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Archaeometric Investigation of Gold Coins (Byzantine Period, Romanus Iii) By Means of Portable Xrf: Characterization and Comparison

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Abstract
Some of the ancient materials in museums can only be examined on-site, which requires in-situ analysis techniques. Coins made of precious metals are one of such materials and portable X-ray fluorescence (p-XRF) spectrometry is one of the most preferred technique for gold and silver-based coins that need to be characterized in situ and non-destructively. In this study, a detailed archaeometric investigation was carried out for the gold coins which were unearthed after the excavations in Melik Ahmet Street (Diyarbakır, 1992) and brought to Directorate of Diyarbakır Museum through confiscation. The chemical compositions of the samples were specified by means of portable XRF which was applied on 45 gold coins of the Romanus III period. The main element in the composition was found as gold detected as 93.89% in average. Silver was the most abundant element after gold, however the highest silver rate did not exceed 9% (5.25% in average). Copper and iron were identified respectively in 12 coins (Cu: 1.05-2.46%) and 18 coins (Fe: 0.87-6.5%). Manganese, nickel, titanium, lead, iridium and osmium were seen in one sample each. The hierarchical clustering analysis applied with gold-silver-copper-iron and gold-silver suggested three different groups. The hierarchical clustering analysis was also applied considering the p-XRF data achieved in this study (belonging to the Romanus III period), solidus samples belonging to six Byzantine period emperors, and for the hollow coins belonging to four Byzantine period emperors. Taking into account the distribution, classification and the variations, the coins of different emperor periods were compared.

1. Introduction

In the most general sense, archaeometry covers the characterization process applied to identify the raw materials and production technologies of the materials found in archaeological research. Spectroscopic and microscopic analysis are the most preferred techniques in terms of elucidating the production stages of the ancient materials. In this context, X-ray fluorescence (XRF), X-ray diffraction (XRD), optical microscopy and scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM/EDX) come forward in archaeometric investigations. On the other hand, the artifacts exhibited in the museums can only be analyzed by means of non-destructive and/or portable analysis devices, which may limit the number of analyses to be used. In such cases, the samples must be analyzed in-situ, and should not be deformed. Coins are one of the best examples for this situation. The coins made of precious metals such as gold and silver can be analyzed on-site by means of portable XRF in order to identify the amounts of Au, Ag and other possible elements like cupper, iron, titanium etc. By determining the chemical composition with the archaeometric studies on the coins, the socio-economic status of the periods, when the coin was struck, can be evaluated [1]-[3].

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Determining the value of goods has revealed the idea of "value" and accordingly the idea of "equivalent", and consequently, money was needed as a means of exchange, and at first, cereal products, animals and manufactured tools were used instead of money [4]. As a result of the increase in people's relations with each other, shopping increased and the way of paying with animals began to seem useless, which resulted in using metal tools (e.g. shovel, hoe, ax) and ornaments (e.g. ring, earring, bracelet) [5]. Since these goods, which are used as money, were difficult to protect, produce and transport, only precious metals such as silver and gold have been used as money over time [4]. The tradition of using precious metals (especially silver) as money goes back to the 2400s BC in Mesopotamia [6].

Constantine VIII, who was on the throne in the Byzantine Empire between 1025 and 1028 AD, had three daughters. Since Constantine III had no successor, he married his middle daughter, Zoe, to Romanus Argyros, who came from an aristocratic family from Constantinople and was the ruler (economos) of Hagia Sophia, in order to take the throne after his death. Three days after marriage Constantine VIII has died and Romanus Argyros (Romanus III) became the Byzantine Emperor in 1028 AD. The coins struck during the reign of Romanus III, who is considered to be the founder of the Peribleotos Church and Monastery, have intense depictions of Mary as an indication of his devotion to her. On the solidus, which are the gold coins of the Romanus III period, there is Mary depicted standing, crowning the emperor [7], [8].

In the present study, the Romanus III period coins, which were confiscated to the Diyarbakır Museum Directorate in 1992, were analyzed by the portable X-ray fluorescent (p-XRF) method and their elemental contents were determined. Before the analyzes, the necessary permits were obtained for the study, and the analyzes were carried out in the museum with the p-XRF device under the supervision of the museum authorities. After the study, the samples were put back to their places in the inventory by the authorities.

2. Material and Method

2.1. Samples

Within the scope of the thesis study, 45 Romanus III period gold coins in Diyarbakır Museum were on-site characterized under the supervision of the museum officials. Although the information on the front and back of the coins, such as the descriptions, inscriptions, period, also the way it came to the museum and the date of arrival are the same, the code, inventory number, diameter, thickness and weight of the coins occasionally vary. A representative coin from the sample set is given in Figure 1 [9], [10].

Description of the front side of the coins: The bearded Jesus is depicted with a halo on his head, sitting on a throne with a double row of dotted borders. Depicted from the front, Jesus is holding a dot-decorated book on his knee with his left hand while his right hand is on his chest in a consecrated position. There is an inscription in the form of “IhSXISRЄX RЄϚNANTıhm” around the depictions within the double-dotted border.

Description of the back side of the coins: On the left, the emperor is depicted frontally holding the loros, his right hand on his chest, and his left hand holding the crusader globus, which symbolizes the world domination. On the right, there is Mary, whose head is in a halo, crowning the emperor with her long tunic and long cloak called maphorion. There is a double line dotted border around the depictions and there is the inscription “ΘCЄbOHΘ RωmAnω” inside the border.

Figure 1. A representative sample of Romanus III coins analyzed in the present work [9], [10].

2.2. Portable X-ray Fluorescence (p-XRF)

Innov-X Omega portable X-ray Fluorescence (p-XRF) spectrometer was used and analyzes were carried out in the "precious metals" mode of the device. During the study, the coins were taken out of the inventory one by one by the museum authorities. After the completion of analysis for each sample, the analyzed coin was put back into the inventory, and then the other coin was removed from the inventory. The fact that the coins were gold eliminated the risk of skidding that would affect the X-rays during the analysis. There were no obvious impurities on the surfaces of the coins, in general, which could affect

the analysis results. Therefore, no additional processing was done for the coins before or after the p-XRF application, and the analyzes were carried out entirely on the original states of the coins. Analyzes were applied separately for the front and back surfaces of each coin

3. Results and Discussion

3.1. Portable XRF results of the Coins

The p-XRF results of the samples are given in Table 1 in which the data obtained for both the front and back sides of the coins are presented

Table 1. Portable XRF results of the Romanus III coins.

