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Analysis of Ayyubid and Mamluk Dirhams Using X-Ray Fluorescence Spectrometry

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Seven ancient dirhams (silver coins) from the Ayyubid period 564–648 AH (1167–1248 AD) and nine dirhams from the Mamluk period 648–865 AH (1248–1459 AD) of the Great Islamic Empire (GIE) were analyzed using x-ray fluorescence spectrometry. The Ayyubid dirhams were found to have compositions ranging from about 8 to 52 wt% Ag, whereas the Mamluk dirhams were found to have compositions ranging from about 12 to 55 wt% Ag. The dirhams were found to contain high concentrations of Cu (about 5–79 wt%), Au (about 600 ppm–15 wt%) and Pb (about 1–9 wt%). In addition to these three elements, the Ayyubid dirhams were found to contain high concentrations of Hg (up to about 30 wt%) whereas its highest concentration in the Mamluk dirhams were about 0.4 wt%. Other elements found in the dirhams with varying concentrations were Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Br, Rb, Sr, Sb and Sm. The silver contents of these dirhams were compared with those of other dirhams from the Umayyad period 83–130 AH (702–748 AD) and the Abbasid period 162–200 AH (779–815 AD) of the same GIE. The correlation between the compositions of various dirhams and the historical implications is discussed, and a possible explanation for the significant variations in the composition of the dirhams is given.

INTRODUCTION

This paper is concerned with the application of x-ray fluorescence (XRF) techniques in the study of coinage belonging to the Great Islamic Empire (GIE). Islamic coinage extended over nearly 14 centuries, and encompassed a region that extended from Spain and Morocco in the west to Malaya and Indonesia in the East. The term 'Islamic coinage,' in practice, is another way of referring to the coinage of the near and Middle East after the rise of Islam in the seventh century. Rightly speaking, an Islamic coin is one designed following the traditions of Islam, that is, with inscriptions in Arabic script and no images. XRF was used here to study 16 ancient silver coins (dirhams) belonging to two powerful and important dynasties, namely the Ayyubid and Mamluk dynasties of the GIE, who were in power during the period 564–865 AH (1167–1459 AD). To convert from AH (Anno Hegirae) dates to AD dates, the following formula may be used: $\text{AD} = 0.97\text{AH} + 622$. On the other hand to convert from AD to AH, the following formula may be used: $\text{AH} = (\text{AD} - 622) \times 1.03$.

The Ayyubid dynasty was in power from 564 to 648 AH (1167–1248 AD).[1] The most famous Sultan of the Ayyubid dynasty is Al-Nasir Salahuddin (Saladin), who recaptured Jerusalem from the crusaders, and defeated the third crusade led by German Emperor Frederick Barbarossa, French King Philip Augustus and English King Richard the Lionheart in 583 AH (1187 AD). After Saladin's death, things did not go as he wished. The strong state that he created for the Ayyubid dynasty was torn apart owing to the struggle between members of the family. Eventually the Ayyubid Sultans became too weak to keep the succession of their family going.[2]

The Mamluk dynasty ruled the GIE from 648 to 865 AH (1248–1459 AD). It is worth mentioning that the Mamluks were slaves for the Ayyubid dynasty in Egypt before they took over and started to rule the GIE. Both dynasties were the real ruler of the GIE, while the Caliph of the state continued to be Abbasid residing in Baghdad (Iraq) during all of the Ayyubid period and during the periods of the first three Mamluk Sultans. That situation lasted for about one century, starting from the age of the Abbasid Caliph Al-Nasir Li-Din Allah in 564 AH (1167 AD) and until the defeat of the last Abbasid Caliph Al-Mustasim Billah and the destruction of Baghdad in 656 AH (1256 AD) by the Mongols of Hulagu. Many Sultans were sharing the power during the Ayyubid period and were ruling various parts of the GIE simultaneously. As for the Mamluk dynasty, only one sultan was ruling all of the GIE parts. The capital of the GIE during the Abbasid period was Baghdad, while the center of power during the Ayyubid and Mamluk dynasties was Cairo. After the Mongols' destruction of Baghdad, the Mamluk continued their control of the remaining parts of the GIE, in particular Egypt and Bilad Al-Sham (Syria, Jordan, Lebanon and Palestine) with Cairo as the capital of the state. That situation continued until the Mamluk Sultan Al-Zahir Baybars fought back the Mongols of Hulagu and defeated them in the Battle Ayn Jalut in 658 AH (1258 AD). The Mamulk then took full and complete control of the GIE.[3,4] A map of the GIE during the Mamluk period is given in Fig. 1.

Most studies of precious ancient coins were concerned with the physical properties (mass and diameter), dates and names of mints where the coins were issued and names of the rulers who issued them. The presence of the

