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## Physico-Chemical and Numismatic Study of Moroccan Silver Coins from the Almohad Dynasty (XII to XIII Century)

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**Abstract:** This study obtains information on the constitution of the coinage alloy and the elements of contamination on the surface of archaeological objects. Thus, this work consists of physico-chemical characterization of old coins by MEB coupled with the EDS of 36 Almohade's dynasty Islamic coins (XII-XIII century). In addition to the physico-chemical analysis of which the data are treated using tools statistical mathematics with the help of software SPSS, the parts being studied were the subject of a historical and numismatic analysis. The results of this work conclude that these silver coins contain: Ag, C, Cu, Mg, O, Si, Al, Au, Cl, Sr, S, Pb and Fe. The analysis also made it possible to dissociate the elements belonging to the original alloy from those, which are not. So we can say that the elements that come primarily from silver-bearing alloys of origin are Ag, C, Cu, Mg, Au, S, Pb and Fe. The other elements are due to different phenomena (corrosion, contamination etc). Let us recall, finally, that in most cases, we notice that a good amount of numismatic, historical, archaeological and mining data is confirmed by the results of the physico-chemical characterization. The novelty of this work lies in the fact that the results can, among other things, be used for improving the methods and techniques of conservation and restoration of these archaeological objects and their development.

**Keywords:** Islamic coin, silver, numismatics, archeology, physico-chemical characterization.

## 阿尔莫哈德王朝 (十二至十三世纪) 摩洛哥银币的物理化学和钱币学研究

**摘要:** 本研究获得了铸币合金的构成和考古物品表面污染元素的信息。因此,这项工作包括通过物质和能量平衡以及 3 种光谱王朝伊斯兰硬币(十二至十三世纪)的能量色散对古钱币进行物理化学表征。除了在社会科学软件统计包的帮助下使用统计数学工具处理数据的物理化学分析外,所研究的部分是历史和钱币分析的主题。这项工作的结果得出结论,这些银币含有:银、C、铜、镁、欧、矽、阿尔、金、氯、锶、小号、铅和铁。该分析还可以将

属于原始合金的元素与不属于原始合金的元素区分开来。因此我们可以说，主要来自含银合金的元素是银、C、铜、镁、金、小号、铅和铁。其他因素是由于不同的现象（腐蚀、污染等）造成的。最后，让我们回顾一下，在大多数情况下，我们注意到大量的钱币、历史、考古和采矿数据得到了物理化学表征结果的证实。这项工作的新颖之处在于，除其他外，其结果可用于改进这些考古物品的保护和修复方法和技术及其发展。

**关键词：**伊斯兰硬币、银币、钱币学、考古学、物理化学特征。

## 1. Introduction

The precious metals gold and silver represent the oldest coin metals and means of exchange used by man. Silver has also been used, according to texts, as a metallic coin since approx. 700 BC [1]. It is in this sense that collections of silver coins are often studied in much research, given their precious evidence of the past.

The results of this research generally contribute, to certain tolerated uncertainty, to confirming historical and political facts as well as to predicting the probable dates of emission [2]. This research applies to the analysis of very precise, even particular, geometric and dimensional specifications, as well as the transcriptions appearing on their facies, their mass, their modulus and especially their title in base metal, that is to say their proportion in precious metal, in this case silver in our case.

Moreover, the silver coinage of the Islamic Empire has enormous importance in the economic history of the medieval world. Islamic coin was the means of trade and exchange over a countless area, and its import reached Europe [3]. And Morocco has an interesting quantity of this metallic archaeological heritage of critical cultural and historical value.

In addition to the studies of decorations and inscriptions read by archaeologists and historians on the facies of coins [4], the analysis of composition is also very useful in understanding the metallurgy of different periods of our history. To do this, the determination of the physicochemical properties of metallic objects is necessary.

To this end, we present, in what follows, the study of 36 silver coins minted by Almohad sovereigns, who reigned in Morocco during the 12th and 13th centuries. The Almohades represent the Berber dynasty founded at the beginning of the 12th century in the Moroccan Anti-Atlas, this dynasty dominated the Maghreb and part of the Iberian Peninsula from 1147 to 1269 [5].

The choice of this period is due, according to historical writings, to the fact that the coinage of the Almohad dynasty was most prestigious. His coins were, moreover, sought after for the purity of their metal [6].

The study consisted in the analysis of the pieces of this corpus by scanning electron microscopy (SEM) associated with energy dispersive spectroscopy (EDS),

the elementary data thus obtained are processed mathematically using tools multivariate statistics. For interpretation, the results are correlated with archaeological, numismatic and historical data. The figure 1 illustrates the methodology for developing this study.