Code (RM)	Analysis Surface*	Au	Ag	Cu	Fe	Ti	Mn	Os	Ir	Ni	Pb
1	F	95,64	4,35	-	-	-	-	-	-	-	-
	B	95,62	4,37	-	-	-	-	-	-	-	-
2	F	92,16	5,74	2,10	-	-	-	-	-	-	-
	B	92,21	5,74	2,05	-	-	-	-	-	-	-
3	F	94,46	4,41	1,12	-	-	-	-	-	-	-
	B	95,48	4,51	-	-	-	-	-	-	-	-
4	F	95,70	4,29	-	-	-	-	-	-	-	-
	B	95,73	4,26	-	-	-	-	-	-	-	-
5	F	95,89	4,10	-	-	-	-	-	-	-	-
	B	95,88	4,11	-	-	-	-	-	-	-	-
6	F	94,48	4,38	1,13	-	-	-	-	-	-	-
	B	94,49	4,32	1,18	-	-	-	-	-	-	-
7	F	92,45	5,72	1,82	-	-	-	-	-	-	-
	B	92,49	5,74	1,77	-	-	-	-	-	-	-
8	F	95,80	4,19	-	-	-	-	-	-	-	-
	B	94,78	4,17	-	1,04	-	-	-	-	-	-

**F: Front Surface, B: Back Surface*

Table 1. Portable XRF results of the Romanus III coins (continued).

Code (RM)	Analysis Surface*	Au	Ag	Cu	Fe	Ti	Mn	Os	Ir	Ni	Pb
9	F	92,83	5,74	1,42	-	-	-	-	-	-	-
	B	93,51	5,16	1,32	-	-	-	-	-	-	-
10	F	94,16	4,61	-	1,22	-	-	-	-	-	-
	B	94,52	4,49	-	0,984	-	-	-	-	-	-
11	F	94	6	-	-	-	-	-	-	-	-
	B	93,15	5,98	-	0,874	-	-	-	-	-	-
12	F	94,32	5,68	-	-	-	-	-	-	-	-
	B	94,36	5,64	-	-	-	-	-	-	-	-
13	F	95,48	4,51	-	-	-	-	-	-	-	-
	B	95,55	4,44	-	-	-	-	-	-	-	-

14	F	94,24	4,89	-	0,871	-	-	-	-	-	-
	B	91,23	4,76	-	4,01	-	-	-	-	-	-
15	F	95,83	4,16	-	-	-	-	-	-	-	-
	B	95,76	4,23	-	-	-	-	-	-	-	-
16	F	94,51	3,96	-	1,52	-	-	-	-	-	-
	B	94,48	4,15	-	1,35	-	-	-	-	-	-
17	F	93,77	5,07	1,15	-	-	-	-	-	-	-
	B	94,98	5,02	-	-	-	-	-	-	-	-
18	F	92,88	5,97	-	1,14	-	-	-	-	-	-
	B	94,03	5,97	-	-	-	-	-	-	-	-
19	F	94,02	4,29	-	1,69	-	-	-	-	-	-
	B	95,89	4,10	-	-	-	-	-	-	-	-
20	F	86,39	6,86	-	6,5	-	-	-	-	0,255	-
	B	91,65	6,33	-	2,01	-	-	-	-	-	-
21	F	90,26	5,82	1,88	0,89	-	-	0,9	0,28	-	-
	B	90,55	5,71	1,63	2,10	-	-	-	-	-	-
22	F	94,41	5,59	-	-	-	-	-	-	-	-
	B	94,42	5,58	-	-	-	-	-	-	-	-
23	F	91,77	8,23	-	-	-	-	-	-	-	-
	B	91,68	8,32	-	-	-	-	-	-	-	-
24	F	95,86	4,13	-	-	-	-	-	-	-	-
	B	94,62	4,22	-	1,15	-	-	-	-	-	-
25	F	95,90	4,09	-	-	-	-	-	-	-	-
	B	95,36	4,63	-	-	-	-	-	-	-	-
26	F	92,75	5,12	1,22	0,89	-	-	-	-	-	-
	B	93,56	5,22	1,22	-	-	-	-	-	-	-
27	F	94,61	5,39	-	-	-	-	-	-	-	-
	B	95,05	4,95	-	-	-	-	-	-	-	-

**F: Front Surface, B: Back Surface*

Table 1. Portable XRF results of the Romanus III coins (continued).

Code (RM)	Analysis Surface*	Au	Ag	Cu	Fe	Ti	Mn	Os	Ir	Ni	Pb
28	F	89,35	6,38	1,96	1,28	-	0,73	-	-	-	0,29
	B	93,17	6,83	-	-	-	-	-	-	-	-
29	F	93,88	5,07	-	1,05	-	-	-	-	-	-
	B	95,09	4,91	-	-	-	-	-	-	-	-
30	F	95,37	4,62	-	-	-	-	-	-	-	-
	B	95,43	4,56	-	-	-	-	-	-	-	-
31	F	91,7	8,3	-	-	-	-	-	-	-	-
	B	91,7	8,3	-	-	-	-	-	-	-	-
32	F	95,13	4,87	-	-	-	-	-	-	-	-
	B	94,99	5,00	-	-	-	-	-	-	-	-
33	F	93,21	5,74	-	1,05	-	-	-	-	-	-
	B	94,34	5,66	-	-	-	-	-	-	-	-

34	F	91,93	6,71	1,36	-	-	-	-	-	-	-
	B	90,97	6,57	2,46	-	-	-	-	-	-	-
35	F	96,20	3,79	-	-	-	-	-	-	-	-
	B	95,80	4,19	-	-	-	-	-	-	-	-
36	F	93,53	6,47	-	-	-	-	-	-	-	-
	B	87,14	6,27	1,05	4,91	0,6	-	-	-	-	-
37	F	95,12	4,87	-	-	-	-	-	-	-	-
	B	95,46	4,54	-	-	-	-	-	-	-	-
38	F	94,55	5,45	-	-	-	-	-	-	-	-
	B	94,6	5,4	-	-	-	-	-	-	-	-
39	F	93,4	5,08	1,51	-	-	-	-	-	-	-
	B	93,58	5,06	1,34	-	-	-	-	-	-	-
40	F	92,56	6,53	-	0,905	-	-	-	-	-	-
	B	93,62	6,38	-	-	-	-	-	-	-	-
41	F	92,68	6,39	-	0,932	-	-	-	-	-	-
	B	92,78	6,29	-	0,925	-	-	-	-	-	-
42	F	95,08	4,92	-	-	-	-	-	-	-	-
	B	94,99	5,00	-	-	-	-	-	-	-	-
43	F	95,01	4,99	-	-	-	-	-	-	-	-
	B	95,03	4,96	-	-	-	-	-	-	-	-
44	F	94,94	5,05	-	-	-	-	-	-	-	-
	B	94,04	4,9	-	1,05	-	-	-	-	-	-
45	F	94,18	4,57	1,24	-	-	-	-	-	-	-
	B	94,51	4,32	1,16	-	-	-	-	-	-	-
Maximum	***F,B***	***96,20***	***8,32***	***2,46***	***6,5***	***0,6***	***0,73***	***0,9***	***0,28***	***0,255***	***0,29***
Minimum	***F,B***	***86,39***	***3,79***	***1,05***	***0,871***	***0,6***	***0,73***	***0,9***	***0,28***	***0,255***	***0,29***
Mean	***F,B***	***93,89***	***5,24***	***1,50***	***1,68***	***0,6***	***0,73***	***0,9***	***0,28***	***0,255***	***0,29***