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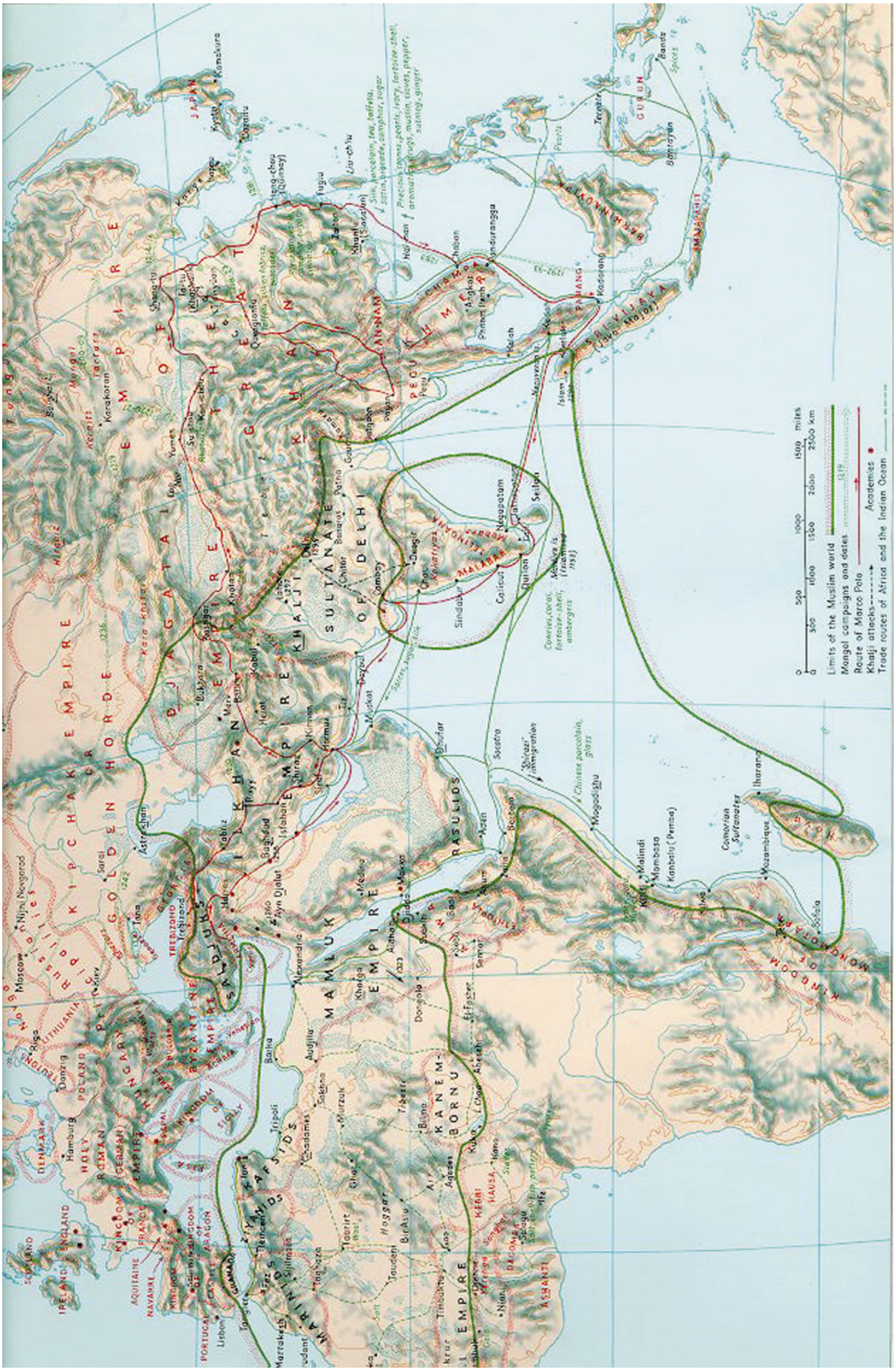

Figure 1. Map showing the Great Islamic Empire during the Mamluk period 648–865 AH (1248–1459 AD). Reference: http://ccat.sas.upenn.edu/~rs143/map5.jpg.

mint name is of interest to historians, for it is contemporary evidence that the ruler mentioned on the coin was in possession, at least nominally, of the city where the coin was produced. Together with the date, this information can often enable a historian to map, year by year, the geographical extent of many mediaeval Islamic Kingdoms.[5]

Interest in elemental analysis studies of precious ancient coins increased in recent years after the development of XRF and other nondestructive analytical techniques. It was almost impossible to study the constituents of such coins using traditional chemical analytical methods, because the elemental analysis of the coin would require its destruction.

Determination of the constituents of ancient coins is important for many reasons. First, from the concentration of silver in dirhams (and/or gold in dinars) historians are able to draw conclusions about the strength or weakness of various states under various rulers. The higher the concentration of silver (or gold), the stronger is the state. Second, from the fluctuations and changes in these concentrations, historians may draw conclusions about economic stability in the states which issued the coin. Fewer fluctuations imply greater economic stability. Third, from identifying the elements in the coin and their relative concentrations, historians may deduce information about the commercial exchanges (concerning metals) between various states. Fourth, from the regularity and consistency in the relative concentrations of various elements in the coins, one may deduce information about the quality control practices adhered to by various mints issuing the coins during various periods of history. Finally, the full elemental analysis of ancient coins may give scientists valuable information about the state of technology and metrology during different periods of human civilization.[6,7]

XRS AND ARCHEOLOGY

The application of x-ray spectrometry (XRS) in the analysis of precious ancient coins is an excellent example of the cooperation between physicists and archeologists at Yarmouk University (Jordan) in shedding more light on the rich human heritage of the Middle East. It is among the many endeavors aimed at producing a better understanding of the history of the region. We started the first work in this regard more than a decade ago by applying particle induced x-ray emission (PIXE) in the study of the constituents of 23 dirhams from the Umayyad period, 702–748 AD, of the GIE.[8] The Umayyad dynasty was the first to introduce a metallic coinage of its own in the history of the GIE. Analysis of such dirhams is very important to archeologists and historian in order to find answers to many unanswered questions about the silver coinage of that period. For example, Umayyad dirhams were found to be of very high quality with concentrations of silver exceeding 90 wt%. The quality of various dirhams was correlated with the Umayyad caliphs who issued them, and it was possible to name the golden periods during this period of the GIE.