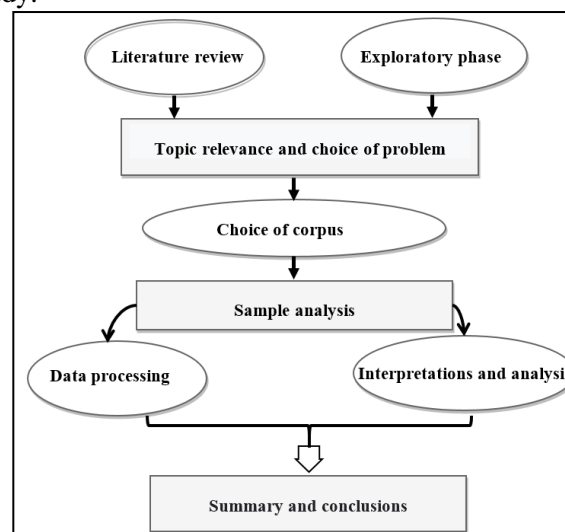


Fig. 1 Flowchart presenting the methodology of the study

## 2. Method and Material

The corpus under study is composed, as already specified, of 36 Almohad silver coins (12th to 13th century) of square shape belonging to a collector, researcher and expert in Islamic numismatics. A detailed description of the coins is presented in the following table indicating the metrological characteristics (dimensions and weights) and information on the minting location of each coin.

For the metrological characteristics (the dimensions and weight of the coins), as well as the numismatic data relating to the date and place of minting, responsible issuer, nominal values are indicated by the supplier of the coins. Furthermore, for the sake of verification and reliability of the information provided, these data are verified before physicochemical analysis, by measurements using a caliper for measuring the dimensional specifications, an electronic scale for weighing and a proofreading of the facies of the samples with the contribution of specialized numismatists of that time. The results are shown in Table 1.

Table 1 Description of the corpus studied

N°	Dimensions (mm)	Weight (g)	Location of minting
1	15x15	1.50	Without indication of the minting location
2	15.5x16	1.56	
3	15.5x16	1.52	
4	15x15	1.52	
5	15x15	1.49	
6	14x14	1.52	
7	15x15	1.52	
8	15x15	1.51	
9	14.5x14.5	1.54	
10	15x15	1.50	
11	14x14	1.53	
12	14x15	1.53	
13	15.5x15.5	1.53	
14	14.5x15	1.53	
15	15x15	1.51	
16	14x14	1.53	
17	15x15	1.50	
18	14.5x15	1.53	
19	15x15	1.52	
20	14.5x15	1.54	Fes
21	14x14	1.54	
22	14.5x14.5	1.53	
23	14.5x15.5	1.53	
24	13.5x14	1.52	
25	14.5x14.5	1.53	
26	15x15	1.52	
27	14x14.5	1.52	
28	15x15	1.52	Mallorca
29	14x14	1.49	Murcia
30	14x14.5	1.54	Sebta
31	14x14	1.53	Tlemcen
32	14x15	1.53	Tlemcen
33	15x15	1.52	Tlemcen
34	15x15	1.46	Seville
35	17x17	1.40	Without indication of the minting location
36	17x17.5	1.27	

According to this table and as certain authors specify, the Almohad silver coins are not dated and quite rarely contain the minting location [6]. This is also confirmed according to a collector's item published on a site for the private sale of old coins (figure 2) (except for the precision of the weight equivalent to 1.52 grams, the item does not contain any indication relating to the mint and on the date of minting). Note that the facies corresponds perfectly to that of the studies studied in this article.



Photo		
Arabic Transcripts	لا إله إلا الله الأمر كله لله لا قوة إلا بالله	الله ربنا محمد رسولنا المهدي إمامنا
Translation of transcripts into English	There is no god except Allah All command is with Allah There is no strength except in god	Allah (is) our Lord Muhammad (is) our prophet Al Mahdi (is) our guide

Fig. 2 Example of minting by the Almohad ruler Al Mahdi: Photo of a coin published in a catalog for the sale of old coins [7]

## 2.1. Physicochemical Analysis

The importance of coins as testimony and proof of

historical events requires monitoring their integrity and preservation against any phenomenon of alteration or disappearance. Thus, any analysis, treatment manipulation requires the use of methods and rules with certain well-adapted characteristics, in particular the non-destructive character for elementary analysis methods, knowing that these must make it possible to determine the concentration of the greatest number of elements with detection limits as low as possible. The analysis should therefore be non-destructive, or at least not cause damage visible to the naked eye [2].

Therefore, the choice of analytical method is important. The different methods that can be used have characteristics which, depending on the alloy and type of coin studied, can be a handicap or an advantage, this apart from considerations of access and cost. The choice of the method to be used will be defined according to the problem and alloy studied, knowing that the physico-chemical and metallurgical characteristics of the coins are different according to the metal or the alloy used.