**F: Front Surface, B: Back Surface*

According to the p-XRF analysis data, the amount of gold in coins varies in the range of 86.39-96.20% (93,89% in average). After gold, the highest element observed in coins was silver. The silver ratio in the samples varies between 3.79% and 8.32% (5.24% in average). Copper was found in 13 coins (1.05-2.46%), and iron in 18 coins (0.87-6.5%). Manganese (RM 28 Front; %0,73), nickel (RM 20 Front; %0,255), titanium (RM 36 Back; %0,6), lead (RM 28 Front; %0,29), iridium (RM 21 Front; %0,73) and osmium (RM 21 Front; %0,9) were seen in one sample each. Since these six elements are thought as the possible contaminations on the coins' surfaces (considering the coin production at Byzantine period), they are not included for the evaluation and comparison of the results.

The distribution of elements with an average of more than 1% in coins is given in Figure 2. Considering the variations in chemical composition, it has been observed that the amount of gold is quite dominant and only the coin RM 20 contains significantly less gold. Only three samples were identified in the sample set containing gold less than 90% (RM 20, RM 28 and RM 36).

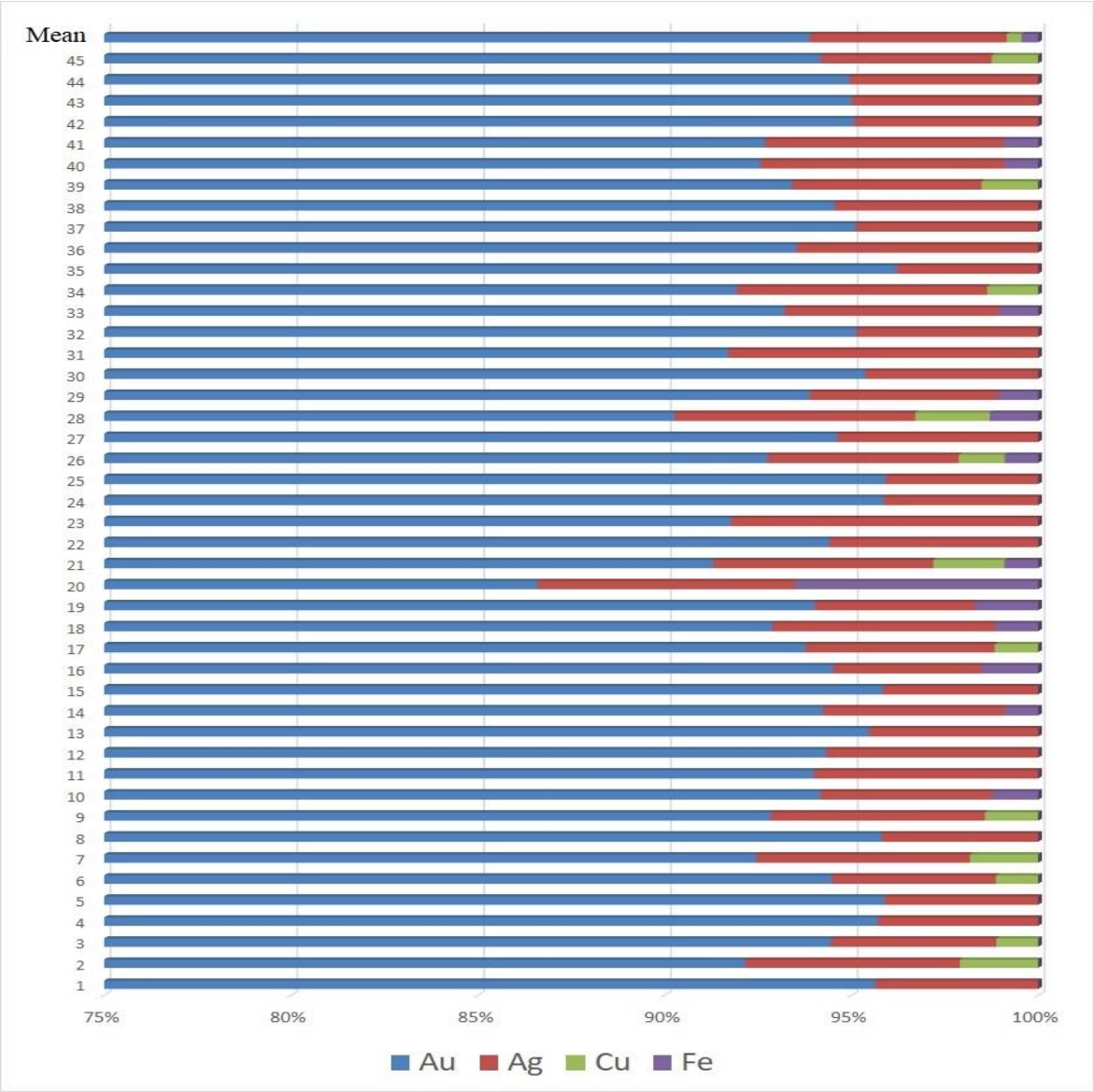

Figure 2. The distribution of elements with an average of more than 1%.

The samples can be initially separated as four main groups given as the followings;

i. The samples possessing only gold and silver: RM 1, RM4, RM 5, RM 12, RM 13, RM 15, RM 22, RM 23, RM 25, RM 27, RM 30, RM 31, RM 32, RM 35, RM 37, RM 38, RM 42, RM 43.

ii. The samples possessing gold, silver and copper: RM 2, RM 3, RM 6, RM 7, RM 9, RM 17, RM 34, RM 39, RM 45.

iii. The samples possessing gold, silver and iron: RM 8, RM 10, RM 11, RM 14, RM 16, RM 18, RM 19, RM 20, RM 24, RM 26, RM 29, RM 33, RM 40, RM 41, RM 44.

iv. The samples possessing gold, silver, copper and iron: RM 21, RM 28, RM 36.

