geta	ND	ND	ND	ND	0.1	ND	7.473	0.04	ND	ND	ND	ND	89.77	0.6	ND	ND	ND	ND	ND	ND	ND	1.9148	0.109	A
X-1861-243/136	Yatagan Hoard	2.76	Geta	ND	ND	ND	ND	ND	ND	8.146	0.05	ND	ND	ND	ND	89.76	0.69	ND	ND	ND	ND	ND	ND	ND	1.2663	0.088	A
X-1861-243/136	Yatagan Hoard	2.76	Geta	ND	ND	ND	ND	0.12	ND	11.73	0.07	ND	ND	ND	ND	85.96	0.77	ND	ND	ND	ND	ND	ND	ND	1.2526	0.091	A
X-1861-243/144	Yatagan Hoard	3.5	Geta	ND	ND	ND	ND	0.08	ND	10.47	0.05	ND	ND	ND	ND	87.97	0.39	ND	ND	ND	ND	ND	ND	ND	0.8725	0.17	A
X-1861-243/142	Yatagan Hoard	2.98	Geta	ND	ND	ND	ND	0.1	ND	17.14	0.06	ND	ND	ND	ND	80.6	0.59	ND	ND	ND	ND	ND	0.05	ND	1.3829	0.078	A
X-1861-243/141	Yatagan Hoard	2.93	Geta	ND	ND	ND	ND	0.22	ND	6.548	0.05	ND	ND	ND	ND	92.23	ND	ND	ND	ND	ND	ND	ND	ND	0.797	0.157	A
1176-41	Bought	3.64	Geta	ND	ND	ND	ND	ND	ND	23.04	0.21	ND	ND	ND	ND	74.51	0.52	ND	ND	ND	ND	ND	0.05	ND	1.5781	0.096	A
1176-41	Bought	3.64	Geta	ND	ND	ND	ND	ND	ND	27.38	0.12	ND	ND	ND	ND	70.4	0.51	ND	ND	ND	ND	ND	ND	ND	1.5038	0.085	A
1420-3-1956	Bought	2.78	Geta	ND	ND	ND	ND	1.1	ND	20.32	0.09	ND	ND	ND	ND	76.97	0.33	ND	ND	ND	ND	0.22	ND	ND	0.9086	0.061	A
1420-3-1956	Bought	2.78	Geta	ND	ND	ND	ND	0.82	ND	23.72	0.09	ND	ND	ND	ND	74.43	ND	ND	ND	ND	ND	ND	ND	ND	0.8708	0.063	A
X-1861-243/155	Yatagan Hoard	3.15	Macrinus	ND	ND	ND	ND	0.07	ND	14.93	0.08	ND	ND	ND	ND	82.77	1.42	ND	ND	ND	ND	ND	ND	ND	0.7291	ND	A
X-1861-243/154	Yatagan Hoard	3.03	Macrinus	ND	ND	ND	ND	0.21	ND	26.91	0.09	ND	ND	ND	ND	70.7	1.36	ND	ND	ND	ND	ND	ND	ND	0.7219	ND	A
X-1861-243/154	Yatagan Hoard	3.03	Macrinus	ND	ND	ND	ND	0.16	ND	20.7	0.15	ND	ND	ND	ND	74.52	2.28	ND	ND	ND	ND	ND	ND	ND	2.187	ND	A
X-1861-243/153	Yatagan Hoard	2.6	Macrinus	ND	ND	ND	ND	0.24	ND	12.09	0.06	ND	ND	ND	ND	86.44	0.48	ND	ND	ND	ND	ND	ND	ND	0.634	0.064	A
X-1861-243/153	Yatagan Hoard	2.6	Macrinus	ND	ND	ND	ND	0.06	ND	8.255	0.04	ND	ND	ND	ND	90.53	0.46	ND	ND	ND	ND	ND	ND	ND	0.5989	0.059	A
X-1861-243/152	Yatagan Hoard	3.19	Macrinus	ND	ND	ND	ND	ND	ND	7.796	0.04	ND	ND	ND	ND	90.91	0.44	ND	ND	ND	ND	ND	ND	ND	0.6698	0.144	A
X-1861-243/151	Yatagan Hoard	2.89	Macrinus	ND	ND	ND	ND	ND	ND	16.89	0.08	ND	ND	ND	ND	81.86	0.59	ND	ND	ND	ND	ND	ND	ND	0.4569	0.121	A
X-1861-243/151	Yatagan Hoard	2.89	Macrinus	ND	ND	ND	ND	0.07	ND	15.02	0.07	ND	ND	ND	ND	83.86	0.45	ND	ND	ND	ND	ND	ND	ND	0.4117	0.116	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
X-1861-243/150	Yatagan Hoard	3.44	Macrinus	ND	ND	ND	ND	0.14	ND	10.51	0.05	ND	ND	ND	ND	88.43	0.42	ND	ND	ND	ND	ND	ND	ND	0.3067	0.128	A
X-1861-243/150	Yatagan Hoard	3.44	Macrinus	ND	ND	ND	ND	0.09	ND	11.78	0.05	ND	ND	ND	ND	87.12	0.49	ND	ND	ND	ND	ND	ND	ND	0.3452	0.125	A
V-1339-12	Museums Gen. Mang.	2.89	Macrinus	ND	ND	ND	ND	0.69	0.04	38.47	0.1	ND	0.01	ND	ND	59.94	0.47	ND	ND	ND	ND	ND	ND	ND	0.2097	0.076	A
V-1339-12	Museums Gen. Mang.	2.89	Macrinus	ND	ND	ND	ND	1.83	ND	29.13	0.08	ND	ND	ND	ND	68.03	0.48	ND	ND	ND	ND	0.13	ND	ND	0.2183	0.094	A
10-M112	Juliopolis Exc.	1.73	Elagabalus	ND	ND	ND	ND	0.04	ND	24.92	0.09	ND	ND	ND	ND	72.13	1.9	ND	ND	ND	ND	ND	ND	ND	0.9206	ND	A
10-1861-243-163	Yatağan Hoard	2.91	Elagabalus	ND	ND	ND	ND	0.09	ND	5.971	0.03	ND	ND	ND	ND	92.97	ND	ND	ND	ND	ND	ND	ND	ND	0.8853	0.048	A
10-1861-243-162	Yatağan Hoard	2.94	Elagabalus	ND	ND	ND	ND	0.13	ND	8.315	0.04	ND	ND	ND	ND	90.7	ND	ND	ND	ND	ND	ND	ND	ND	0.8131	ND	A
10-1861-243-161	Yatağan Hoard	2.31	Elagabalus	ND	ND	ND	ND	0.09	ND	11.58	0.04	ND	ND	ND	ND	85.91	1.19	ND	ND	ND	ND	ND	ND	ND	1.1853	ND	A