Non-destructive methods can be classified according to their penetrating power (depth or thickness analyzed). Among these we distinguish:

- Surface analysis methods, which only study the surface of the object. The term surface here defines a layer that goes from the actual surface of the object to a depth of about 30 to 50 micrometers. It is generally within this layer that corrosion or enrichment phenomena are the most significant.

- Methods of semi-global analysis. The layer analyzed here is of the order of a few hundred micrometers. In a certain number of cases (mainly precious metals) this is sufficient to disregard the corrosion phenomena.

- Global methods that analyze the entire object and, which make it possible to obtain an average composition of the alloy used. These methods are of interest in the case of alloys that are strongly disturbed by corrosion or are very heterogeneous (mainly copper alloys).

Superficial and semi-global analysis methods are often also ad hoc. The volume of metal studied can be likened to a cylinder whose diameter varies between a few tens of micrometers and several millimeters in diameter, depending on the method used. The choice of technique is therefore important and will depend on the expected homogeneity of the alloy studied.

To select the method used, a last important criterion is the number of elements analyzed by the latter. This number varies from one method to another and may, in some cases, depend on the alloy studied [8].

In our case, depending on the availability of the techniques and machines used and the conditions required by the suppliers of the parts, in this case the preservation of the integrity of the parts. Given the non-destructive nature of the technique, we had to use

scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS), available in the laboratories of the Technical Support Units for Scientific Research (UATRS) of the National Center for Scientific and Technical Research (CNRST) in Rabat, Morocco. This center also has various techniques commonly used in materials science, but which are not always adapted to the materials and the geometric and dimensional specifications of heritage objects (coins) and do not best meet the criterion of non-destructiveness required by our samples.

The SEM+EDS technique has most of the qualities and conditions required for the study of cultural heritage objects, since it is non-destructive, quantitative with precision generally better than 5%, multi-elementary up to light elements, likely to provide information on the spatial distribution of elements (depth profile and lateral distribution with a resolution of up to one micrometer).

However, the following limitations of this technique should be noted, in particular the fact that the analysis concerns the surface area of the material (up to a few tens of micrometers) and can therefore be biased by surface alteration (corroded metals, for example) and no information is provided on the chemical state of the elements.

The conduct of the analysis can be summarized in three main phases. The first concerns the preparation and cleaning of the samples, the second is reserved for calibrating the analysis device and the third and last phase is dedicated to taking measurements.

## 2.2. Sample Preparation

Before going through the SEM, the samples are carefully cleaned, the cleaning consisted of washing with soapy distilled water, followed by rinsing in alcoholic water. The parts were then weighed using an electronic scale (UATRS/CNRST) and determination of the dimensions were measured using a caliper at 1/50.

In accordance with the rules and instructions provided, to be considered for handling and cleaning the parts by the sample supplier managers, and for the sake of preserving the integrity of the parts, certain precautions were considered during the cleaning of the parts for their preparation to analysis.

So to remove superficial dirt, we generally proceed as follows:

- Wash each portion in lukewarm distilled water with a mild liquid soap.
- If necessary, pass the parts through an ultrasonic bath, which allows the removal of granules that may remain stuck to the surface of the parts.
- Always rinse with distilled water, as tap water contains chlorine, which may leave chloride deposits on the surface of the part. These deposits can affect the reliability of the measurements and will eventually

corrode the metal.

- Use, if necessary, acetone to degrease the part after washing.
- Thoroughly wipe the samples dry.

## 2.3. Calibration

The head of the laboratory handling the SEM conducts a systematic calibration of the device. To further ensure the reliability of the measurements, the operator performs, at our request, an additional calibration for each batch to be analyzed using five reference coupons.

Table 2 shows the nominal composition of the standard samples. The values are indicated in quantity per thousand of each constituent (g/kg) [9].

Table 2 Nominal composition of calibration standard samples

Coupon	Alloy	As (g/kg)	Sn (g/kg)	Zn (g/kg)	Pb (g/kg)
1	Quaternary bronze	1.84 <sup>±0.1</sup>	71.6 <sup>±2.1</sup>	60.2 <sup>±2.2</sup>	79 <sup>±7</sup>
2	Arsenic copper	46 <sup>±2.7</sup>	2.02 <sup>±0.29</sup>	0.55 <sup>±0.05</sup>	1.75 <sup>±0.14</sup>
3	Tin bronze	1.94 <sup>±0.20</sup>	70 <sup>±6</sup>	1.57 <sup>±0.25</sup>	2.04 <sup>±0.18</sup>
4	Lead bronze	2.85 <sup>±0.22</sup>	101 <sup>±8</sup>	1.84 <sup>±0.24</sup>	92 <sup>±17</sup>
5	(Tin) brass	0.99 <sup>±0.10</sup>	20.6 <sup>±0.7</sup>	148 <sup>±5</sup>	3.9 <sup>±0.3</sup>