In order to see the correlation between the coins more clearly, hierarchical clustering analysis was carried out with gold, silver, copper and iron contents (Figure 3). Since the predominance of gold amount suggested a sample set with a single type chemical composition, the majority of the samples were accordingly gathered in one group in the hierarchical clustering analysis carried out considering the data achieved for the front surfaces of the coins. Three groups were determined in the classification made with gold-silver-copper-iron, and the majority of the coins (42 samples) were in a single group and three subgroups were identified in this group. The second group included only RM 21 and RM 28. The third group alone constituted RM 20. The lowest gold amounts were thought to be the decisive factor in the formation of the second and

third groups. The samples forming separate groups also showed themselves in the scatter plot of gold and silver (Figure 4)

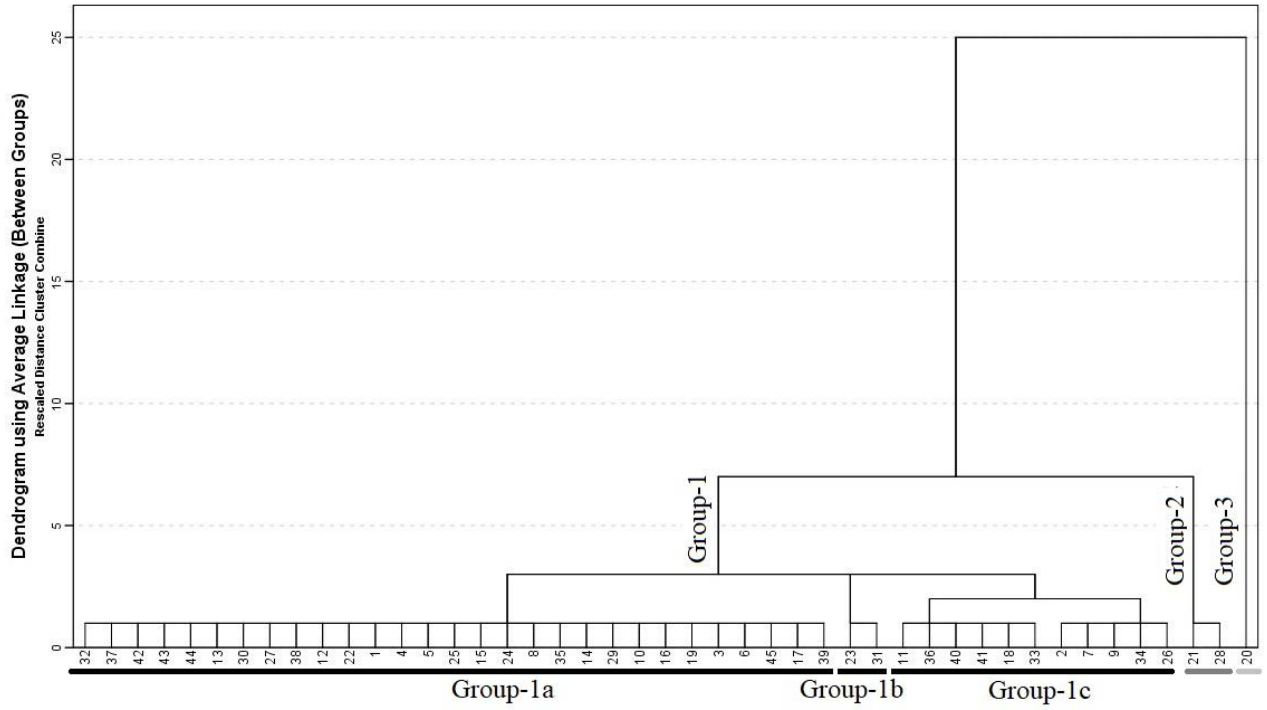

Figure 3. Dendrogram showing the groups (considering gold, silver, copper and iron).

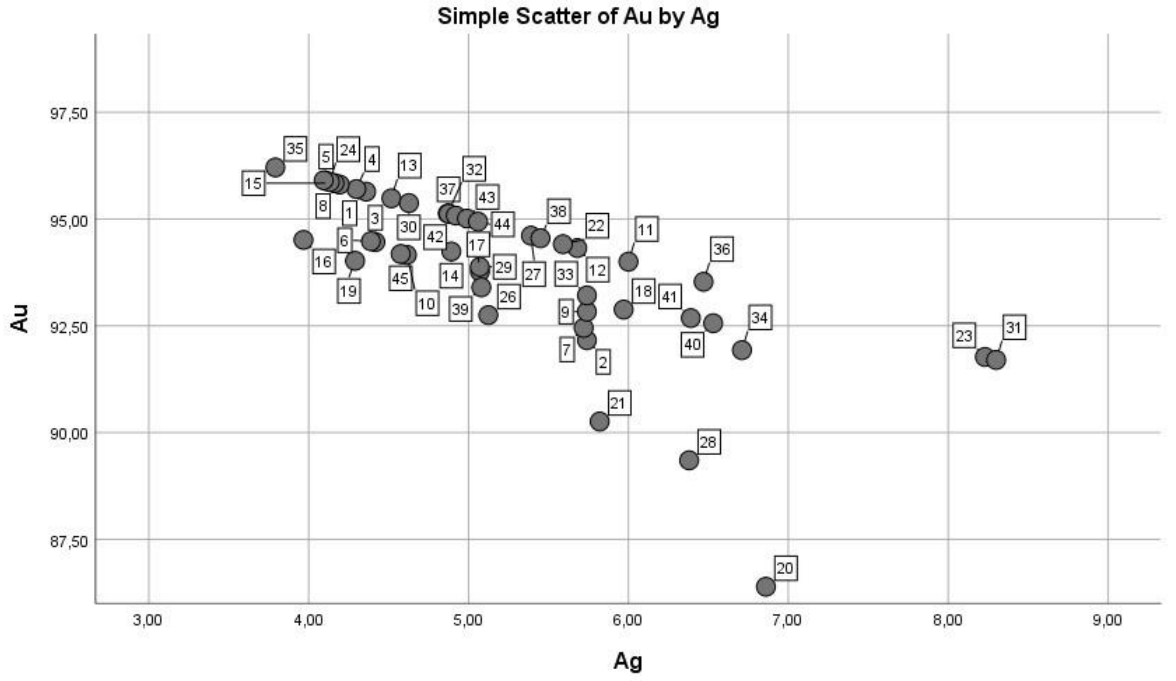

Figure 4. Scatter plot of gold and silver.

