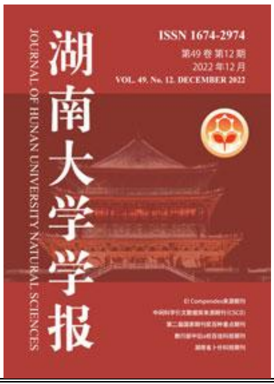

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Physico-Chemical, Archaeological and Numismatic Analysis of Almoravid Gold Coins (XIth to XIIth Century)

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Abstract: This study concerns a batch of 15 ancient Almoravid gold coins, the objects are analyzed by scanning electron microscopy (SEM) coupled with energy dispersion spectroscopy (EDS), the data collected is processed using statistical math tools. Indeed, the results obtained confirm the mastery of coinage, as stipulated in historical writings, and made it possible to distinguish and qualify the elements that may belong to the original alloy, namely: Ag, Au, Cu, Fe and Ni of those related to the patina such as: Si, O, Mn, Mg and N. These results are very useful, knowing that they can also serve any need for the conservation and restoration of archaeological objects and their enhancement since they can guide the choice of restoration techniques and conservation treatments for metallic heritage objects, while making it possible to inhibit or slow down the corrosion processes and to replace the common artisanal methods, practiced in certain places of conservation, which can sometimes be unsuitable for the elementary composition of the alloy constituting the object. For further analysis, this analysis technique deserves to be complemented by complementary analyzes that can achieve other scientific research objectives, namely; go back to the techniques of making coins, origin of metals, etc.

Keywords: gold coin, the dinar, numismatics, archaeology, physico-chemical characterization, chemical elements

阿尔摩拉维金币的物理化学、考古学和钱币学分析（11 至 12 世纪）

摘要：本研究涉及一批 15 枚阿尔摩拉维古金币，通过扫描电子显微镜结合能量色散光谱分析对象，使用统计数学工具处理收集的数据。事实上，所获得的结果证实了对造币的掌握，正如历史著作中所规定的那样，并使得区分和限定可能属于原始合金的元素成为可能,即:与合金相关的银、金、铜、铁和你古铜色,例如: 矽、欧、锰、镁和否。这些结果非常有用，因为它们可以指导修复技术的选择和 对金属文物进行保护处理，同时可以抑制或减缓腐蚀过程，并取代在某些保护地点采用的常见手工方法，这些方法有时可能不适合构成该物品的合金

的基本成分。为了进一步分析，这种分析技术应该得到可以实现其他科学研究目标的互补分析的补充,即; 回到制造硬币的技术，金属的起源等.

关键词：金币，第纳尔，钱币学，考古学，理化特性，化学元素.

1. Introduction

The application of metallurgy in numismatics has fostered numerous analyzes of ancient coins. The vast majority of these analyzes determined the composition of the alloy of the coins to understand the coinage policies in relation to the historical, political and economic events of a given time [1].

Similarly, the application of physics to archeology has made significant progress recently. The contribution of physics to the study of archaeological materials has become widely recognized. Analytical data, in conjunction with historical and archaeological hypotheses can, in addition to studies of decorations and inscriptions read by archaeologists and historians on the facies of pieces, provide indications of the development, evolution and mastery of manufacturing technologies. To do this, non-destructive physicochemical analysis techniques can identify the major, minor and trace elements that can achieve this goal [2].

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 in correlation with numismatic and archaeological analysis [3]. It is also a prerequisite for any intervention in conservation and restoration. The analysis can also provide important indications for knowing the state of conservation of the objects before any intervention.

Knowing that an object made from a metal alloy may have a certain surface composition (patina), which does not reflect its volume composition, in addition to possible alterations by zones. Moreover, analysis of old coins shows that some samples of the coins analyzed are enriched in gold on the surface [4].

Thus, to reach the volume of a part through a surface analysis, it would be necessary to proceed to the elimination of the external layer. But collectors would rather give up knowledge of the metal than allow it to be scrapped [5]. Consequently, the choice of the analysis technique must be thought out in such a way as to find a compromise between the disparate requirements of the scientist, the historian, archaeologist, and the conservator-restorer of archaeological objects.