## 2.4. Measurement

For a reliable and efficient analysis, the electron beam is oriented on well-cleaned and flat areas to avoid the phenomenon interference. The measurements are taken at several points (2 to 3 points), sometimes by scanning over a control area that can reach up to 400 microns, sometimes by spot taking over a surface of 80 to 100 nm. The accelerating voltage ranges from 16 to 20 KV, reaching a penetration of up to 1.28 microns [10].

## 3. Results

If the interest of the elemental analysis of coined metals is no longer to be demonstrated, whatever the coinage is considered, it is, on the other hand, important to underline the extent to which the collaboration between the numismatists and historians on the one hand, the physicist, the geologist and metallurgist on the other hand, is decisive so that the exploitation of the numerical data obtained is effective and relevant. The definition of the problem and the choice of the resulting method of analysis to be applied to solve it constitute the essential stages of this approach. They partly condition the importance that the analysis results will take in the discussion [8].

To this end, different issues can be addressed depending on the metal or alloy that enters into the composition of the coinage to be studied:

- The variation of the title according to the topological evolution of the coin;
- The modes of alteration of the precious metal;
- The study of possible overhauls and recycling;
- The origin or the nature of the ores exploited for

the coined metal;

- The origins of the various elements detected in the analyzed samples.

The issues addressed are of course not set in stone; they are likely to change as research advances and it may be useful to compare the results of the analysis obtained with those of another coinage. This was the case of this study, in which we refer to mining, metallurgical, historical and numismatic data as well as examples of the analysis of other currencies around the world.

It should also be noted that to establish a hypothesis, which is the most probable on the historical level, research on the sources of supply of coined metals must be confronted with the study of archaeological, textual and numismatic data. The mixture of different metal sources is likely to give the resulting alloy a geochemical signature corresponding to an existing source, without there being any real link with it. It is also possible that two different sources, exploited at the same time and under the same authority, have geochemical characteristics indistinguishable by analysis [2].

### 3.1. Results of Physico-Chemical Analyses

The table below presents the values of the total spectrum, in mass percentage, of the contents of the various elements detected in the parts analyzed.

Table 3 Elemental composition of the parts analyzed (values in mass percentage w%)

N°	Ag (w%)	Cu (w%)	Mg (w%)	C (w%)	O (w%)	Si (w%)	Total (w%)
1	87.38	0.00	0.00	5.10	5.62	1.91	100
2	84.87	4.30	0.67	5.10	4.42	0.66	100
3	88.67	0.00	0.76	3.86	4.51	1.86	100
4	88.39	0.00	0.62	4.70	4.59	1.46	100
5	87.95	3.28	0.70	4.50	3.11	0.46	100
6	88.12	2.46	0.30	5.01	2.67	0.42	99
7	86.89	3.28	0.58	4.28	3.97	1.03	100
8	89.33	0.00	0.49	3.44	4.73	2.03	100
9	92.28	0.00	0.49	4.21	2.27	0.58	100
10	89.36	4.00	0.00	3.83	2.82	0.00	100
11	89.61	0.00	0.94	4.03	4.01	1.42	100
12	92.70	0.00	0.62	3.40	2.33	0.97	100
13	92.68	0.00	0.66	3.37	2.64	0.67	100
14	89.89	0.00	0.84	3.56	4.22	1.52	100
15	86.33	5.32	0.25	4.34	2.96	0.48	100
16	90.63	0.00	0.75	4.15	3.49	1.00	100
17	89.35	0.00	0.86	4.31	4.40	1.09	100
18	89.63	0.00	0.73	4.40	4.04	1.21	100
19	89.79	0.00	0.67	4.65	3.98	0.93	100
20	94.93	0.00	0.36	3.13	1.12	0.48	100
21	90.75	0.00	0.65	4.49	3.28	0.85	100
22	90.53	0.00	0.69	4.02	3.57	1.20	100
23	93.22	0.00	0.99	3.50	1.81	0.50	100
24	88.07	0.00	0.89	4.37	4.87	1.81	100
25	90.14	0.00	0.64	3.58	4.34	1.32	100
26	88.46	0.00	0.63	4.07	4.81	2.05	100
27	87.63	0.00	0.70	4.82	5.24	1.62	100
28	91.25	0.00	0.79	4.29	2.85	0.83	100
29	89.89	2.36	0.62	4.05	2.37	0.71	100
30	89.85	0.00	0.86	3.64	4.00	1.66	100
31	91.10	0.00	0.33	3.63	3.60	1.36	100
32	92.88	0.00	0.58	3.56	2.33	0.67	100
33	88.09	0.00	0.61	4.48	4.90	1.94	100
34	89.08	2.22	0.62	4.07	3.18	0.83	100
35	79.17	8.75	0.00	4.58	6.37	1.15	100
36	75.47	11.06	0.00	5.60	7.31	0.56	100