For the Figures 2-4, please see the codes (RM) given in Table 1 to follow the samples.

3.2. Comparison with the Solidus Coins of Six Byzantine Emperors

The coins of the Romanus III period (1028-1034) analyzed within the scope of this work are in the solidus group. Based on this, the examples in the present research were compared with the solidus coins belonging to the periods of Leo I (457-474 AD), Anastasius I (491-518 AD), Mauricius Tiberius (539-602 AD), Constans II (641-668 AD), Constantinus IV (668-685 AD) and Iustinianus II (685-695 AD) [11], [12]. The distribution of gold and silver in the solidus samples from different periods mentioned and from the Romanus III period is given in Figure 5 (sample order: 1-3 Leo I; 4,5 Anastasius I; 6,7 Mauricius Tiberius; 8-13 Constans II; 14-20 Constantinus IV; 21-28 Iustinianus II; 29-73 Romanus III). According to the variation in terms of gold and silver contents, it was observed that the gold ratio in the solidus coins of six emperors, who have been on the throne between 457-695 AD, was close to the solidus samples of the Romanus III period, yet was relatively higher. It was seen that the solidus samples of the Romanus III period were mostly close to each other and likewise the solidus samples of other emperors, who have been on the throne in different periods, in general. The silver ratio was seen to increase during the Romanus III period, which indicated that silver was used instead of gold in parallel with the decrease in the gold rate with the Romanus III period. In a way, this may suggest that the cost of gold, the precious element in coins, would have been reduced

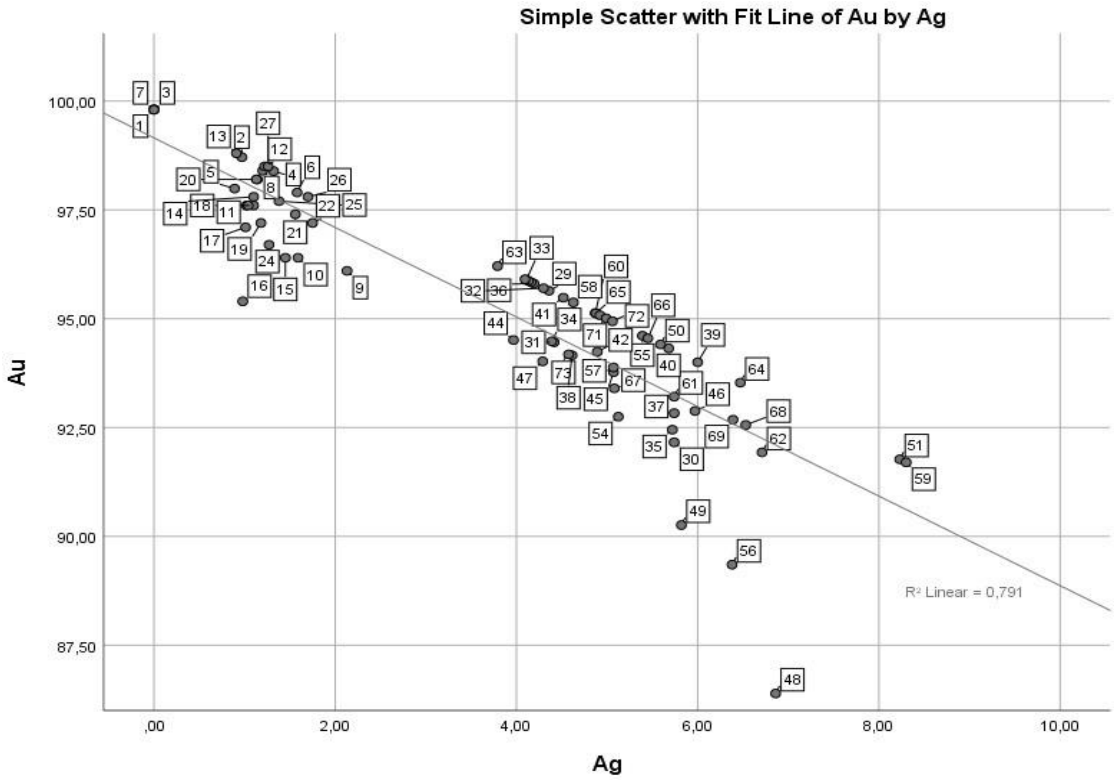

Figure 5. Scatter plot of Au and Ag (comparison of Romanus III coins with solidus samples of six emperors).

3.3. Comparison with the Hollow Coins of Four Byzantine Emperors

The Romanus III period coins examined within the scope of the study were also compared with the data of the Byzantine hollow coins (electrum) from Diyarbakır Museum, which were analyzed with the same p-XRF device by Ayhan (2021) [3]. In Ayhan's work, the hollow coins respectively belong to Constantine Ducas X (1059-1067), Romanus Diogenes IV (1068-1071), Michael Ducas VII (1071-1078) and John II (1118-1143) periods [3]. The distribution of gold, silver, copper and iron in the solidus samples of Romanus III together with the hollow coins of four Byzantine emperors is given in Figure 6. Considering the gold and silver contents, it can be deduced that the dominant gold amounts decreased significantly after Romanus III, which may indicate that the cost of precious metals in coins would have been reduced. It has been observed that the amount of silver and copper started to increase with the period of Constantine Ducas X (1059-1067), and the silver ratio increased significantly, especially in the period of Michael Ducas VII (1071-1078). In the samples of John II (1118-1143) period, it was seen that copper almost approached the level of silver