In the second study, we used XRF to study the composition of five dirhams from the early Abbasid period, 162–200 AH (779–815 AD), of the GIE.[9] The Abbasid dynasty came to power after it defeated the Umayyad dynasty in 132 AH. Silver concentrations in the Abbasid dirhams were found to be about 60 wt%. This comes to about two thirds of its concentration in the Umayyad dirhams, indicating that the economy of the GIE during the Abbasid period may have been weaker than that of the Umayyad period, where silver concentrations in the dirhams exceeded the 90 wt% level.

Finally, in this third study of the silver coinage of the GIE, XRF techniques have been used to study 16 dirhams belonging to the Ayyubid and Mamluk periods of the GIE. The Ayyubid and Mamluk were the last two dynasties to rule the GIE before the rise of the Ottoman Empire in 1459 AD. The metrology of Ayyubid and Mamluk coinage is a little known problem. Coins issued during the rule of these two dynasties did not conform to any regular ponderal system and had irregular weight.[3] This work was aimed at demonstrating the power of XRF techniques in the elemental analysis of Ayyubid and Mamluk dirhams and in shedding more light on the composition of dirhams issued during the periods of these dynasties. The composition of these dirhams is compared with that of dirhams from the Umayyad and Abbasid dynasties.

XRF is a well-established technique for non-destructive analysis of samples. It has the advantages of multi-elemental analysis, from Na to U, in one run with a precision of better than 5%. Essentially, the primary beam from an x-ray tube or a radioisotope excites the characteristic x-rays of each element present in the sample. Processing the complete spectrum of the sample to measure the energies of these characteristic x-rays identifies the elements and then the intensities of these energies indicate their relative concentrations.

Analysis of precious coins belonging to ancient civilizations by XRS techniques (PIXE and XRF) is of interest not only to scientists and researchers at Yarmouk University. Many other workers have used various non-destructive techniques to study coinage belonging to ancient civilizations in different parts of the world. For example, PIXE was used for the elemental analysis of ancient Chinese artifacts belonging to the period 618–1679 AD.[10] External-beam PIXE was used for the analysis of Chinese coins belonging to the period 1644–1911 AD.[11] Instrumental neutron activation analysis (INAA) was used for the analysis of ancient punchmark coins ranging from the 8th to the 2nd century BC.[12] Concentration levels of the elements Cu, Ag, Sn, Sb, Au and As have been estimated in different ancient Indian coins using a ^{252}Cf neutron source by INAA.[13] The metal contents of several ancient Portuguese gold coins, with compositions ranging from about 35 to 99% Au, were determined and compared by using the two XRS techniques, XRF and PIXE.[14]

EXPERIMENTAL

Sample preparation

The 16 dirhams were cleaned with water and soap using a steel brush and then dried with a clean piece of cloth. Soft cotton and acetone were then used to clean the coins from any residues that may have been left on their surfaces.

Sample irradiation

The coin samples were made of homogeneous alloys, hence the analysis of their outermost surface areas can be considered representative of the whole sample. The Oxford ED2000 energy-dispersive XRF spectrometer[15] at the Physics Department of Yarmouk University was used to irradiate the coins and to collect their characteristic x-ray spectra. This system uses a rhodium target and a set of aluminum and copper filters and apertures with a high-voltage power supply of up to 50 kV. It operates under more than 20 preset fixed settings for the filters and/or apertures and for the high voltage of the x-ray tube. The proper filter and/or aperture for each 'fixed condition' of the system are selected through the software package XpertEase (Oxford Instruments Industrial Analysis Group, Oxford, UK) running within a Windows environment on an IBM-PC. The term 'fixed condition' here stands for a pre-programmed and optimized analytical parameters setting for the ED2000 spectrometer. XpertEase also sets the tube current and voltage and controls the acquisition of x-ray spectra on-line. Moreover, XpertEase controls the motion of a spinning d.c. motor, which rotates the sample holder continuously during irradiation. This is very important in order to compensate for any irregularities that may exist in the coin surface.

In a typical run, the coin sample is placed on the rotating sample holder (spinner) inside the vacuum chamber horizontally such that the incident primary (excitation) x-ray beam and the Si(Li) detector make an angle of 45° with its surface from two opposite sides. A schematic diagram of the experimental set-up is shown in Fig. 2. At the beginning of the run, the vacuum pump starts to pump air out from the chamber until the pressure reaches a preset value (usually about 10^{-6} Torr). Then, using the 'Set Deadtime' option of the package XpertEase, the x-ray tube current is set by increasing the current gradually, until the dead time reaches 45%, which is the recommended value for

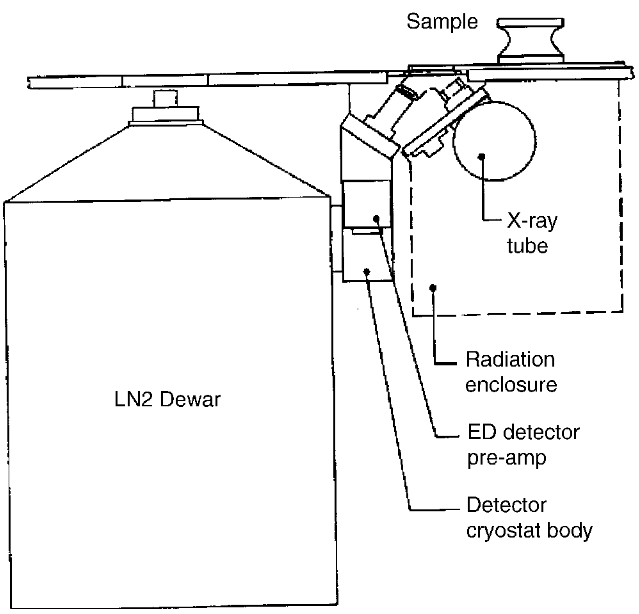

Figure 2. Schematic diagram of the experimental set-up showing the geometrical arrangement of the x-ray tube, Si(Li) detector and sample.

the ED2000 XRF spectrometer. The count rate of x-ray photons associated with this dead time is about 10^4 cps.