For the interpretation of these data, we carried out a

mathematical processing, using ascending hierarchical classification (AHC) and principal component analysis (PCA) [11]. The CHA classifies the samples according to their degree of similarity, this classification is represented graphically by a dendrogram summarizing the mutual similarities and the relationships between the individuals of a given population. The PCA highlights the families of the elements constituting the parts and makes it possible to classify them into elements belonging to the original alloy (in major or minor quantities), or those due to incrustation deposits and concretions on the surface of the parts.

### 3.2. Statistical Processing of Elementary Data

#### 3.2.1. Dendrogram and Binary Diagrams - Hierarchical Ascending Classification (AHC)

AHC [11] is one of the commonly used automatic classification method which consists of progressively grouping individuals according to their degree of resemblance until a single class grouping them all together is obtained.

The results can be provided, as needed, in the form of a graph called a dendrogram. It is a graphical representation of a hierarchical classification tree highlighting the progressive inclusion of classes.

The fusion or separation of the objects to be classified appearing on the dendrogram makes it possible to specify at what level the groups are formed.

In our study, this method will shed light on the degrees of similarity that could exist between the currencies analyzed by the issuing sovereigns, workshops, or minting period.

Thus, in our case, on the basis of the contents of the elements presented in table 2, the dendrogram in figure 2 makes it possible to classify the parts into three groups (marked G1, G2, and G3):

The G1 group includes most parts (32 parts) and it is in turn divided into three subgroups of parts, called G12, G12 and G13, of similar elementary compositions and four parts divided between the two small groups G2 and G3, as shown in the following graph.

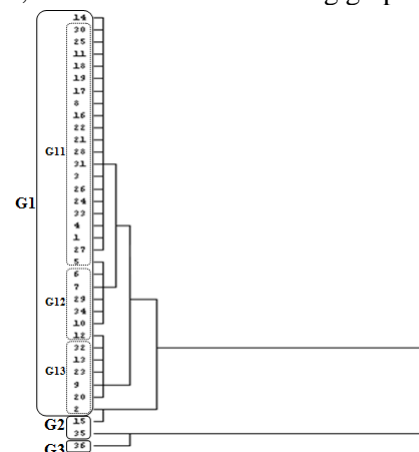


Fig. 3 Dendrogram of ascending hierarchical classification (AHC)

A description of the elementary compositions of the parts according to each group (G1, G2, and G3) is provided in the following table 2:

Table 4 Comparison of average levels

	G1		G2		G3	
	Average	Ecart Type	Average	Ecart Type	Average	Ecart Type
Ag	89,95	1,91	85,60	1,03	77,32	2,62
C	4,08	0,51	4,72	0,54	5,09	0,72
Cu	0,55	1,20	4,81	0,72	9,91	1,63
Mg	0,62	0,23	0,46	0,30	0,00	0,00
O	3,61	1,08	3,69	1,03	6,84	0,66
Si	1,14	0,54	0,57	0,13	0,86	0,42

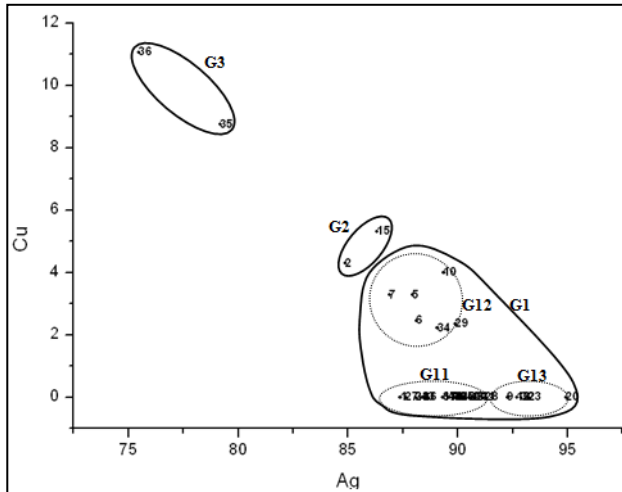


Fig. 4 Ag/Cu binary diagram

The results of the CHA (figure 2), confirmed by binary diagram figure 3, make it possible to identify a G1 group made up of 32 pieces whose average Ag content is around 90%. This group is in turn subdivided into three subgroups: G11, G12, and G13.