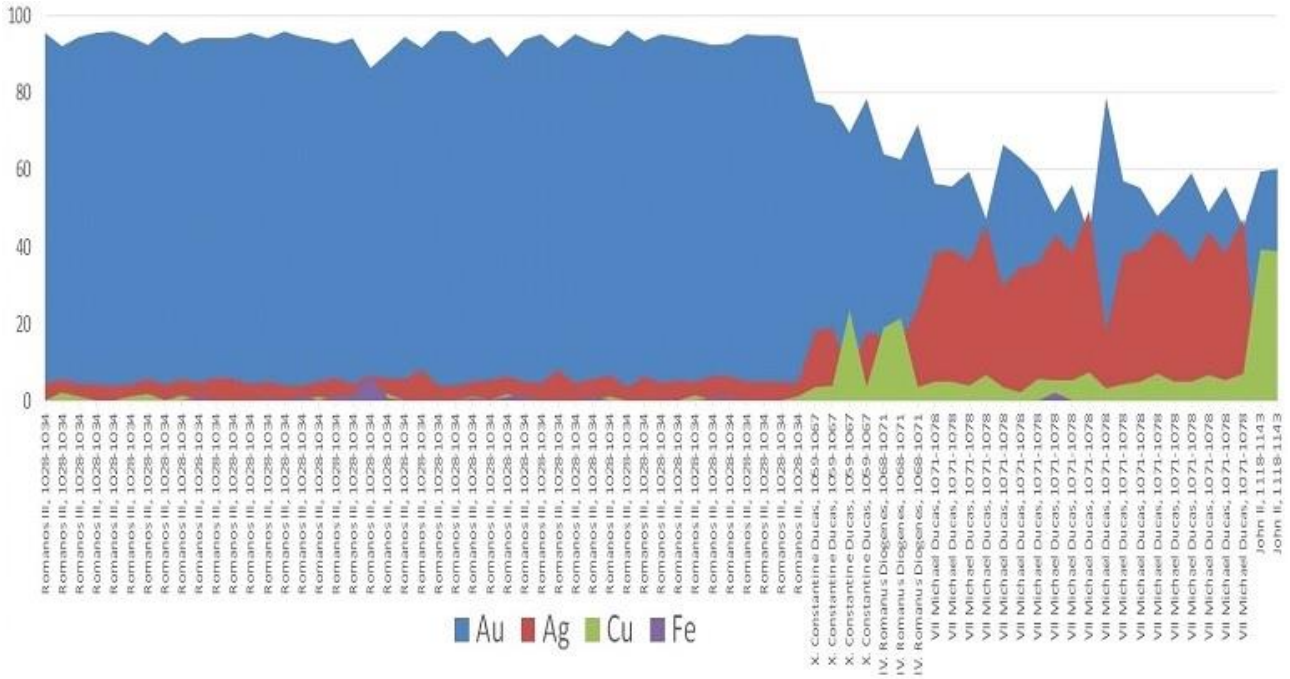

Figure 6. The distribution of gold, silver, copper and iron in the solidus samples of Romanus III, and the hollow coins of four Byzantine emperors.

In the comparison of the gold, silver and copper ratios in the Romanus III period coins with the hollow coins (Figure 7), it was observed that the coins of the same period mostly came together among themselves. This indicated that there were no significant changes in the coin production (in general) during the period of each emperor, but there were fluctuations in the use of precious metals as the emperor changed. The decrease in the amount of gold and the corresponding increase in the silver content in the coins caused a negative correlation (Figure 8) between these two precious metals. This may suggest a gold-silver alloy (electrum) in some examples.

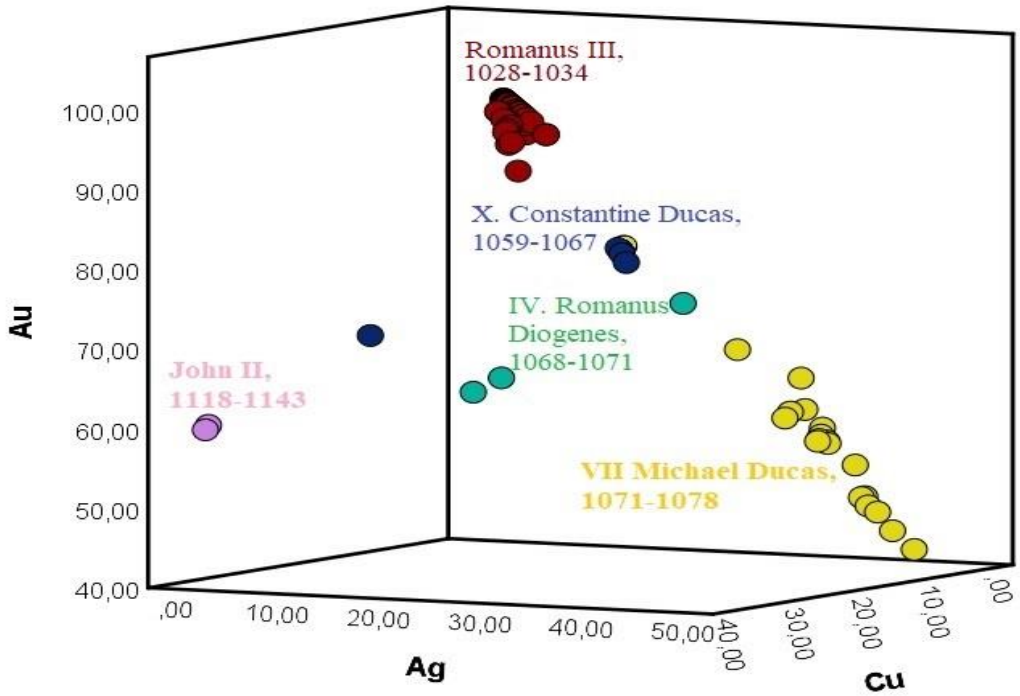

Figure 7. Distribution of Au, Ag and Cu in solidus coins of Romanus III, and the hollow coins.

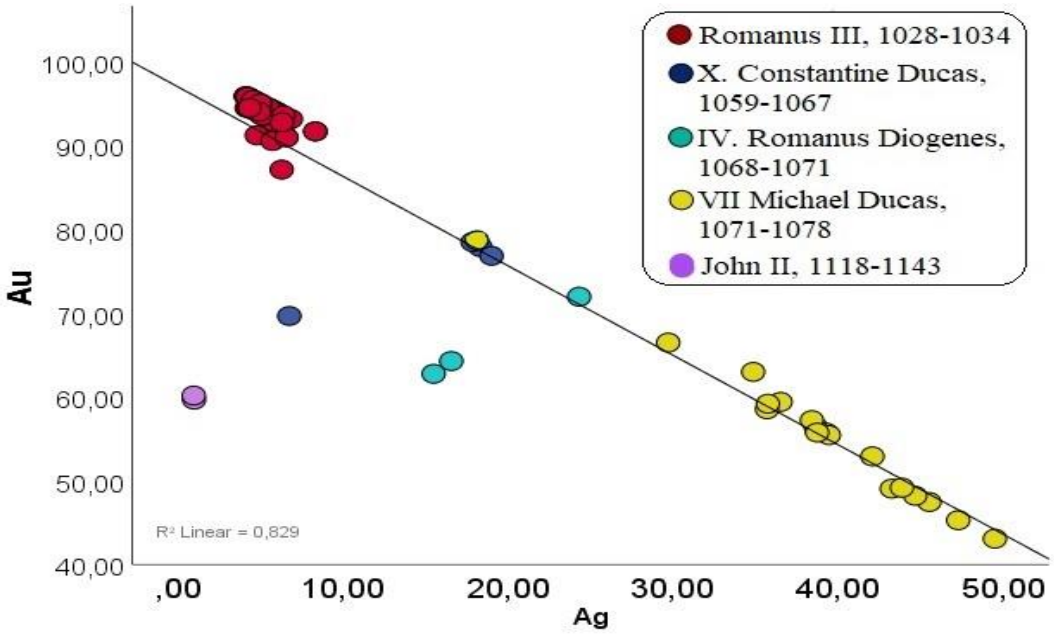

Figure 8. The correlation between gold and silver (Romanus III, and the hollow coins).