The x-ray current needed varies from sample to sample depending on the major constituents of the sample matrix. For example, metallic samples demand much less tube current than insulating samples. The current also depends on the selected fixed condition for the run. More current is required for the cases that implement a filter between the sample and the x-ray tube. After the proper tube current has been set, the actual data acquisition starts. Owing to the high count-rate, the measurement time for each run is usually a few minutes. We have set this time to 180 s in the present work. The acquired spectrum is displayed live on the monitor of the PC for on-line peak identification and qualitative analysis. At the end of the data acquisition cycle, the collected XRF spectrum for the sample is stored on the hard disk of the PC and used for quantitative on- and off-line analysis.

The samples were irradiated using two different fixed conditions under vacuum to achieve the best sensitivity and to cover all elements in the Periodic Table between Na and U. These conditions are named General and Very Heavy Elements. The General Fixed Condition (GFC) uses a tube voltage of 25 kV (at 10 mA) without a primary beam filter to excite all the elements from sodium to uranium in the sample. A primary beam aperture of 4.5 mm is used to restrict the forward power so that the count rate remains within the normal measurement range. The characteristic x-ray K lines are used to identify elements between Na and Mo while the characteristic L lines are used for the identification of heavier elements from rhodium to uranium.

The Very Heavy Elements Fixed Condition (VHEFC) uses a tube voltage of 50 kV (at 280 mA) with a thick copper filter. This method is suitable for major to trace concentration levels of the elements Nb to Nd (K lines) and Th to U (L lines). K line peaks resolve well in this region showing both $K\alpha_1$ and $K\alpha_2$ and $K\beta_1$ and $K\beta_2$. The two methods complemented one another in the comprehensive analysis of the coin samples. The GFC is suitable for elements having concentrations of 0.1 wt% or more, while the VHEFC is suitable for elements at trace concentration.

Data analysis

Figures 3 and 4 show representative XRF spectra for an Ayyubid and a Mamluk dirham, respectively. The spectra show the characteristic K and L lines of various elements present in the dirham samples. Processing the complete spectra to measure the energies of these characteristic x-rays identifies the elements and then the intensities of these energies indicate their concentration. For fully characterized materials, i.e. samples of definable composition and matrix, the traditional method is to set up an instrument by establishing calibration lines using a range of well-analyzed standards. This gives precise and accurate analysis but the initial calibration procedure is time consuming and requires costly reference materials. However, techniques are available to produce a good analysis without the full calibration procedure while retaining the rapid basic measurement. At the heart of this process is the 'fundamental parameters technique' (FPt), but the price of this

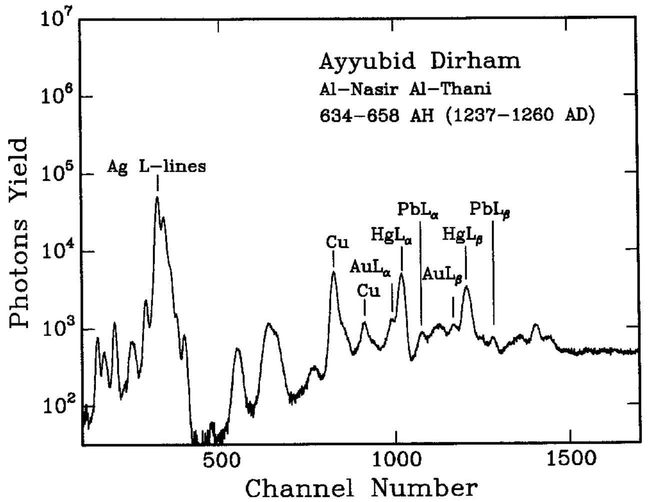

Figure 3. Representative XRF spectrum of an Ayyubid dirham (A5) from the period of Sultan Al-Nasir Al-Thani, the ruler of Cairo, 634–658 AH (1236–1259 AD). Note the high peaks of Cu, Au and Hg characteristic lines in the spectrum.

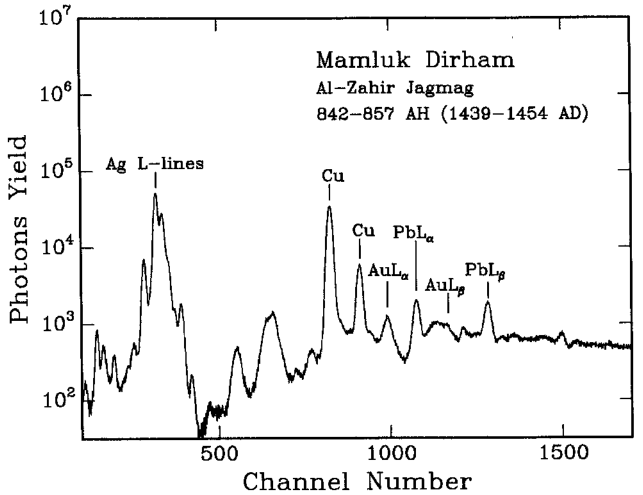

Figure 4. Representative XRF spectrum of a Mamluk dirham (M5) from the period of Sultan Al-Zahir Jagmag, 842–857 AH (1438–1453 AD). Note the high peaks of Cu, Au and Pb characteristic lines in the spectrum.

convenience is that the results are generally semiquantitative rather than fully quantitative. The measurement process of the ED2000 produces intensities for all the elements in the sample. The system then compares these with a pre-installed library of intensities from pure elements to give a first tentative concentration. Each is then subjected to an iterative set of theoretical corrections for matrix effects to give the final result. This is 'standardless fundamental parameter analysis.'