In this article, we present the study of Moroccan gold coins, analyzed by Scanning Electron Microscopy (SEM) coupled with Energy Dispersion Spectroscopy (EDS). The analytical data obtained are statistically processed statistically and then compared with historical and archaeological data. The following flowchart illustrates the methodology for developing this study.

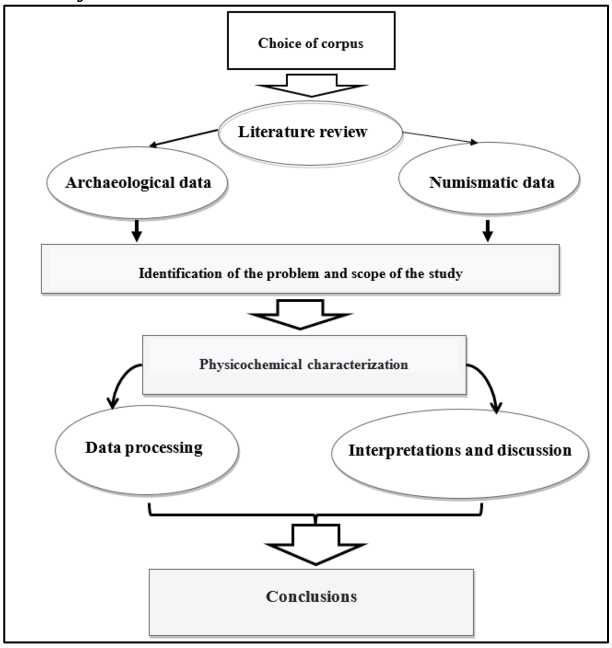

Fig. 1 Flowchart presenting the methodology of the study

2. Materials and Methods

2.1. Corpus Analyzed

From the early days of Morocco, coinage follows in the wake of Eastern Islamic coinage. As a result, in the Islamic Maghreb and in Muslim Spain, the monetary question took the same trajectory as in the East [6].

The coins studied in this article belong to the Almoravid period of Moroccan history. The Almoravids constituted an empire encompassing the western Sahara, the western part of the Maghreb and part of the Iberian Peninsula, from the 11th century to the 12th century.

The Almoravid dinar (The word dinar, derived from the Latin word "Denarius," refers to Islamic gold currency) is known for its good striking quality, its good gold title and the regularity of its weight in most minting workshops, especially that of the North African. This allowed it to be a recognized currency in the Mediterranean basin, competing with all contemporary Islamic and Christian currencies extending as far as Western Europe for several centuries. This situation is mainly due to their dominance of Sudanese gold, especially that of Ghana, which is renowned for its good quality [7].

The Almoravid coinage reached its peak, particularly, at the time of the first two sovereigns, Youssouf Ben Tachfine and his son Ali. Emir Ali Ben Youssouf, a sovereign perfectly known by the accounts of certain Arab chroniclers, reigned for 37 years, from 1106 AD to 1143 AD, thus living the last fine days of Almoravid power and the beginning of its decline. In his time, the monetary situation improved, minting houses were activated in both Morocco and Andalusia, monetary issues followed one another in the various minting workshops and the quantities of coins multiplied. Still, despite the problems encountered by the Almoravids because of their conflicts with the Almohads, this did not prevent the Almoravid workshops from conducting their activities as they should by issuing coins in gold and silver, and this at least, until the end of the reign of *Ali Ben Youssouf*, given the wealth of gold available to this sovereign [8].

The above data motivated our choice of the study of this period. Thus, the corpus of Almoravid coins analyzed consists of 15 gold coins from an official state site, in this case the Coin Museum of Bank-Al Maghrib (Bank of Morocco, Rabat). Detailed descriptions of the samples are presented in the following table.