10-1861-243-160	Yatağan Hoard	2.73	Elagabalus	ND	ND	ND	ND	0.26	0.04	11.53	0.06	ND	ND	ND	ND	87.29	ND	ND	ND	ND	ND	ND	ND	ND	0.7788	0.035	A
10-1861-243-158	Yatağan Hoard	2.78	Elagabalus	ND	ND	ND	ND	0.1	ND	14.08	0.07	ND	ND	ND	ND	82.91	1.66	ND	ND	ND	ND	ND	ND	ND	1.0611	0.127	A
7-1903-1	Bought	2.83	Elagabalus	ND	ND	ND	ND	0.22	ND	25.52	0.13	ND	ND	ND	ND	71.68	1.42	ND	ND	ND	ND	ND	ND	ND	0.9176	0.117	A
10-1861-243-/166	Yatağan Hoard	3.54	Elagabalus	ND	ND	ND	ND	0.23	ND	10.35	0.08	ND	ND	ND	ND	84.85	2.36	ND	ND	ND	ND	ND	ND	ND	2.0817	0.057	A
10-1861-243-/165	Yatağan Hoard	2.19	Elagabalus	ND	ND	ND	ND	0.08	0.04	8.477	0.06	ND	ND	ND	ND	90.29	0.44	ND	ND	ND	ND	ND	ND	ND	0.5207	0.097	A
VII-1903-1	Bought	2.82	Elagabalus	ND	ND	ND	ND	0.32	ND	25.84	0.15	ND	ND	ND	ND	71.34	1.42	ND	ND	ND	ND	ND	ND	ND	0.8176	0.122	A
VII-1903-1	Bought	2.82	Elagabalus	ND	ND	ND	ND	0.23	ND	22.69	0.14	ND	ND	ND	ND	74.6	1.39	ND	ND	ND	ND	ND	ND	ND	0.8128	0.139	A
X-1861-243/165	Yatagan Hoard	3.29	Elagabalus	ND	ND	ND	ND	0.11	0.03	6.637	0.05	ND	ND	ND	ND	92.22	0.4	ND	ND	ND	ND	ND	ND	ND	0.4515	0.095	A
1967-VI-1733-732/165	Bought	4.4	Elagabalus	ND	ND	ND	ND	0.08	0.06	43	0.16	ND	ND	ND	ND	52.42	0.85	ND	ND	ND	ND	ND	0.07	ND	3.3685	ND	A
1967-VI-1733-732/165	Bought	4.4	Elagabalus	ND	ND	ND	ND	0.13	0.06	36.43	0.13	ND	0.01	ND	ND	62.18	0.48	ND	ND	ND	ND	ND	0.07	ND	0.4815	0.041	A
80-M174	Juliopolis Exc.	2.01	Severus Alexander	ND	ND	ND	ND	0.03	ND	45.92	0.1	ND	0.01	ND	ND	51.49	0.85	0.31	ND	ND	ND	ND	0.05	ND	1.0616	0.185	A
10-1861-243/191	Yatağan Hoard	3.9	Severus Alexander	ND	ND	ND	ND	0.1	ND	13.1	0.12	ND	ND	ND	ND	83.22	1.66	ND	ND	ND	ND	ND	ND	ND	1.6349	0.162	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
10-1861-243/190	Yatağan Hoard	3.03	Severus Alexander	0.233	ND	ND	ND	0.09	ND	9.933	0.05	ND	ND	ND	ND	87.76	0.56	ND	ND	ND	ND	ND	ND	ND	1.1462	0.221	A
10-1861-243/189 rev.	Yatağan Hoard	2.84	Severus Alexander	ND	ND	ND	ND	0.09	ND	12.88	0.05	ND	ND	ND	ND	85.77	0.38	ND	ND	ND	ND	ND	ND	ND	0.7779	0.041	A
10- 1861-243/188	Yatağan Hoard	2.75	Severus Alexander	ND	ND	ND	ND	0.13	ND	11.41	0.06	ND	ND	ND	ND	87.65	ND	ND	ND	ND	ND	ND	0.07	ND	0.6006	0.077	A
10-1861-243/187	Yatağan Hoard	2.65	Severus Alexander	ND	ND	ND	ND	0.12	ND	8.921	0.05	ND	ND	ND	ND	90.21	ND	ND	ND	ND	ND	ND	0.06	ND	0.5977	0.04	A
10- 1861-243/186	Yatağan Hoard	2.75	Severus Alexander	ND	ND	ND	ND	0.1	ND	12.28	0.07	ND	ND	ND	ND	84.78	1.43	ND	ND	ND	ND	ND	ND	ND	1.2785	0.053	A
10-861-243/185	Yatağan Hoard	2.1	Severus Alexander	0.262	ND	ND	ND	0.12	ND	8.094	0.06	ND	ND	ND	ND	86.84	2.34	ND	ND	ND	ND	ND	ND	ND	2.235	0.048	A
10-1861-243/184	Yatağan Hoard	2.46	Severus Alexander	ND	ND	ND	ND	0.09	ND	9.221	0.05	ND	ND	ND	ND	89.94	ND	ND	ND	ND	ND	ND	ND	ND	0.6483	0.055	A
10-1861-243/183	Yatağan Hoard	2.88	Severus Alexander	ND	ND	ND	ND	0.07	0.04	13.86	0.06	ND	ND	ND	ND	84.99	ND	0.43	ND	ND	ND	ND	ND	ND	0.4612	0.09	A
10-861-243/182	Yatağan Hoard	2.85	Severus Alexander	ND	ND	ND	ND	0.1	0.02	14.16	0.07	ND	ND	ND	ND	85.01	ND	ND	ND	ND	ND	ND	ND	ND	0.5069	0.128	A
10-1861-243/181	Yatağan Hoard	3.43	Severus Alexander	ND	ND	ND	ND	0.1	ND	20.71	0.07	ND	ND	ND	ND	78.28	ND	ND	ND	ND	ND	0.17	ND	ND	0.6284	0.033	A
10-1861-243/181	Yatağan Hoard	3.43	Severus Alexander	ND	ND	ND	ND	0.11	ND	21	0.09	ND	ND	ND	ND	77.97	ND	ND	ND	ND	ND	0.14	ND	ND	0.662	0.039	A