With a single similar standard a more accurate calculation is possible. The analytical errors become known by first measuring the similar standard as an unknown sample using the appropriate method. For subsequent samples the first tentative result receives a correction for these errors before the theoretical corrections. Therefore, the accuracy is better because there is real matrix matching between the sample and standard and this reduces the need for theoretical matrix corrections. This is 'similar standard fundamental parameter analysis.' All FPt methods provided with the ED2000 use precise theoretical models to give accurate results, typically within $\pm 10\%$ relative for major elements. By using similar standards this normally improves to $\pm 5\%$ relative.

The XpertEase software package was used for the analysis of the XRF spectra of the dirham samples. After acquiring an XRF spectrum for a dirham sample, a qualitative analysis was performed to identify the constituents. Then a method was tailored using the General and Very Heavy Fixed conditions and the acquired spectrum to evaluate the composition of the sample. Owing to a lack of costly multiple standards and since our interest is mainly in the concentrations of the major constituents, we used the FPt method with a similar standard for the computation of element concentrations. The similar standard does not have to be certified, but simply be a sample of reliably known composition. An Umayyad dirham of known composition from our previous work[8] was used for this purpose. A multi-element standard was used for the energy calibration of the spectrometer. Another standard (pure titanium, 99.99%) was used for the sensitivity calibration of the system. This sensitivity calibration is necessary to relate the intensity of x-ray photons at a specific tube current with elemental concentration for each fixed condition. A set of data libraries for the standard profiles of K and L lines of various elements under the relevant fixed condition is used to convert peak intensities to concentrations.

To ensure that the spectrum deconvolution accurately determines the intensities of elements in the sample, all elements in the sample must have the appropriate profile selected for the element as an 'analyte' (defined in the method). Any element which will be excited under other fixed conditions being used must be specified as 'other' element for these conditions and have profiles selected for their measurements.

A common problem that occurs when analyzing samples for the concentration of Ag ($Z = 47$) with an XRF spectrometer using a rhodium target ($Z = 45$) is the interference between the L lines of these two neighboring elements. For example, there is an overlap between the Ag $L\alpha_1$ (2.984 keV) and Rh $L\beta_1$ (2.834 keV) lines because the energy difference between their centroids is less than the energy resolution of the Si(Li) detector in the ED2000, which is about 160 eV. Likewise, there is another overlap between the Ag $L\beta_1$ (3.151 keV) and Rh $L\gamma_1$ (3.144 keV) lines.

Fortunately, XpertEase has a solution to these overlap problems through the standard profiles stored in its data libraries. The L lines of the Rh tube are treated as part of the generated background in the iteration process. The intensity of these lines is a function of the chosen tube current. Therefore, the proper clean peaks for the Ag L lines are extracted and their corresponding intensities are evaluated.

RESULTS AND DISCUSSION

In this section, a brief description of the dirhams is given along with their physical properties. Then the constituents of the dirhams along with their concentrations are tabulated. This section also includes a discussion of the results and a comparison between the Ayyubid and Mamluk dirhams with other dirhams belonging to other dynasties from the GIE.

Description of the dirhams

Table 1 shows the places of issue, the diameters and masses of the seven Ayyubid dirhams and nine Mamluk dirhams that were investigated. As shown, six Ayyubid dirhams were issued in Damascus and the seventh in Aleppo, and six Mamluk dirhams were issued in Cairo and three in Damascus. Under the powerful Ayyubid and Mamluk dynasties, whose territories encompassed all of Syria and Egypt, a centralized minting system seems to have prevailed. This was due to the strong central government which was powerful and could effectively regulate the kingdom's monetary supplies Only six mints were operated during these periods, two in Egypt (Cairo and Alexandria) and four in Syria (Damascus, Aleppo, Hums and Hamah). It is worth mentioning that the values of these dirhams are equal, regardless of their mass and diameter. There were three types of coins in that period with three different values: the golden coin (dinar), the silver coin (dirham) and the copper coin (fals).[15,16] Obviously, the dinar is the most valuable and the fals is the least.

Arabic inscriptions from the Quran, the holy book of Islam, decorated the two sides of the coins. For convenience, these two sides are named obverse and reverse in this study. All of the 16 dirhams have the Arabic inscription known as 'shahada,' the declaration of faith, which appears in several forms in the obverse side. In its basic and most common form it states that 'There is only one God, Allah; Muhammad is the Apostle of God.' Figures 5 and 6 shows photographs of two representative dirhams from the Ayyubid and Mamluk periods, respectively.