Table 1 Description of Almoravid gold coins (Coin Museum, Bank of Morocco, Rabat)

n° inventory	Mark	Dynast	Unity	Minting	Weight (g)	Diameter (mm)
1111	A274	Abû Bakr ben Omar	*The dinar*	*Sijilmassa*	4,2	25
1119	A275	Abû Bakr ben Omar	*The dinar*	*Sijilmassa*	4,2	24
1131	A276	Youssef b. tâchfîn	*The dinar*	*Aghmât*	4,1	28
1140	A277	Youssef b. tâchfîn	*¼ dinar*	*Sijilmassa*	1,1	16
1150^2	A278	Youssef b. tâchfîn	*¼ dinar*	*Sijilmassa*	1,4	16
1150^6	A279	Youssef b. tâchfîn	*The dinar*	*Sijilmassa*	4,2	24
1164^5	A280	‘Ali ben Youssef	*The dinar*	*Séville*	3,9	28
1188^2	A281	‘Ali ben Youssef	*The dinar*	*[Aghmât]*	4,1	25
1215	A282	‘Ali ben Youssef	*The dinar*	*Sijilmassa*	4,1	26
1246	A283	‘Ali ben Youssef	*The dinar*	*Fâs*	4,1	27
1256^2	A284	‘Ali ben Youssef	*The dinar*	*Marrakech*	4,1	26
1257^2	A285	‘Ali ben Youssef	*The dinar*	*Marrakech*	4,2	26
1279	A286	‘Ali ben Youssef	*The dinar*	*Alméria*	4,0	24
1303	A287	‘Ali ben Youssef	*The dinar*	*Noul Lamta*	4,1	26
1380	A288	Ishâq ben ‘Ali	*The dinar*	*Marrakech*	4,2	25

The choice of the objects of this study is carried out on the basis of the availability of the coins at the partners who accepted to collaborate with our laboratory “Laboratory of Spectrometry, Materials and Archaeomaterials, Faculty of Science, Moulay Ismail University, Meknes, Morocco” Consequently, the results obtained in this article require the widening of this study to a representative number of coins emitted at that time to be able to be generalized to the whole of the old monetary heritage of Morocco. However, the holders of archaeological objects reserve the right to deliver their objects for possible analysis for fear of deterrification, destruction, or loss.

2.2. Physicochemical Analysis

The definition of the problem and the resulting choice of the method of analysis to be applied [9]. The SEM+EDS analysis technique has most of the qualities and conditions required for the study of objects of cultural archaeological heritage. The operation of this technique is deeply described in many specialized works, in particular that of Eberhardt [10]. The choice of this technique is justified by the fact that it is non-destructive, quantitative with accuracy generally better than 5%, multi-element capable of providing information on the spatial distribution of the elements (depth profile and lateral distribution with a resolution that can reach the micrometer).

2.3. Statistical Data Processing

For the analysis of the physicochemical data, we carried out a mathematical processing of the results of the elemental composition, using the ascending hierarchical classification (CHA) [11] and the principal component analysis (PCA) [11]. The AHC 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. Results

3.1. Elementary Data

The application of SEM + EDS to the fifteen Almoravid gold coins in our corpus shows that the coins analyzed contain 90.2% to 98.48% Au, in addition to the elements Ag, Cu, Si, O, Mn, Na, Mg, Fe, Ni.

The elements detected in most samples analyzed are Au, Ag, Cu, Si, O and Fe, while the elements Mn, Na, Mg and Ni were detected only in a minority of coins.