10-1861-243/180	Yatağan Hoard	2.98	Severus Alexander	ND	ND	ND	ND	0.16	ND	17.75	0.08	ND	ND	ND	ND	81.26	ND	ND	ND	ND	ND	ND	ND	ND	0.7018	0.045	A
10-1861-243/179	Yatağan Hoard	3.14	Severus Alexander	ND	ND	ND	ND	0.08	ND	9.493	0.05	ND	ND	ND	ND	86.69	1.44	ND	ND	ND	ND	ND	ND	ND	2.2558	ND	A
10-1861-243/178	Yatağan Hoard	2.77	Severus Alexander	ND	ND	ND	ND	0.13	ND	21.99	0.07	ND	ND	ND	ND	75.61	1.27	ND	ND	ND	ND	ND	ND	ND	0.8917	0.049	A
10- 1861-243/177	Yatağan Hoard	2.53	Severus Alexander	ND	ND	ND	ND	0.13	ND	8.209	0.05	ND	ND	ND	ND	87.32	2.63	ND	ND	ND	ND	ND	ND	ND	1.5745	0.09	A
10- 1861-243/184	Yatağan Hoard	2.86	Severus Alexander	ND	ND	ND	ND	0.11	ND	9.839	0.06	ND	ND	ND	ND	89.48	ND	ND	ND	ND	ND	ND	ND	ND	0.4602	0.058	A
10- 1861-243/176	Yatağan Hoard	2.59	Severus Alexander	ND	ND	ND	ND	0.14	ND	6.205	0.1	ND	ND	ND	ND	86.73	3.52	ND	ND	ND	ND	ND	0.06	ND	3.1804	0.065	A
11-788-23	Bought	3.16	Severus Alexander	ND	ND	ND	ND	ND	ND	38.65	0.25	ND	0.01	ND	ND	59.26	0.66	ND	ND	ND	ND	ND	0.06	ND	0.8944	0.211	A
1128-67	Bought	3.32	Severus Alexander	0.356	ND	ND	ND	1.86	0.02	28.5	0.11	ND	ND	ND	ND	66.86	1.07	ND	ND	ND	ND	ND	ND	ND	1.1582	0.059	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
5-1339-12	Bartın Museum	2.7	Severus Alexander	ND	ND	ND	ND	ND	ND	24.39	0.1	ND	ND	ND	ND	74.9	ND	ND	ND	ND	ND	ND	ND	ND	0.4813	0.124	A
80-M174	Juliopolis Exc.	2.01	Maximinus I	ND	ND	ND	ND	0.03	ND	45.92	0.1	ND	0	ND	ND	51.49	0.9	0.31	ND	ND	ND	ND	0.1	ND	1.062	0.18	A
10-1861-243/219	Yatağan Hoard	2.93	Maximinus I	ND	ND	ND	ND	0.35	ND	17.71	0.07	ND	ND	ND	ND	78.31	2.3	ND	ND	ND	ND	ND	ND	ND	1.2632	ND	A
10-1861-243/218	Yatağan Hoard	2.8	Maximinus I	ND	ND	ND	ND	0.1	ND	16.39	0.06	ND	ND	ND	ND	82.12	0.45	ND	ND	ND	ND	ND	ND	ND	0.8721	ND	A
10-1861-243/217	Yatağan Hoard	2.28	Maximinus I	ND	ND	ND	ND	0.09	ND	10.89	0.06	ND	ND	ND	ND	86.9	0.4	0.49	ND	ND	ND	ND	ND	ND	1.0953	0.082	A
10-1861-243/217	Yatağan Hoard	2.28	Maximinus I	ND	ND	ND	ND	0.1	ND	4.896	0.04	ND	ND	ND	ND	93.63	ND	ND	ND	ND	ND	ND	ND	ND	1.2387	0.094	A
10-1861-243/216	Yatağan Hoard	2.91	Maximinus I	ND	ND	ND	ND	0.06	ND	21.8	0.08	ND	0.01	ND	ND	76.5	0.4	0.53	ND	ND	ND	ND	ND	ND	0.5055	0.111	A
10-1861-243/214	Yatağan Hoard	2.58	Maximinus I	ND	ND	ND	ND	0.08	ND	24.58	0.08	ND	0.01	ND	ND	74.44	0.4	ND	ND	ND	ND	ND	ND	ND	0.3726	0.03	A
10-1861-243/214	Yatağan Hoard	2.58	Maximinus I	ND	ND	ND	ND	0.21	ND	15.37	0.05	ND	ND	ND	ND	83.56	0.36	ND	ND	ND	ND	ND	ND	ND	0.4215	0.033	A
10-1861-243/213	Yatağan Hoard	3.25	Maximinus I	ND	ND	ND	ND	0.23	ND	9.989	0.05	ND	ND	ND	ND	88.88	0.37	ND	ND	ND	ND	ND	ND	ND	0.4795	ND	A
10-1861-243/212	Yatağan Hoard	1.99	Maximinus I	ND	ND	ND	ND	0.36	ND	14.53	0.05	ND	ND	ND	ND	84.11	0.39	ND	ND	ND	ND	0.14	ND	ND	0.4217	ND	A
10-1861-243/212	Yatağan Hoard	1.99	Maximinus I	ND	ND	ND	ND	0.18	ND	12.84	0.05	ND	ND	ND	ND	85.52	0.42	0.44	ND	ND	ND	ND	ND	ND	0.5201	0.035	A
10-1861-243/212	Yatağan Hoard	1.99	Maximinus I	ND	ND	ND	ND	0.08	ND	10.85	0.06	ND	ND	ND	ND	88.51	ND	ND	ND	ND	ND	ND	ND	ND	0.472	0.035	A
10-1861-243/210	Yatağan Hoard	2.78	Maximinus I	ND	ND	ND	ND	0.04	ND	10.9	0.04	ND	ND	ND	ND	88.18	0.38	ND	ND	ND	ND	ND	ND	ND	0.4537	ND	A
10-1861-243/211	Yatağan Hoard	2.22	Maximinus I	ND	ND	ND	ND	0.19	ND	12.32	0.05	ND	ND	ND	ND	86.46	ND	0.46	ND	ND	ND	ND	ND	ND	0.5131	ND	A
10-1861-243/209	Yatağan Hoard	3.03	Maximinus I	ND	ND	ND	ND	0.07	ND	16.52	0.05	ND	ND	ND	ND	82.54	0.37	ND	ND	ND	ND	ND	ND	ND	0.4132	0.041	A