The G11 sub-group contains 20 coins including: ten without indication of the mint (1, 3, 4, 8, 11, 14, 16, 17, 18, 19), six struck in Fez (21, 22, 24, 25, 26, 27), a sample in Mallorca (28), one in Sebta (30), and two samples minted in Tlemcen (31, 32, 33). These twenty coins are characterized by the presence of a significant amount of silver, at content between 90 and 92%. The G12 subgroup is made up of six pieces with high copper content and silver content of around 90%, including four pieces without an indication of the name of the mint (5, 6, 7, 10), a sample hit in Murcia (29) and one in Seville (34). G13 contains six pieces with high silver content exceeding 92%, consisting of three samples without any indication of the mint (9, 12, 13), two samples from Fez (20, 23), and one sample from Tlemcen (32). Table 4 presents the values of the average contents of the elements of the elemental composition of each subgroup.

Table 4 Average levels of elements present in each subgroup

	Ag	C	Cu	Mg	O	Si
G11	89,43	4,18	0	0,67	4,25	1,45
G12	83,94	3,96	1,04	0,58	3,6	1,12
G13	83,93	3,66	1,38	0,53	2,48	0,63

Group G2 contains the two coins 2 and 15 samples without indication of the minting workshop, distinguished by a relatively average copper content reaching 5%.

Finally, group G3 contains the two samples 35 and 36, having high copper content, against silver content of less than 80%.

By comparing the binary diagrams to the dendrogram, we observe that the parts are divided into three main categories:

- The first category is characterized by a high copper content, low silver content compared to the whole lot and an absence of magnesium, including parts 35 and 36. By comparison of the facies, metrological data (weight and dimensions) and inscriptions indicated on the obverse and reverse of these two coins with the rest of the samples, as shown in Figure 4, and referring to historical texts describing Almohad counterfeiting, we can conclude that these are two counterfeit coins from the Almohad period, these coins are called, in literature, the Millares [12].

Facies d'une pièce authentique		Facies de l'échantillon 35 (Millares)	
Avers	Reverse	Avers	Reverse
لا إله إلا الله الأمر كله لله لا قوة إلا بالله	الله ربنا محمد رسولنا المهدي إمامنا	لا إله إلا الله الأمر كله لله لا قوة إلا بالله	الله ربنا محمد رسولنا المهدي إمامنا
There is no god except Allah All command is with Allah There is no strength except in god	Allah (is) our Lord Muhammad (is) our prophet Al Mahdi (is) our guide	There is no god except Allah All command is with Allah There is no strength except in god	Allah (is) our Lord Muhammad (is) our prophet Al Mahdi (is) our guide

Fig. 5 Comparative photos of real and fake coins

In addition to the metrological data indicated in table 3, figure 5 makes it possible to show that despite the literally identical transcriptions of meaning, a clear difference in the metrological calligraphic quality appears between the two parts 35 and 36, represented by part 35 in figure 5 compared to the rest of the parts of the whole batch represented by an authentic part facies. Although parts 35 and 36 are large, their respective weights are lower than the other parts of the lot, which suggests that the manufacture of these two parts is made from an alloy rich in copper, since this metal is lighter compared to silver.

Counterfeit coins are not an exception to this era only, but they have existed at other times and in other places in the world. Writing has also been devoted to the broad development of counterfeiting [13].

- The second category: whose copper content varies between 2 and 5% and that of silver between 85

and 89%

- The third category: is characterized by zero copper content and high silver content reaching 95%.

### 3.2.2. Principal Component Analysis (PCA)

PCA [10] is a simple factorial method which is considered one of the most classic techniques of multivariate statistics and as the basic method of data analysis. Karl Person described it first [14].

This method is an excellent example for illustrating the multivariate study of data and makes it possible to extract the maximum information on a given subject from few more easily interpretable elements, presented in a simple and coherent form from a countless set of data. It serves to highlight the interrelationships between the variables and the similarities and oppositions between the different units analyzed.

It mainly applies to measurement tables, i.e., to a set of quantitative variables that are both homogeneous and heterogeneous.

Principal component analysis is an analysis whose results are usually considered new hypotheses to broaden and better understand the problem under study.

In our case, the PCA will make it possible to develop hypotheses relating to the possible sources of the elements detected on the surface of the analyzed parts.

The histograms of the following figure 6 represent the results of the PCA.