Table 2 Elementary composition of Almoravid gold coins

	Au	Ag	Cu	Si	O	Mn	Na	Mg	Fe	Ni
A274	91,69	4,19	0,16	0,16	3,05	0,21	0,00	0,00	0,56	0,00
A275	91,91	3,51	0,92	0,54	2,15	0,00	0,00	0,00	0,98	0,00
A276	91,86	1,99	1,05	0,59	3,43	0,45	0,00	0,00	0,66	0,00
A277	90,20	5,97	0,99	0,23	1,73	0,00	0,00	0,00	0,89	0,00
A278	92,89	3,29	0,94	1,25	0,00	0,00	0,40	0,00	1,23	0,00
A279	94,00	2,5	2,09	0,28	0,00	0,00	0,33	0,00	0,82	0,00
A280	94,70	2,37	0,94	0,85	0,00	0,00	0,00	0,00	1,15	0,00
A281	94,11	2,36	0,72	0,53	0,00	0,00	0,00	0,00	1,05	0,84
A282	92,15	2,81	0,68	0,33	3,00	0,00	0,00	0,33	0,69	0,00
A283	94,78	2,27	0,82	0,25	0,00	0,00	0,00	0,00	0,78	1,10
A284	94,43	2,83	0,67	0,57	0,00	0,00	0,00	0,00	0,88	0,64
A285	95,09	1,83	0,8	0,43	0,00	0,00	0,00	0,00	1,01	0,85
A286	96,42	1,22	0,24	0,51	0,86	0,00	0,00	0,00	0,77	0,00
A287	91,99	3,90	0,39	0,44	2,46	0,00	0,00	0,00	0,83	0,00
A288	98,48	0,00	0,42	0,00	0,00	0,00	0,27	0,19	0,64	0,00

3.2. Statistical Data

In the following, we present the results of the statistical processing of the analytical data. Said data is processed, as already mentioned, using the computer software SPSS. The results presented relate successively to those of the AHC method followed by those of the PCA.

3.2.1. Ascending Hierarchical Classification (AHC)

This classification highlights the presence of three groups (G1, G2, and G3) of coins with an isolated coin (A277). The average contents of the elements detected relative to each group are presented in the following table.

Table 3 Comparison of average levels % of almoravid groups

Elements	G1	G2	G3
Au	91,92	94,29	97,45
Ag	3,28	2,49	0,61
Cu	0,64	1,00	0,33
Si	0,41	0,59	0,26
O	2,82	0,00	0,43
Mn	0,13	0,00	0,00
Mg	0,07	0,00	0,10
Fe	0,74	0,99	0,71
Ni	0,00	0,49	0,00
Na	0,00	0,10	0,14

According to the table above; the parts analyzed can be grouped into two main families:

- The first consists mainly of broadcasts by Youssouf Ben Tachfine and his son Ali ben Youssouf. All the pieces of this family are grouped in group G2 whose average gold content reaches 94.29%, except two samples belonging to the group (G1) richest in gold: (A286) containing 96 .4% Au minted by Ali Ben Youssouf and (A288) minted by Ishaq at a higher grade of 98.5%.
- The second family includes the parts contained in G3 and the isolated part (A277). The G3 coins have an average gold content of around 91.92% and the coin (A277) contains 90.2% Au, 5.97% Ag, 0.99% Cu 0, 23% Si, 1.73% O and 0.89% Fe.

3.2.2. Principal Component Analysis (PCA)

The PCA applied to the elements detected in the Almoravid coins analyzed highlights the distribution of these elements into four main components: the first component CP1 bringing together Mn and O, the second component CP2 containing Si, Mg and Fe, the third component CP3 composed of Au and Cu and the fourth and last CP4 component consisting of Ag and Na.

4. Discussions

4.1. Characteristics and Composition of Coinage Alloys

To give a frame of reference to this study, we present in what follows the quintessence of various bibliographical sources consulted:

- The literature shows that among the elements deemed to belong to the original alloy are: Au, Ag, Cu, Fe and Ni [1, 12] - as well as other elements belonging to the patina and/or encrustation on the surface of the pieces in their places of conservation [13]. Several alloys are abundant. As a result, the gold is not found there in its pure state, but it always contains a certain amount of silver and copper and, often, a little iron. Native gold can contain up to a maximum of 20% copper [14]. Generally speaking, the most important and most common constituent of native gold is silver, it can also be alloyed with several other elements, such as: Cu, Hg, Bi, Fe, Ni, Pd and Pt [13].
- Ancient coins are usually, like most archaeological material, buried in the ground for several centuries. They are often covered with a layer of earth and oxides. Abundant elements in soils such as; iron, manganese, calcium, silicon, aluminum accumulate on the surface of the parts. Other elements of the monetary alloy, such as copper, zinc and tin, are preferentially eliminated by corrosion, which can distort the determination of the original elemental composition of the coin [15].
- The presence of carbon can be attributed to the contamination of the parts during the molding of the blanks, which were poured in crucibles made from animal bones. As for magnesium, it can come from contamination during the silver refining operation using refractory soil [16]. As for copper, it does not always belong to the gold ore, but it can be added voluntarily for metallurgical purposes, flowability, and malleability of the blanks to allow hammering and other decorative and writing work on the pieces. The SEM images show, moreover, that it is corroded and completely transformed into several shades of copper [17].
- The origin of the gold ore is usually determined by calculating the Au/Ag ratio, however, other elements belonging to the original alloy can also be detected, such as Cu and Fe [12].
- Copper is not refined from gold ore as easily or as economically as silver. Although copper is difficult to

extract from gold ore, it can easily be easily added to form a gold alloy. This does not appear to be the case with the coins we reviewed. The percentage of copper is so low, usually less than 1.5%, that it was probably not added to the alloy. Therefore, any copper present is a factor of the gold ore and can be used as a clue to the place of origin of that ore [7].

- Iron and nickel, they cannot help, easily, in the identification of the originality of the alloy. These two metals are among the elements, which, in addition to their belonging to the original alloy, can come from encrustations on the surface, given their significant abundance in nature [18].
- To conclude this paragraph, we present in the table below a summary of the origin of the elements that can constitute a gold object [19]. However, recycling, commonly practiced in the development of these objects, is generally considered as a major obstacle in the studies of the origin of precious metals [20], since it is based on the mixture of metals from different sources.

Table 4 Elements detected in archaeological gold objects [19]

Elements sensitive to melting conditions	**Elements resistant to melting conditions**
Cr, Mn, Fe, Co, As, Se, Cd, In, Sn, Sb, Te, Pb, Bi, Hg	Ag, Cu, Rh, Pd, Pt, Ir, Ge, Ni, Os, Ru

4.2. Interpretation of Results

The results of the AHC confirm the mastery of monetary minting by the sovereigns encountered in this study since the currencies of each of these sovereigns are found together in the same group. The minting of the Almoravid dinars analyzed in this study is distributed according to the issuing sovereigns as follows:

- Two analyzed coins (A274 and A275) are issued by Abou Bakr Ben Omar: They are both in group G1 with an average gold content equivalent to 91.92%. The minting of this sovereign's coins was centralized at Sijilmassa, the only mint at the time, which could justify the mastery of the minting quality confirmed by the results of the analysis.
- Youssouf Ben Tachfine's four Almoravid strikes are in two distinct groups. A coin (A276) minted in Aghmat was in Group G1 group with an average gold content of 91.92%, two (A278 and A279) in Sijilmassa present in G3 with an average grade of 94.29% and an isolated coin (A277) at 90.2% Au. This could mean the poor mastery of the strike by this sovereign both within the same workshop and from one workshop to another. According to the results of the analysis, this multiplicity of mints would probably have led to poor mastery of the coinage by the sovereign.
- Referring to the elementary composition and more precisely to the gold content, the coins issued by Ali Ben Youssouf are divided as follows: Five coins (A280, A281, A283, A284, and A285) were in the G3 group with an average gold content of 94.29%, one piece (A286) at a grade of 96.42% gold and in the G4 group of average gold content equivalent to 97.45% and two (A282 and A287) in the G1 group at 91.92% Au. The coins are minted in different mints in both Africa (Sijilmassa, Nul, Aghmat, Marrakech) and Spain (Seville and Almeria). Thus, we can say that Ali Ben Youssouf mastered the coinage at the various workshops of his time.
- A single piece analyzed from Ishaq Ben Ali (A288) of excellent quality (98.48% Au). This was the highest gold content among the coins analyzed in this study. According to the gold content of this coin, one could say that the sovereign watched over the minting of dinars of good quality in gold. However, the confirmation of such a hypothesis requires an enlargement of the sample on a larger number of pieces to be able to draw conclusions that could be generalized at the time of this sovereign.