10-1861-243/208	Yatağan Hoard	3.16	Maximinus I	ND	ND	ND	ND	0.1	ND	9.761	0.04	ND	ND	ND	ND	89.67	ND	ND	ND	ND	ND	ND	ND	ND	0.4322	ND	A
10-1861-243/207	Yatağan Hoard	2.32	Maximinus I	ND	ND	ND	ND	0.13	ND	7.651	0.04	ND	ND	ND	ND	91.23	0.37	ND	ND	ND	ND	ND	ND	ND	0.4769	0.104	A
10-1861-243/206	Yatağan Hoard	2.71	Maximinus I	ND	ND	ND	ND	0.22	ND	17.44	0.07	ND	ND	ND	ND	80.91	0.4	0.47	ND	ND	ND	ND	ND	ND	0.4666	0.029	A
10-1861-243/205	Yatağan Hoard	2.52	Maximinus I	ND	ND	ND	ND	0.21	ND	18.4	0.07	ND	ND	ND	ND	78.04	2.21	ND	ND	ND	ND	ND	ND	ND	1.082	ND	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
10-1861-243/204	Yatağan Hoard	3.51	Maximinus I	ND	ND	ND	ND	0.11	ND	17.1	0.06	ND	ND	ND	ND	80.65	0.42	ND	ND	ND	ND	ND	ND	ND	1.661	ND	A
10-1861-243/204	Yatağan Hoard	3.51	Maximinus I	ND	ND	ND	ND	0.1	ND	12.39	0.05	ND	ND	ND	ND	84.88	0.53	0.46	ND	ND	ND	ND	ND	ND	1.5913	ND	A
84-3-75	Bought	3.55	Maximinus I	ND	ND	ND	ND	0.24	ND	41.59	0.08	ND	0.01	ND	ND	56.41	0.47	0.3	ND	ND	ND	0.19	ND	ND	0.7095	ND	A
11-M112	Juliopolis Exc.	1.3	Gordian III	ND	ND	ND	ND	ND	ND	14	0.07	ND	ND	ND	ND	81.4	1.43	0.5	ND	ND	ND	ND	ND	ND	2.3725	0.216	A
11-788-23	Bought	3.44	Gordian III	ND	ND	ND	ND	0.04	ND	36.65	0.22	ND	0.01	ND	ND	61	1.18	ND	ND	ND	ND	ND	0.05	ND	0.8538	ND	A
7-1741-10/8	Bought	2.98	Gordian III	ND	ND	ND	ND	0.07	ND	8.498	0.05	ND	ND	ND	ND	89.02	0.97	ND	ND	ND	ND	ND	0.07	ND	1.2099	0.11	A
10-1861-243/238	Yatağan Hoard	3.02	Gordian III	ND	ND	ND	ND	0.21	0.09	10.88	0.08	ND	ND	ND	ND	87.59	0.67	ND	ND	ND	ND	ND	ND	ND	0.4894	ND	A
10-1861-243/227	Yatağan Hoard	2.47	Gordian III	ND	ND	ND	ND	0.09	ND	15.63	0.06	ND	ND	ND	ND	83.66	ND	ND	ND	ND	ND	ND	0.06	ND	0.4499	0.049	A
10-1861-243/226	Yatağan Hoard	2.94	Gordian III	ND	ND	ND	ND	0.06	0.03	21.23	0.09	ND	ND	ND	ND	77.58	0.53	ND	ND	ND	ND	ND	ND	ND	0.4811	ND	A
10-1861-243/225	Yatağan Hoard	2.67	Gordian III	ND	ND	ND	ND	0.1	ND	15.55	0.07	ND	ND	ND	ND	82.26	0.96	ND	ND	ND	ND	ND	ND	ND	0.9939	0.068	A
10-1861-243/224	Yatağan Hoard	3.01	Gordian III	ND	ND	ND	ND	0.23	ND	26.08	0.1	ND	0.01	ND	ND	71.93	0.77	ND	ND	ND	ND	ND	ND	ND	0.8077	0.068	A
10-1861-243/231	Yatağan Hoard	2.91	Gordian III	ND	ND	ND	ND	0.1	ND	13.68	0.06	ND	ND	ND	ND	84.84	0.53	ND	ND	ND	ND	ND	ND	ND	0.788	ND	A
10-1861-243/232	Yatağan Hoard	3.1	Gordian III	ND	ND	ND	ND	0.2	ND	6.44	0.04	ND	ND	ND	ND	91.61	1.03	ND	ND	ND	ND	ND	ND	ND	0.6119	0.067	A
10-1861-243/233	Yatağan Hoard	3.17	Gordian III	ND	ND	ND	ND	0.15	ND	7.04	0.05	ND	ND	ND	ND	92.22	ND	ND	ND	ND	ND	ND	ND	ND	0.5034	0.035	A
10-1861-243/234	Yatağan Hoard	2.82	Gordian III	ND	ND	ND	ND	0.09	ND	12.33	0.05	ND	ND	ND	ND	85.77	0.97	ND	ND	ND	ND	ND	ND	ND	0.714	0.084	A
10-1861-243/235	Yatağan Hoard	2.37	Gordian III	ND	ND	ND	ND	0.1	ND	15.81	0.08	ND	ND	ND	ND	82.42	0.84	ND	ND	ND	ND	ND	0.07	ND	0.6365	0.032	A
10-1861-243/236	Yatağan Hoard	2.95	Gordian III	ND	ND	ND	ND	0.19	ND	10.86	0.06	ND	ND	ND	ND	87.8	0.47	ND	ND	ND	ND	ND	ND	ND	0.5881	0.036	A
10-1861-243/237	Yatağan Hoard	2.87	Gordian III	ND	ND	ND	ND	0.14	ND	17.11	0.07	ND	ND	ND	ND	81.42	0.64	ND	ND	ND	ND	ND	ND	ND	0.6052	ND	A
10-1861-243/238	Yatağan Hoard	2.70	Gordian III	ND	ND	ND	ND	0.22	ND	6.306	0.04	ND	ND	ND	ND	92.11	0.64	ND	ND	ND	ND	ND	ND	ND	0.6354	0.054	A
10-1861-243/239	Yatağan Hoard	2.47	Gordian III	ND	ND	ND	ND	0.09	ND	11.51	0.06	ND	ND	ND	ND	87.03	0.67	ND	ND	ND	ND	ND	0.07	ND	0.5651	ND	A