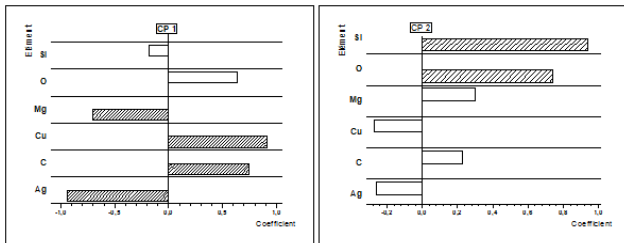


Fig. 6 Histogram of principal components

The PCA made it possible to classify the elements of the elementary composition into two large families, the first family containing the elements Ag, C, Cu, and Mg, united in the Main Component CP1. The second family is made up of the elements Si and O united in the Principal Component CP2.

## 4. Discussions

The justification of the elemental composition of archaeological object results from several factors, in particular, historical, mining and metallurgical. According to bibliographical sources, elementary analyzes of archaeological objects, such as coins in our case, generally provide important information.

This information contributes to knowing the silver content, which confers the intrinsic value to the piece, the contents of the minor and trace elements that make it possible to identify the origin and provenance of the metal as well as the metallurgical practices carried out

to obtain it. of the coin and finally the elements present on the surface of the coins that are due to the manipulation, the environment and the methods of storage and conservation of these objects [3, 15].

The minor and trace elements contained, for example, in silver-copper alloys are contributed by one or the other of the two metals or even by both simultaneously, as impurities or as elements of addition aimed at improving certain physicochemical and aesthetic characteristics of the coins.

Writings specify that silver is obtained by extraction or by separation of other metals [1]. The ores exploited for this metal in ancient times are most often rich in lead, so silver coins in most cases contain a significant amount of lead, knowing that the latter is not altered by the processes. Metallurgical processes implemented to obtain the silver, which could provide information on the possible sources of the original ore [2].

Certain elements follow the silver during the various metallurgical operations, so that the ratio, in certain cases, between their concentration and that of the silver is preserved from the ore to the finished object. Furthermore, the concentrations of these minor and trace elements in the finished product depend on various parameters: their initial levels in the ore, their behavior during the various metallurgical and forming operations. We cite for this purpose the example of elements commonly detected in the silver alloy, such as: tin, gold, copper, arsenic, antimony, zinc, lead, bismuth [16].

Gold and bismuth can come from the original ore, preserved by the refining process, with Au being completely preserved and Bi, resistant to oxidation, being partially preserved. Gold is frequently associated with silver ore in small quantities, it is usually found in quantities below 1% by weight. Although it is unlikely that Au was deliberately added to the silver, it can sometimes have an exogenous origin, resulting from Au contamination or gilding during recycling. The amount of Bi is related to the Pb content, so the ratio of these elements remain constant after refining [16].

For lead, a study of minting in the Islamic world (Umayyads and Abbasid) indicates that silver stocks are confined both regionally and chronologically, which means that the stock used by the Umayyads may be different from that used by the Abbasids of Baghdad and that the stock used in Baghdad is not the same as that used in Iran and Central Asia. These results are encouraging for origin studies based on isotopic and elemental analysis of lead [17].

However, it is difficult to have this information simultaneously, knowing that certain practices such as recycling which is generally considered as a major obstacle in the studies of the origin of precious metals [18], since it is based on the mixture of metals from different sources, as well as certain surface treatments, such as bleaching or dressing, which enriches the

surface of silver coins [19-22]. These practices remove any specific signatures that can provide information on the exact origin of the metal coin.

Additionally, according to a study [18], recycling allows evaluating long-distance commercial networks, the movement of coins and the frequency of recycling events and helps understand socio-cultural and economic phenomena on a large scale.

In this study, PCA has made it possible to highlight two families of elements, the first of which contains the elements that may belong to certain silver ores (Ag, C, Cu, Mg). Thus, these elements can be considered as coming from the original alloy. The presence of carbon can also be attributed to the contamination of the parts during the molding of the blanks, the casting of which was done in crucibles made from animal bones [23], as it can also result from concretions accumulated on the surface. Coins in their places of conservation or burial in the case of treasures found underground.

Magnesium is like carbon, its content is uniform in most samples, so it can come from the original alloy, i.e. from the ore, or due to contamination during operation silver refining using refractory earths.

## 5. Conclusion

In conclusion, the results confirm, generally, the statements quoted in historical writings stipulating that the evolution of the processes of elaboration of gold and silver metals reached its maturity during the Almohad period. The mastery and maturity of metallurgical techniques during this period was developed compared to the periods, which preceded it, this had a positive impact on the techniques of coinage manufacture, which could subsist until the period of the Merinid dynasties (13th to 14th century) or Sadian (16th to 17th century) testified by the skill of the Almohad workshops to manufacturing very precise counterfeit coins from copper coins, which perfectly resembled those of gold [24].

This work also allowed to distinguish the elements that could belong to the alloy and those that do not, as well as the confirmation of two counterfeit coins and confirmations of historical writings.