3.4. Comparison of All Solidus and Hollow Coins

When the gold-silver-copper distribution of solidus and hollow coins from different periods is examined, it could be seen that the solidus samples with high gold ratios are close together, and hollow coins with lower gold ratios and higher silver ratios come together within themselves (Figure 9; sample order: 1-3 Leo I; 4,5 Anastasius I; 6,7 Mauricius Tiberius; 8-13 Constans II; 14-20 Constantinus IV; 21-28 Iustinianus II; 29-73 Romanus III; 74-77 Constantine Ducas X; 78-80 Romanus Diogenes IV; 81-99

Michael Ducas VII; 100,101 John II). While the coins of the John II period (100-101 in Fig 9), which are the coins with the highest copper content, form a separate group, two hollow coins of Romanus Diogenes IV (78-79 in Figure 9), which also contain high copper, formed a different group due to its high silver content (please see the references [3], [10], [11], [12] for the details).

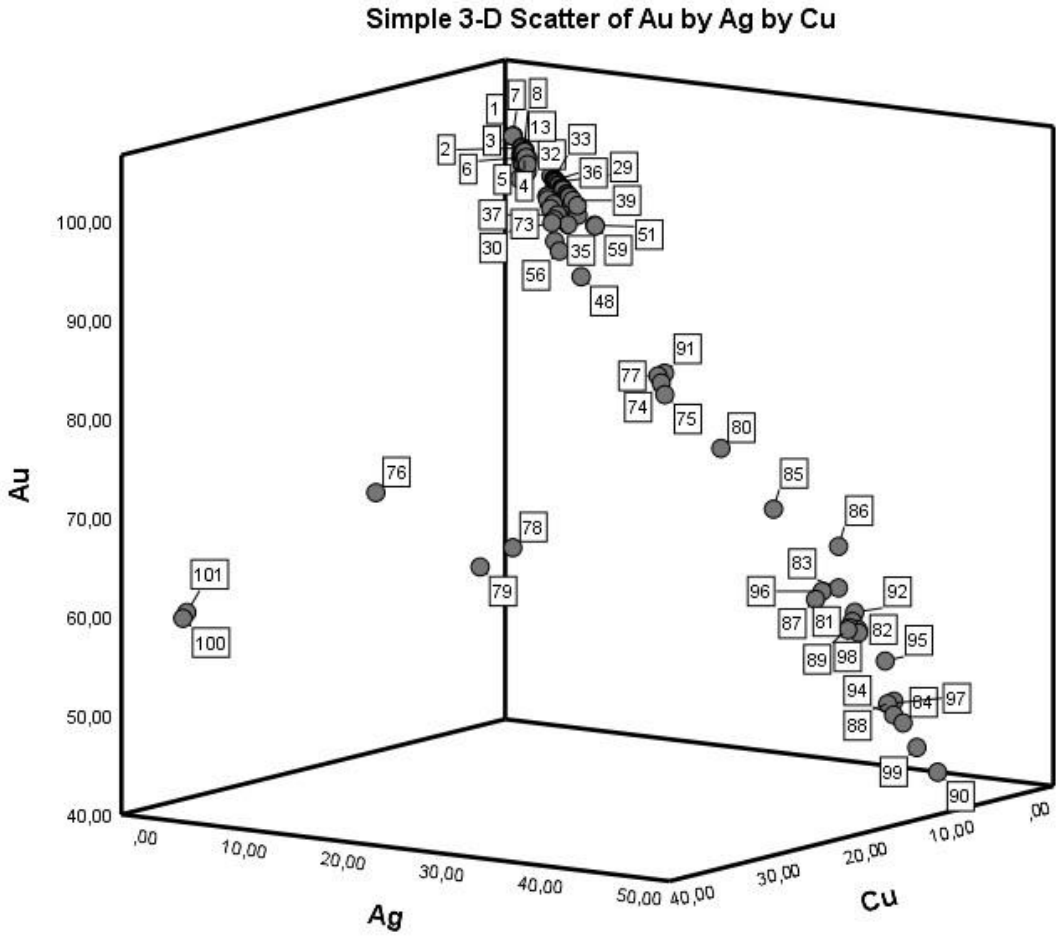

Figure 9. Au-Ag-Cu distribution in all solidus and hollow coins from different periods.

The data of all coins (Au, Ag, Cu, Fe) were subjected to hierarchical clustering analysis in order to make a classification. According to the results of the clustering analysis (Figure 10), the samples were generally divided into two groups and each group has two subgroups. All solidus coins and only four hollow coins (with a high gold rate) took place in Group-1. In Group-1a, there are solidus coins with a gold percentage over 95.36%, in Group-1b there are three Romanus Diogenes IV and one Michael Ducas VII hollow coins with a gold percentage above 70%. These data showed that the high gold ratio was effective in the formation of Group-1. The second group consists of hollow coins, which are outside of Group-1b. There are 18 hollow coins in total in the first subgroup (Group-2a) of the second group. The element averages of these coins are as follows; Au 54.35%, Ag 40.10%, Cu 5.38%. Only one of the hollow coins in Group-2a contains iron with a percentage of 2.34%. The second subgroup (Group-2b) of the second group consisted of 5 hollow coins, 1 of Constantine Ducas X, 2 of Romanus Diogenes IV and 2 of John II. The fact that the coins in Group-2b are the ones with the highest copper content showed that the most important factor in the formation of this group was the high copper ratio in the coins.