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
10-1861-243/240	Yatağan Hoard	2.60	Gordian III	ND	ND	ND	ND	0.16	ND	11.82	0.06	ND	ND	ND	ND	86.72	0.63	ND	ND	ND	ND	ND	ND	ND	0.614	ND	A
10-1861-243/241	Yatağan Hoard	3.48	Gordian III	ND	ND	ND	ND	0.08	0.05	21.37	0.08	ND	ND	ND	ND	77.49	0.41	ND	ND	ND	ND	ND	ND	ND	0.5191	ND	A
10-1861-243/242	Yatağan Hoard	2.07	Gordian III	ND	ND	ND	ND	0.09	ND	10.49	0.05	ND	ND	ND	ND	87.7	0.46	ND	ND	ND	ND	ND	ND	ND	1.1071	0.104	A
10-1861-243/243	Yatağan Hoard	2.67	Gordian III	ND	ND	ND	ND	0.1	ND	11.01	0.06	ND	ND	ND	ND	87.13	0.77	ND	ND	ND	ND	ND	ND	ND	0.8697	0.073	A
U-2-4	By Police From Uşak	3.45	Augustus	ND	ND	ND	ND	0.49	ND	2.338	ND	0.01	ND	ND	ND	97.06	ND	ND	ND	ND	ND	0.07	ND	ND	0.0414	ND	F
U-2-5	By Police From Uşak	3.4	Augustus	ND	ND	ND	ND	0.87	ND	1.813	ND	0.01	ND	ND	ND	97.18	ND	ND	ND	ND	ND	0.1	ND	ND	0.0261	ND	F
U-2-6	By Police From Uşak	3.43	Augustus	ND	ND	ND	ND	0.9	ND	1.414	ND	ND	ND	ND	ND	97.66	ND	ND	ND	ND	ND	ND	ND	ND	0.0237	ND	F
U-3-8	By Police From Uşak	3.48	Claudius	ND	ND	ND	ND	0.24	ND	2.048	ND	ND	ND	ND	ND	97.68	ND	ND	ND	ND	ND	ND	ND	ND	0.0261	ND	F
U-3-8	By Police From Uşak	3.48	Claudius	ND	ND	ND	ND	0.93	ND	1.758	ND	ND	ND	ND	ND	97.3	ND	ND	ND	ND	ND	ND	ND	ND	0.0164	ND	F
U-3-10	By Police From Uşak	3.35	Claudius	ND	ND	ND	ND	1.25	ND	1.363	ND	0.02	ND	ND	ND	97.17	ND	ND	ND	ND	ND	0.17	ND	ND	0.0229	ND	F
U-3-11	By Police From Uşak	3.51	Claudius	ND	ND	ND	ND	1.12	ND	2.267	0.03	0.01	ND	ND	ND	96.46	ND	ND	ND	ND	ND	0.1	ND	ND	0.0307	ND	F
U-3-12	By Police From Uşak	3.58	Claudius	ND	ND	ND	ND	0.32	ND	2.045	ND	ND	ND	ND	ND	97.61	ND	ND	ND	ND	ND	ND	ND	ND	0.0265	ND	F
U-3-12	By Police From Uşak	3.58	Claudius	0.381	ND	ND	ND	0.71	ND	1.94	ND	ND	ND	ND	ND	96.94	ND	ND	ND	ND	ND	ND	ND	ND	0.0209	ND	F
15-216/1-75	Donation	1.8	Nero	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	47.3	0.2	3.32	0.16	ND	ND	0.43	ND	48.629	ND	F
U-4-14	By Police From Uşak	3.52	Vitellius	ND	ND	ND	ND	0.18	ND	1.558	ND	ND	ND	ND	ND	98.23	ND	ND	ND	ND	ND	ND	ND	ND	0.0227	ND	F
U-4-15	By Police From Uşak	3.32	Vitellius	ND	ND	ND	ND	0.64	ND	1.254	ND	ND	ND	ND	ND	98.09	ND	ND	ND	ND	ND	ND	ND	ND	0.0219	ND	F
U-4-16	By Police From Uşak	3.57	Vitellius	ND	ND	ND	ND	0.46	ND	1.738	ND	ND	ND	ND	ND	97.77	ND	ND	ND	ND	ND	ND	ND	ND	0.0289	ND	F
U-5-2	By Police From Uşak	3.45	Vespasian	ND	ND	ND	ND	0.94	ND	1.756	ND	0.01	ND	ND	ND	97.12	ND	ND	ND	ND	ND	0.14	ND	ND	0.0349	ND	F
U-5-3	By Police From Uşak		Vespasian	0.291	ND	ND	ND	1.08	ND	1.661	ND	0.01	ND	ND	ND	96.79	ND	ND	ND	ND	ND	0.14	ND	ND	0.0254	ND	F
1962 11-1571-16/4	Bought	3.29	Trajan	ND	ND	ND	ND	0.07	0.34	24.94	0.99	ND	0.01	ND	ND	72.08	0.49	ND	ND	ND	ND	0.39	ND	ND	0.6955	ND	F