The results correlate with other studies of the same type we cite, for example [25].

That said for the gold coins, as for the silver coins, the discovery of a treasure in which the facies of the coins seem in excellent condition, testifies to the good quality of the Almohad minting, these coins seem clean and little oxidized since they contain high levels of Ag.

It should also be noted that analyses of coins carried out by various specialists (numismatists and scientists), also testify to this evolution. For example, the gold content of certain samples of a batch of Almohad coins, analyzed in 1974, reached 99.7%, while that of its predecessors (Almoravids) rarely exceeded 96% [6].

As a result, the information that can emerge from

the results of physicochemical analysis applied to archaeological objects is means that contribute effectively to their reintegration into history [4]. The multidisciplinary identification (history, archaeology, physic-chemistry) of a coin has an added value having a direct impact on the economic and social promotion through the valorization of this heritage on the cultural and socio-economic level.

Restoration of archaeological objects and their enhancement, knowing that the knowledge of the chemical composition is essential to control the state of conservation of the work and to possibly deduce the aging mechanism by comparison with materials of similar composition, subjected to accelerated aging tests. These data can also guide the choice of the best restoration technique, as they can guide the choice of conservation treatments for restoration of heritage metal objects likely to help inhibit or slow down corrosion processes and compensate for traditional methods. Common, practiced in certain places of conservation, namely, the application of a protective layer (varnish) to the surface of the pieces, which can have harmful long-term effects on these pieces.

In our case, scanning electron microscopy coupled with EDS provided relevant information on the elemental composition of the pieces, however, when the patina is thick, the concretions on the surface prevent in-depth analysis of the samples.

Abundant elements in the soil, such as: iron, manganese, calcium, silicon, aluminum, accumulate on the surface of the parts. Other elements of the coin alloy, such as copper, zinc and tin, are preferentially eliminated by corrosion. This can falsify the determination of the original elemental composition of the coin.

The circulation of coins and their manipulation leads, over time, to significant changes in the original elemental composition on the surface.

In the cleaning procedures carried out, usually after excavations or in museums, commonly used commercial chemicals preferentially attack the copper and, therefore, contribute to the increase in the silver content on the surface of the pieces.

The SEM coupled with the EDS has the advantage of a non-destructive technique and therefore meets the requirements of the holders of the archaeological heritage, however the limits of this analysis technique lie in the fact that it is superficial (depth of penetration not exceeding certain level), thus the analysis results are affected by contaminations on the surface of the coins

Thus, the textual, archaeological and analytical data must, therefore, be crossed and confronted to try having information on the probable origin of the metal of a given coinage [2].

We note that some pieces have particular elementary compositions compared to the whole

corpus, therefore, a study of samples from the same family (same mint, same date), must be carried out to draw more relevant information. on this category of parts, information which must be corroborated with historical data.

This method constitutes preliminary work for any preservation or restoration intervention and deserves to be supplemented by more advanced analyses that can reach the heart of the pieces analyzed, which will allow more advanced conclusions to be drawn that will help, for example, to identify the original ores, or even the manufacturing and processing phases through which these parts have passed.

Finally, the kind of results obtained in this study can be used for the need conservation and restoration of archaeological objects and their enhancement, knowing that the knowledge of the chemical composition is essential to control the state of conservation of the work and to possibly deduce the aging mechanism by comparison with materials of similar composition, subjected to accelerated aging tests. These data can also guide the choice of the best restoration technique, as they can guide the choice of conservation treatments for restoration of heritage metal objects likely to help inhibit or slow down corrosion processes and compensate for traditional methods. Common, practiced in certain places of conservation, namely, the application of a protective layer (varnish) to the surface of the pieces, which can have harmful long-term effects on these pieces.

Thus, the characterization must consider any changes in the composition of the surface toward the inside of the coin to be representative of the analysis of the object as a whole. Various studies have attest that neutron or proton activation methods and LA-ICP-MS (Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry, etc.) meet these different criteria for both gold and silver coins [2].

And the study by Gondonneau & Guerra, which includes 4 analyzes per activation proton of coins of the same series [26].

As a result, surface analyzes can be strongly affected, the best way to have an accurate and reliable analysis of the original alloy would be local abrasion followed by a good cleaning of the surface. But collectors prefer to give up knowledge of the metal rather than allow it to be scraped [27], given the considerable archaeological value of the pieces, especially the patina.

To confirm certain results and deepen this work, it is worth supplementing it with the determination of trace elements using the most appropriate techniques, among those already mentioned.

The analyses can also provide important indications for knowing the state of conservation of the objects before any intervention. They can generally provide information on the state of conservation of the objects,

which it is important to know well before any intervention [28].

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