The component analysis made it possible, in turn, to distinguish and qualify the elements that may belong to the original alloy from those related to the patina. Thus, the main components identified can be categorized into two large families:

- The first is made up of CP3 and CP4 including the elements belonging to the original alloy, except Na, which is present in only three parts at very low levels not exceeding 0.4%. The presence of this element could be linked to contamination during the handling of the parts.
- The second family is made up of CP1 and CP2 grouping the elements probably due to contamination and encrustation on the surface of the samples. However, the presence of iron could be attributed both to the original alloy and to other sources given its very high natural abundance, which may justify its strong correlation with the elements detected mainly on the surface of the parts.

A summary of the interpretation of the results is presented in the conclusion. This is the comparison of the results of this study with those of previous studies.

This allows to say that there is a correlation between the results of our studies with those that preceded it.

5. Conclusion

The results of the analysis confirm the historical writings, knowing that the contents of the coins analyzed within the framework of this research are comparable to those of the analysis of coins from contemporary Islamic dynasties or other analyzes which concerned the Almoravid dinars. For example, numismatists consider the minting of the Sijilmassa city as the leading workshop in the Almoravid coinage minting from 1059, this site was mainly supplied with gold by way of caravans traveling to this precious metal from Sudan. The coins analyzed in our work confirm this.

Work preceding this study confirms the following:

- The study of a batch of gold coins shows that a quantity equivalent to 49% of the coins of this batch has gold content lower than that of the Almoravid dinars of North Africa. Knowing that the latter rarely exceeds gold content equivalent to 96% [7].
- Analysis have shown that the gold content of the Almoravid dinar, which became the numeraire of trade, is around 95%. These analysis clearly show the use of the same gold as that of Sudan both for the Almoravid dinars minted in Al-Andalus and those of the African minting, located in the most important stations of the trans-Saharan circuit [21].
- Neutron activation analysis for the determination of gold content was applied to a batch of ten ancient Muslim gold coins, from a hoard discovered in the province of Essaouira in Morocco, prove that the content in the gold of the Almoravid coins of this lot reached 94% [22].

In addition to this information on the gold content of the coins analyzed and referring to bibliographical data, we can conclude that only the elements Ag, Cu, Fe and Ni could be considered to belong to the original alloy while the elements Mn, O, Si, Mg and Na would, on the other hand, be related to the patina.

The SEM+EDS 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 the light elements and capable of providing information on the spatial distribution of the elements (depth profile and lateral distribution with a resolution of up to one micrometer).

However, note that this technique faces certain limitations, knowing that it 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 does not provide any information on the chemical state of the elements.

Note that scanning electron microscopy coupled with EDS made it possible to provide relevant information on the elementary composition of the samples. However, when the patina is thick, the concretions on the surface prevent an in-depth analysis of the samples.

As a result, surface analysis can be strongly affected and the best way to guarantee an accurate and reliable analysis of the original alloy would be local abrasion followed by a good cleaning of the surface. We can use other techniques requiring only tiny samples or better still, those allowing an in situ analysis without sampling.

Moreover, a single method cannot, of course, provide complete documentation and reading of the work and generally several methods of examination and analysis are associated, knowing that in many cases, simple elementary analysis is not enough. does not identify materials unambiguously. Such a method should necessarily be completed by a structural analysis by using X-ray diffractometry or Raman micro-spectrometry as well as other more appropriate analysis techniques such as Neutron Activation Analysis (NAA), spectrometry mass inductive plasma with micro-sampling by laser ablation.

And this, to establish hypotheses the most probable on the historical level, the data of research on coined metals must be confronted with the study of archaeological, textual and numismatic data [23, 24].

To this end, the creation of multidisciplinary synergy between physico-chemists, historians, and archaeologists gets a high priority.

Thus, we hope, through this study, of physico-chemical characterization of the Moroccan numismatic heritage, to deepen the scientific knowledge of the coinage materials, and to contribute to the efforts made for their conservation and development.

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