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
1962 11-1571-16/4	Bought	3.29	Trajan	ND	ND	ND	ND	0.1	0.36	24.55	1.06	ND	ND	ND	ND	72.25	0.53	ND	ND	ND	ND	0.39	ND	ND	0.7559	ND	F
U-6-1	By Police From Uşak	3.56	Hadrian	ND	ND	ND	ND	ND	ND	2.076	ND	ND	ND	ND	ND	97.72	ND	ND	ND	ND	ND	ND	ND	ND	0.0223	ND	
U-6-17	By Police From Uşak	3.48	Hadrian	ND	ND	ND	ND	0.25	ND	1.785	ND	ND	ND	ND	ND	97.95	ND	ND	ND	ND	ND	ND	ND	ND	0.0151	ND	F
U-6-18	By Police From Uşak	3.55	Hadrian	0.403	ND	ND	0.07	0.29	ND	1.782	ND	ND	ND	ND	ND	97.43	ND	ND	ND	ND	ND	ND	ND	ND	0.0216	ND	F
U-6-19	By Police From Uşak	3.36	Hadrian	ND	ND	ND	ND	1.09	ND	2.098	ND	0.01	ND	ND	ND	96.67	ND	ND	ND	ND	ND	0.11	ND	ND	0.0181	ND	F
U-6-20	By Police From Uşak	3.46	Hadrian	ND	ND	ND	ND	0.83	ND	1.968	ND	0.01	ND	ND	ND	97.09	ND	ND	ND	ND	ND	0.09	ND	ND	0.0173	ND	F
U-6-21	By Police From Uşak	3.57	Hadrian	0.394	ND	ND	ND	1.37	ND	1.672	ND	0.05	ND	ND	ND	96.26	ND	ND	ND	ND	ND	0.23	ND	ND	0.0161	ND	F
U-7-22	By Police From Uşak	3.58	Pertinax	0.273	ND	ND	ND	1.62	0.03	2.807	0.04	0.02	ND	ND	ND	94.95	ND	ND	ND	ND	ND	0.21	ND	ND	0.0495	ND	F
U-7-23	By Police From Uşak	3.51	Pertinax	ND	ND	ND	0.07	1.36	ND	1.486	0.04	0.02	ND	ND	ND	96.81	ND	ND	ND	ND	ND	0.19	ND	ND	0.0321	ND	F
U-7-24	By Police From Uşak	3.48	Pertinax	ND	ND	ND	ND	2.1	0.02	2.401	0.08	0.02	ND	ND	ND	95.13	ND	ND	ND	ND	ND	0.21	ND	ND	0.0331	ND	F
U-7-25	By Police From Uşak	3.48	Pertinax	0.333	ND	0.1	ND	1.54	ND	1.497	ND	0.02	ND	ND	ND	96.32	ND	ND	ND	ND	ND	0.16	ND	ND	0.0316	ND	F
U-8-26	By Police From Uşak	3.47	Pescennius Niger	0.294	ND	ND	0.08	0.96	ND	2.08	0.03	0.01	ND	ND	ND	96.53	ND	ND	ND	ND	ND	ND	ND	ND	0.0266	ND	F
U-9-27	By Police From Uşak	3.41	Septimius Severus	ND	ND	ND	ND	0.71	ND	2.282	ND	0.01	ND	ND	ND	96.91	ND	ND	ND	ND	ND	0.07	ND	ND	0.0239	ND	F
U-9-28	By Police From Uşak	3.5	Septimius Severus	ND	ND	ND	ND	1.01	ND	1.493	0.03	ND	ND	ND	ND	97.45	ND	ND	ND	ND	ND	ND	ND	ND	0.0217	ND	F
U-9-28	By Police From Uşak	3.5	Septimius Severus	ND	ND	ND	ND	0.21	ND	1.674	ND	ND	ND	ND	ND	98.09	ND	ND	ND	ND	ND	ND	ND	ND	0.0183	ND	F
U-9-30	By Police From Uşak	3.51	Septimius Severus	ND	ND	ND	ND	1.6	ND	1.936	0.16	0.02	ND	ND	ND	96.08	ND	ND	ND	ND	ND	0.16	ND	ND	0.0464	ND	F
U-9-31	By Police From Uşak	3.5	Septimius Severus	ND	ND	ND	ND	1.22	ND	2.023	ND	0.01	ND	ND	ND	96.57	ND	ND	ND	ND	ND	0.13	ND	ND	0.0342	ND	F
U-9-32	By Police From Uşak	3.45	Septimius Severus	0.45	ND	ND	ND	1.52	ND	1.919	0.03	0.02	ND	ND	ND	95.89	ND	ND	ND	ND	ND	0.15	ND	ND	0.0308	ND	F
U-9-33	By Police From Uşak	3.45	Septimius Severus	ND	ND	ND	ND	1.02	ND	1.954	0.03	0.01	ND	ND	ND	96.88	ND	ND	ND	ND	ND	0.09	ND	ND	0.0302	ND	F
U-10-34	By Police From Uşak	3.42	Geta	ND	ND	ND	ND	0.1	ND	1.421	ND	ND	ND	ND	ND	98.45	ND	ND	ND	ND	ND	ND	ND	ND	0.0226	ND	F