On the reverse side, most dirhams have the name of the city where they were issued, the date of issue and the name of the ruler. The Ayyubid dirhams were characterized by the presence of the name of the Abbasid Caliph followed by the name of the Ayyubid Sultan, while the Mamluk dirhams were characterized by the name of the Mamluk Sultan only. The title Al-Malik al-Nasir ('The Victorious King') is used on the Ayyubid coins before the name of the Sultan. The system of

Table 1. Information on the 16 silver coins (dirhams) studied: coin symbol in the present work, name of the Sultan who issued the coin, city and date of issue, mass and diameter

Coin symbol	Sultan's name	City of issue	Date of issue (AH)	Mass (g)	Diameter (mm)
A1	Al-Nasir Salahuddin	Damascus	564–589	2.59	21
A2	Al-Afdal Ali	Damascus	582–592	3.00	21
A3	Al-Zahir Ghazi	Aleppo	582–613	3.00	21
A4	Al-Adil AbuBakir	Damascus	596–615	2.91	20
A5	Al-Kamil Al-Awwal	Damascus	615–635	1.50	14
A6	Al-Imam Al-Zahir	Damascus	620–623	1.26	13
A7	Al-Nasir Al-Thani	Damascus	634–658	2.55	20
M1	Al-Zahir Baybars	Cairo	658–676	2.76	19
M2	Al-Zahir Baybars	Cairo	658–676	3.00	20
M3	Al-Mansour Qalaun	Cairo	678–689	1.44	12
M4	Husameddin Lajin	Damascus	696–698	3.32	21
M5	Al-Zahir Jagmag	Cairo	842–857	1.75	15
M6	Al-Zahir Jagmag	Cairo	842–857	1.75	15
M7	Al-Ashraf Sayfeddin Aynal	Damascus	857–865	1.49	15
M8	Al-Ashraf Sayfeddin Aynal	Damascus	857–865	1.49	15
M9	Al-Ashraf Sayfeddin Aynal	Cairo	857–865	1.52	14

Figure 5. Photograph showing the obverse and reverse sides of a typical Ayyubid dirham from the period of Sultan Al-Kamil Al-Awwal, the ruler of Damascus, 615–635 AH (1218–1237 AD).

Figure 6. Photograph showing the obverse and reverse sides of a typical Mamluk dirham from the period of Sultan Al-Ashraf Sayfeddin Aynal, 857–865 AH (1453–1461 AD).

placing a hierarchically arranged sequence of names on the coinage, from that of the local Sultan up through that of the Abbasid caliph, prevailed throughout most of the territories that acknowledged the spiritual authority of the Abbasid caliph. The Mongol conquest of Baghdad forced a sudden end to these practices by destroying the Abbasid caliphate in 656 AH (1258 AD).[17]

In addition to the Arabic inscriptions on the dirhams, there were some geometrical ornaments and drawings of animals on the obverse side. For example, an image of a six-point star decorated the Ayyubid dirhams and a lion decorated the Mamluk dirhams.

Constituents of the dirhams

Table 2 gives the constituents of the seven Ayyubid dirhams and Table 3 those of the nine Mamluk dirhams. The major elements in the dirhams, with concentrations of 1 wt% or more, are Ag, Cu, Pb, Au, Hg, Si, Ca and Fe. The minor elements, with concentrations between 1 and 0.1 wt%, are S, Ti, Cr, Ni and Sb. The trace elements, with concentrations of less than 0.1 wt%, are Co, Br, Rb, Sr and Sm. However, this classification of the elements is not strict, because some of them have major concentrations in some dirhams but minor concentrations in others. Examples of such elements are Al, Si and S. The experimental error in the measured concentrations, including the statistical error, is estimated to be less than $\pm$5%. In general, the highest errors are found to be associated with the lowest concentration levels.

DISCUSSION

As shown in Table 2, the Ayyubid dirhams were found to have compositions ranging from about 8.45 to 52.41 wt% Ag, 5.44% to 79.34 wt% Cu, 1.86 to 8.86 wt% Pb, 713 ppm to 29.80 wt% Hg and 593 ppm to 15.46 wt% Au. In addition to these major elements, the dirhams were found to contain the following elements with varying concentrations: Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Br, Rb, Sr, Sb and Sm. The most important element, which determines the quality of the dirham, is silver. Dirhams with high silver concentrations are considered of high quality and those with low silver concentrations are considered to be of a much lower quality. The average silver contents of the seven Ayyubid dirhams is 31.79 wt% with a variance of 15.50 wt%.

Dirhams numbered A2, A3, A4, A6 and A7 are of good quality with Ag concentrations of more than 30 wt%. Dirham A3 is the best with a silver concentration of 52.41 wt%. This dirham was issued during the period of the Ayyubid Sultan Al-Zahir Ghazi, 582–613 AH (1186–1216 AD). A mint in Aleppo issued this dirham at the beginning of the Ayyubid dynasty for Sultan Ghazi, who ruled Aleppo at the same time as Sultan Saladin was ruling Cairo. These were the golden days of the Ayyubid dynasty, where the state was rich and strong. The high silver concentration may be attributed to the prosperity of Aleppo during that period.

Dirham number A5 may be labeled as being of the lowest quality because its silver content is 8.45 wt%. A mint in Damascus issued this dirham during the period of the Sultan Al-Kamil Al-Awwal, 615–635 AH (1218–1237 AD). The reason for this low silver concentration is that during this period silver was very rare and people used to hide it in their homes as gold was missing from the markets.[3,4,18,19]

As shown in Table 3, the Mamluk dirhams were found to have compositions ranging from about 12.25 to 55.52 wt% Ag, 9.68 to 76.16 wt% Cu, 0.96 to 7.50 wt% Pb, 0 to 0.42 wt% Hg and 0.34 to 7.75 wt% Au. In addition to these major elements, the dirhams were found to contain the following elements with varying concentrations: Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Br, Rb, Sr, Sb and Sm. The average silver contents of the nine Mamluk dirhams is 35.72 wt% with a variance of 17.52 wt%.