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
U-10-34	By Police From Uşak	3.42	Geta	0.32	ND	ND	ND	0.13	ND	1.436	ND	ND	ND	ND	ND	98.09	ND	ND	ND	ND	ND	ND	ND	ND	0.0224	ND	F
U-11-36	By Police From Uşak	3.55	Diadumenian	ND	ND	0.1	ND	0.95	ND	2.261	0.02	0.01	ND	ND	ND	96.54	ND	ND	ND	ND	ND	0.08	ND	ND	0.0384	ND	F
U-11-36	By Police From Uşak	3.55	Diadumenian	ND	ND	ND	ND	1.93	ND	2.142	ND	0.02	ND	ND	ND	95.64	ND	ND	ND	ND	ND	0.25	ND	ND	0.0174	ND	F
U-11-38	By Police From Uşak	3.48	Diadumenian	ND	ND	ND	ND	0.38	ND	2.207	ND	ND	ND	ND	ND	97.38	ND	ND	ND	ND	ND	ND	ND	ND	0.0379	ND	F
U-11-38	By Police From Uşak	3.48	Diadumenian	ND	ND	ND	ND	0.68	ND	2.237	0.03	0.01	ND	ND	ND	96.92	ND	ND	ND	ND	ND	0.1	ND	ND	0.0353	ND	F
U-11-40	By Police From Uşak	3.47	Diadumenian	ND	ND	ND	ND	1.07	ND	2.623	0.06	0.01	ND	ND	ND	96.01	ND	ND	ND	ND	ND	0.16	ND	ND	0.0638	ND	F
U-11-40	By Police From Uşak	3.47	Diadumenian	ND	ND	ND	ND	1.99	ND	2.787	0.06	0.03	ND	ND	ND	94.81	ND	ND	ND	ND	ND	0.27	ND	ND	0.0563	ND	F
EC1	Tried to sell museum	16.92	Great Alexander	ND	ND	ND	ND	0.17	0.25	2.78	0.43	ND	ND	ND	ND	96.32	ND	ND	ND	ND	ND	ND	ND	ND	0.053	ND	F
EC2	Tried to sell museum	16.69	Great Alexander	ND	ND	ND	ND	0.1	ND	2.01	0.1	ND	ND	ND	ND	97.74	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	F
EC3	Tried to sell museum	16.85	Great Alexander	0.38	ND	ND	ND	0.15	ND	2.37	0.06	ND	ND	ND	ND	97	ND	ND	ND	ND	ND	ND	ND	ND	0.045	ND	F
EC4	Tried to sell museum	16.81	Great Alexander	ND	ND	0.1	ND	0.41	ND	1.75	0.09	0.01	ND	ND	ND	97.59	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	F
EC5	Tried to sell museum	16.93	Great Alexander	ND	ND	ND	ND	0.1	0.09	2.45	0.22	ND	ND	ND	ND	97.11	ND	ND	ND	ND	ND	ND	ND	ND	0.018	ND	F
EC6	Tried to sell museum	16.91	Great Alexander	ND	ND	0.18	ND	0.67	ND	2	0.08	0.01	ND	ND	ND	97.03	ND	ND	ND	ND	ND	ND	ND	ND	0.029	ND	F
EC7	Tried to sell museum	17.04	Great Alexander	ND	ND	ND	ND	0.19	0.08	3.29	0.29	ND	ND	ND	ND	96.09	ND	ND	ND	ND	ND	ND	ND	ND	0.048	ND	F
EC8	Tried to sell museum	16.65	Great Alexander	ND	ND	ND	ND	0.08	ND	2.16	0.05	ND	ND	ND	ND	97.7	ND	ND	ND	ND	ND	ND	ND	ND	0.017	ND	F
EC9	Tried to sell museum	16.89	Great Alexander	ND	ND	ND	0.07	0.45	ND	1.99	0.11	0.01	ND	ND	ND	97.35	ND	ND	ND	ND	ND	ND	ND	ND	0.019	ND	F
EC10	Tried to sell museum	16.83	Great Alexander	ND	ND	0.17	ND	0.71	0.75	2.39	0.52	ND	ND	ND	ND	95.44	ND	ND	ND	ND	ND	ND	ND	ND	0.025	ND	F
EC11	Tried to sell museum	16.92	Great Alexander	ND	ND	ND	ND	0.3	0.26	2.29	0.61	ND	ND	ND	ND	96.51	ND	ND	ND	ND	ND	ND	ND	ND	0.036	ND	F

Inventory Number	Form of Acquisition	W, (g)	Emperor & Empress	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Mo	Rh	Pd	Ag	Sn	Sb	Hf	W	Re	Ir	Pt	Au	Pb	Bi	Decision
EC12	Tried to sell museum	17.06	Great Alexander	ND	ND	ND	ND	0.11	0.1	2.6	0.28	ND	ND	ND	ND	96.87	ND	ND	ND	ND	ND	ND	ND	ND	0.037	ND	F
EC13	Tried to sell museum	16.74	Great Alexander	ND	ND	ND	0.06	0.1	0.24	2.61	0.17	ND	ND	ND	ND	96.81	ND	ND	ND	ND	ND	ND	ND	ND	0.052	ND	F
EC14	Tried to sell museum	16.83	Great Alexander	ND	ND	ND	ND	0.07	ND	1.95	0.04	ND	ND	ND	ND	97.92	ND	ND	ND	ND	ND	ND	ND	ND	0.022	ND	F
EC15	Tried to sell museum	16.78	Great Alexander	ND	ND	ND	ND	0.13	ND	2.17	0.08	ND	ND	ND	ND	97.59	ND	ND	ND	ND	ND	ND	ND	ND	0.023	ND	F

VITA

Family name : **Aydın**

First names : **Mahmut**

Date of birth : **06.03.1976**

Nationality : **Turkish**

Civil status : **Married**

Mail : **aydinm135@mynet.com**

Mobile : **+905357236743**

Education

Institution [Date from - Date to]	Degree(s) or Diploma(s) obtained:
2007- 2013	Ph.D. Middle East Technical University, Department of Archaeometry
2001-2004	Master, Middle East Technical University, Department of Settlement Archaeology
1996-2000	Under Graduate, Dicle University, Department of Classic Archaeology

Short Term Trainings

- Training Course on "Application of Nuclear Analytical Techniques in the field of Cultural Heritage" by International Atomic Energy Agency In 7-11 May 2012 Vienna.
- Training Course on "Museum Security" by International Committee of Museums (ICOM) 26-28 June 2012 Ankara
- Training Course on "Scientific Techniques in Museums" by International Atomic Energy Agency, 6-8 September 2012 Ankara.
- Summer School "6th Intensive School on Conservation Science, 17-24 June 2012" by the Evora University/ Portugal 2012.
- Training Course on "Using of Innov-X Omega XRF Spectrometer" by Epsilon on 16/17 August 2010 Ankara.
- Training Course on "Project Cycle Management" by Mediterranean Heritage June 2006 Venice/Italy.
- Training Course on "Project Cycle Management" by Ankara University on 27-29 May 2005 Ankara.
- Training Course on "Health and Safety" by Hacettepe University 29-30 April 2003 Ankara

Language skills: Indicate competence on a scale of 1 to 5 (1 - excellent; 5 - basic)

Language	Reading	Speaking	Writing
Turkish	1	1	1
English	1	2	1
Arabic	5	1	5
Kurdish	4	3	3

Professional experience

Date from - Date to	Location	Company	Position	Description
1998-2000	Aksaray	Istanbul University	Archaeologist	Join to excavation as stager student
2000-2002	Muğla/ Datça Ankara	Middle East Technical University	Archaeologist	Join to Burgaz Excavation as Archaeologist
2003-2005	Erzincan	Tepe Construction	Archaeologist	Responsible archaeologist of protection archaeological remains from BTC pipe line construction activities
2005-2007	Ankara	Blue Hope Company	Project Expert	Preparing project for foundations to get grant from EU resources
2007-2009	Kırşehir	Culture and Tourism Ministry	Archaeologist	Work in the Kırşehir Museum
2009..	Ankara	Culture and Tourism Ministry	Archaeologist	The Museum of Anatolian Civilizations
2011-2012	Ankara	The Museum of Anatolian Civilizations	Project Coordinator	Organization of the Scientific Techniques and Risk Management Project which financially supported by EU and TR

Publications

Books

- Guner S., Öz A.K, Aydın M., 2007, Translation of EU and International Legislations about Cultural Heritage from Turkish to English (2 volume 800 pages) İstanbul
- Aydın M., Zoroğlu C., 2012, Scientific Techniques and Risk Management in The Museum (English-Turkish 170 pages) Ankara
- Aydın M., 2012, Translation of "Securing Heritage of Religious Interest" UNESCO 6th Hand Book from English to Turkish (51 pages).

Articles

- Guner S., Öz A..K, Aydın M., 2010, *Protection of Cultural Heritage in the Turkish Higher Education System within the Framework of the International Legislation*, World Universities Congress 20/24 October 2010 Proceedings II, Çanakkkale
- Guner S. Öz A. K, Aydın M 2010, Uluslararası Mevzuatlar Işığında Türkiye'deki Yüksek Eğitim Sisteminde Koruma Eğitimi, Restorasyon-Konservasyon Çalışmaları Dergisi, İBB-İstanbul
- Arslan M, Aydın M 2010, *Ankara Maltepe Kurtarma Kazısı 2009*, 19. Müze Çalışmaları ve Kurtarma Kazıları Sempozyumu, Ankara
- Aydın M., Zararsız A., Demirci Ş., 2011, *Geç Roma-Erken Bizans Dönemi Ankara Maltepe Kurtarma Kazısından Elde Edilen Bazı Buluntular Üzerinde Arkeometrik Çalışmalar*, 26. Arkeometri Sonuçları Toplantısı Ankara
- Aydın M., Mutlu S., 2012, *The Use of Non-Destructive Archaeometric Techniques and Visual Methods in Determining Authentification of Golden Coins From Byzantine Period (Bizans Dönemine Ait Altın Sikke Orijinalliğinin Tespitinde Tahribatsız Arkeometri Yöntemler)* , Two Eminent Contributors to Archaeometry in Turkey to Honor of Prof. Dr. Aymelek ÖZER and Prof Dr. Şahinde DEMİRCİ, Ankara