Dirhams numbered M1, M2, M3, M4, M5 and M7 are of good quality with Ag concentrations of more than

Table 2. Constituents of Ayyubid dirhams[a]

Element	A1	A2	A3	A4	A5	A6	A7
Mg	1.43 wt%	0.23 wt%	—	0.99 wt%	0.35 wt%	3.08 wt%	0.39 wt%
Al	2.16 wt%	0.22 wt%	0.43 wt%	497 ppm	0.43 wt%	0.39 wt%	0.59 wt%
Si	7.90 wt%	0.96 wt%	1.28 wt%	1.91 wt%	0.58 wt%	1.57 wt%	7.39 wt%
S	0.27 wt%	0.11 wt%	0.22 wt%	1.64 wt%	939 ppm	—	0.38 wt%
Ca	14.87 wt%	4.28 wt%	9.67 wt%	6.63 wt%	2.41 wt%	7.23 wt%	4.47 wt%
Ti	0.34 wt%	576 ppm	622 ppm	697 ppm	256 ppm	0.23 wt%	971 ppm
Cr	226 ppm	934 ppm	739 ppm	—	—	0.28 wt%	—
Fe	2.28 wt%	0.40 wt%	0.68 wt%	11.88 wt%	0.25 wt%	0.73 wt%	0.30 wt%
Co	371 ppm	416 ppm	780 ppm	905 ppm	179 ppm	768 ppm	378 ppm
Ni	0.13 wt%	0.18 wt%	0.37 wt%	0.19 wt%	627 ppm	0.27 wt%	0.20 wt%
Cu	34.44 wt%	44.67 wt%	21.42 wt%	5.44 wt%	79.34 wt%	12.88 wt%	7.31 wt%
Br	696 ppm	314 ppm	924 ppm	—	276 ppm	—	—
Rb	0.15 wt%	0.25 wt%	0.24 wt%	0.36 wt%	624 ppm	0.45 wt%	0.26 wt%
Sr	409 ppm	0.17 wt%	0.28 wt%	0.15 wt%	0.17 wt%	0.13 wt%	518 ppm
Ag	18.86 wt%	30.84 wt%	52.41 wt%	31.57 wt%	8.45 wt%	49.67 wt%	45.32 wt%
Sb	2.09 wt%	0.45 wt%	1.39 wt%	0.84 wt%	0.19 wt%	1.12 wt%	0.78 wt%
Sm	461 ppm	0.16 wt%	0.28 wt%	171 ppm	—	0.30 wt%	0.14 wt%
Au	593 ppm	7.93 wt%	5.00 wt%	5.55 wt%	1.80 wt%	15.46 wt%	3.28 wt%
Hg	713 ppm	0.61 wt%	1.05 wt%	29.80 wt%	0.10 wt%	1.43 wt%	26.14 wt%
Pb	8.86 wt%	8.32 wt%	4.98 wt%	2.69 wt%	4.80 wt%	4.64 wt%	1.86 wt%

[a] The dashes represent concentrations below the detection limit of the ED2000 XRF spectrometer.

Table 3. Constituents of Mamluk dirhams[a]

Element	M1	M2	M3	M4	M5	M6	M7	M8	M9
Mg	0.12 wt%	1.88 wt%	1.18 wt%	1.12 wt%	705 ppm	0.65 wt%	0.12 wt%	0.14 wt%	0.58 wt%
Al	2.23 wt%	5.30 wt%	1.24 wt%	0.86 wt%	3.11 wt%	0.68 wt%	0.34 wt%	0.20 wt%	0.68 wt%
Si	5.17 wt%	10.72 wt%	2.72 wt%	1.03 wt%	7.86 wt%	3.58 wt%	1.11 wt%	0.88 wt%	2.28 wt%
S	0.37 wt%	2.18 wt%	3.64 wt%	0.17 wt%	1.66 wt%	933 ppm	883 ppm	203 ppm	0.22 wt%
Ca	6.27 wt%	17.89 wt%	5.12 wt%	7.68 wt%	7.61 wt%	4.76 wt%	3.03 wt%	2.11 wt%	6.79 wt%
Ti	0.20 wt%	0.53 wt%	0.16 wt%	510 ppm	0.67 wt%	845 ppm	388 ppm	272 ppm	603 ppm
Cr	0.38 wt%	—	166 ppm	0.12 wt%	867 ppm	—	182 ppm	304 ppm	94 ppm
Fe	12.55 wt%	3.18 wt%	1.12 wt%	0.39 wt%	4.26 wt%	0.89 wt%	0.41 wt%	0.22 wt%	1.51 wt%
Co	978 ppm	448 ppm	340 ppm	21 ppm	690 ppm	302 ppm	102 ppm	230 ppm	304 ppm
Ni	0.22 wt%	0.17 wt%	0.14 wt%	0.16 wt%	0.26 wt%	0.11 wt%	706 ppm	611 ppm	970 ppm
Cu	9.68 wt%	11.00 wt%	17.39 wt%	27.34 wt%	16.72 wt%	64.47 wt%	50.24 wt%	76.16 wt%	64.88 wt%
Br	492 ppm	0.23 wt%	0.63 wt%	0.29 wt%	0.34 wt%	29 ppm	114 ppm	231 ppm	—
Rb	0.19 wt%	289 ppm	634 ppm	245 ppm	0.22 wt%	0.10 wt%	129 ppm	998 ppm	453 ppm
Sr	648 ppm	945 ppm	495 ppm	484 ppm	888 ppm	—	—	—	—
Ag	48.53 wt%	37.03 wt%	55.52 wt%	52.49 wt%	47.48 wt%	13.08 wt%	39.45 wt%	12.25 wt%	15.69 wt%
Sb	—	2.99 wt%	—	0.62 wt%	—	0.50 wt%	996 ppm	—	1.25 wt%
Sm	0.12 wt%	—	0.10 wt%	0.11 wt%	0.12 wt%	49 ppm	450 ppm	—	192 ppm
Au	7.75 wt%	3.85 wt%	3.62 wt%	1.75 wt%	5.41 wt%	3.02 wt%	0.34 wt%	2.74 wt%	1.50 wt%
Hg	0.42 wt%	—	0.11 wt%	634 ppm	—	0.14 wt%	550 ppm	305 ppm	328 ppm
Pb	5.57 wt%	2.89 wt%	7.50 wt%	5.64 wt%	0.96 wt%	7.80 wt%	4.45 wt%	5.20 wt%	4.29 wt%

[a] The dashes represent concentrations below the detection limit of the ED2000 XRF spectrometer.

35 wt%. Dirham M3 is the best with a silver concentration of 55.52 wt%. This dirham was issued during the period of the Mamluk Sultan Al-Mansour Qalaun, 678–689 AH (1279–1290 AD). This Sultan came to power after Sultan Al-Zahir Baybars, who overcame most of the problems that were facing the Mamluk dynasty. The Mamluk Kingdom was in a good economic state during Sultan Qalaun's period.[20] The high silver concentration may be attributed to the prosperity of Cairo during that period.

Dirham numbers M6, M8 and M9 are of the lowest quality with silver contents of about 12–15 wt%. These three dirhams were minted in Damascus and Cairo during the periods of Sultans Al-Zahir Jagmag and Al-Ashraf Sayfeddin Aynal, 842–865 AH (1438–1460 AD), the last two Sultans of the Mamluk dynasty. The low silver concentration may be attributed to cheating practices, which was common in some mints near the end of the Mamluk's rule of the GIE. Those mints were using copper as a substitute for silver in the smelting of dirhams. This can be seen from the high concentrations of copper in these dirhams, which ranged between 64 and 76 wt%.

The average concentrations of the five major elements, Ag, Cu, Hg, Pb and Au, in the Ayyubid and Mamluk dirhams are compared with those in dirhams minted by the Umayyad and Abbasid dynasties in Table 4. The variances in these concentrations are also given. The

Table 4. Comparison between the average concentrations of Ag, Cu, Hg, Au and Pb in groups of dirhams belonging to the four important dynasties of the Great Islamic Empire, namely the Umayyad, Abbasid, Ayyubid and Mamluk

Element	Umayyad dirhams: 83–130 AH, 702–748 AD	Abbasid dirhams: 162–200 AH, 779–815 AD	Ayyubid dirhams: 564–648 AH, 1167–1248 AD	Mamluk dirhams: 648–865 AH, 1248–1459 AD
Ag	92.37 ± 7.09	60.52 ± 20.47	31.79 ± 15.50	35.72 ± 17.52
Cu	5.96 ± 6.68	2.39 ± 2.38	28.80 ± 22.84	37.54 ± 26.34
Hg	0.06 ± 0.15	28.59 ± 23.87	8.89 ± 11.66	0.10 ± 0.13
Au	0.34 ± 0.47	2.85 ± 5.47	5.48 ± 4.39	3.33 ± 2.22
Pb	0.74 ± 0.60	2.07 ± 2.41	4.86 ± 2.44	4.92 ± 2.13

tabulated data for the Umayyad and Abbasid dirhams were calculated from results published in Refs 8 and 9, respectively.

From Table 4, it is clear that the average concentration of silver is highest in the Umayyad dirhams, where it exceeded the ‘scale’ of 90 wt%. The silver ‘scale’ of Abbasid dirhams is next, where it exceeded the value of 60 wt%. Finally, moving to the Ayyubid and Mamluk dirhams, we can see that the silver ‘scale’ of these dirhams is about 30–35 wt%.

The high ‘scale’ of the Umayyad dirhams can be understood in the light of the fact that the Umayyad dynasty was the caliphate which introduced Islamic coinage for the first time during the period of Caliph Abd al-Malik bin Marwan in 77 AH (697 AD). He initiated the minting of dirhams and laid down its specifications and strict composition.[21] The high average concentration of silver and small variance are an indication of the strong economy and stable government during the rule of the Umayyad dynasty.

The group of dirhams representing the Abbasid dynasty in the present study belongs to the first century of its rule, which lasted for about six centuries. During this early period of the Abbasid dynasty, the state was strong and stable, but not as much it was during the Umayyad period. This explains the decrement in the silver ‘scale’ of the Abbasid dirhams to about 60 wt% with a variance of more than 20 wt%. Moreover, the Abbasid started to use Hg with ratios approaching 50% of that of Ag in the dirhams. As for the other three major elements, Cu, Pb and Au, their concentrations in both of the Umayyad and Abbasid dirhams remained of the order of a few per cent.

For the Ayyubid and Mamluk dirhams, one can see that their silver ‘scale’ is about the same. This also applies to the average concentrations of lead and gold. The only significant difference in composition is attributed to Hg, which has an average concentration of about 9 wt% in the Ayyubid dirhams compared with 0.10 wt% for the Mamluk dirhams.

The decrement in the silver ‘scale’ for the Ayyubid and Mamluk dirhams to about 30 wt% can be understood in the light of the lengthy wars with the crusaders and the Mongols and the costly building of castles. Other reasons for the decrease in the silver ‘scale’ of dirhams during the periods of these two dynasties were mentioned earlier.

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