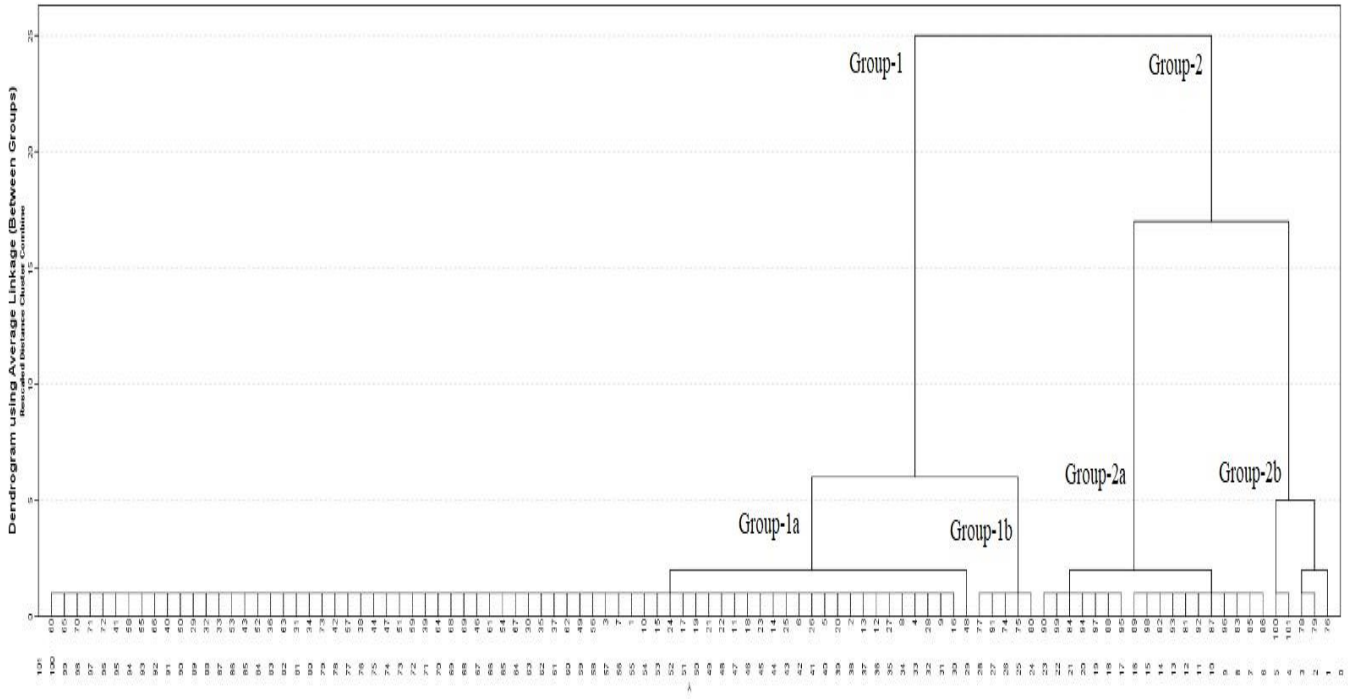

Figure 10. Dendrogram showing the groups identified by clustering analysis applied for all coins.

Finally, Table 2 shows the presence of gold-silver, gold-silver-copper, gold-silver-iron, gold-silver-copper-iron, gold-iron and gold-iron-copper for an overview in order to see the main elemental distribution comparatively in all of the samples. It can be seen that gold, silver, copper and iron are simultaneously present in most of the early samples (from Leo I to Iustinianus II). At the period of Romanus III, the solely existence of gold and silver is obvious, while the coexistence of iron and/or copper in such coins is limited. At the periods of Michael Ducas VII and John II, excluding only one sample, it can be observed that iron does not exist in the coins which are consisted of gold, silver and copper.

Table 2. Presence of Au, Ag, Cu, Fe in the solidus and hollow coins.

SPSS No	Emperor*	Au, Ag, Cu, Fe
1	Leo I (M.S. 457-474)	Au-Fe
2	Leo I (M.S. 457-474)	Au-Ag-Cu-Fe
3	Leo I (M.S. 457-474)	Au-Fe-Cu
4	Anastasius I (M.S. 491-518)	Au-Ag-Cu-Fe
5	Anastasius I (M.S. 491-518)	Au-Ag-Cu-Fe
6	Mauricius Tiberius (539-602)	Au-Ag-Cu-Fe
7	Mauricius Tiberius (539-602)	Au-Fe-Cu
8	Constans II (MS 641-668)	Au-Ag-Cu-Fe
9	Constans II (MS 641-668)	Au-Ag-Cu
10	Constans II (MS 641-668)	Au-Ag-Cu-Fe
11	Constans II (MS 641-668)	Au-Ag-Cu-Fe
12	Constans II (MS 641-668)	Au-Ag-Cu-Fe
13	Constans II (MS 641-668)	Au-Ag-Cu-Fe
14	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe

15	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe
16	Constantinus IV (MS 668-685)	Au-Ag-Fe
17	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe
18	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe
19	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe
20	Constantinus IV (MS 668-685)	Au-Ag-Cu-Fe
21	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
22	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
23	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
24	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
25	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
26	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
27	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
28	Iustinianus II (MS 685-695)	Au-Ag-Cu-Fe
29	Romanus III (1028-1034)	Au-Ag
30	Romanus III (1028-1034)	Au-Ag-Cu
31	Romanus III (1028-1034)	Au-Ag-Cu
32	Romanus III (1028-1034)	Au-Ag
33	Romanus III (1028-1034)	Au-Ag
34	Romanus III (1028-1034)	Au-Ag-Cu
35	Romanus III (1028-1034)	Au-Ag-Cu
36	Romanus III (1028-1034)	Au-Ag
37	Romanus III (1028-1034)	Au-Ag-Cu
38	Romanus III (1028-1034)	Au-Ag-Fe
39	Romanus III (1028-1034)	Au-Ag
40	Romanus III (1028-1034)	Au-Ag

**Please see the references [3], [10], [11], [12] for the details.*

Table 2. Presence of Au, Ag, Cu, Fe in the solidus and hollow coins (continued).

SPSS No	**Emperor***	**Au, Ag, Cu, Fe**
41	Romanus III (1028-1034)	Au-Ag
42	Romanus III (1028-1034)	Au-Ag-Fe
43	Romanus III (1028-1034)	Au-Ag
44	Romanus III (1028-1034)	Au-Ag-Fe
45	Romanus III (1028-1034)	Au-Ag-Cu
46	Romanus III (1028-1034)	Au-Ag-Fe
47	Romanus III (1028-1034)	Au-Ag-Fe
48	Romanus III (1028-1034)	Au-Ag-Fe
49	Romanus III (1028-1034)	Au-Ag-Cu-Fe
50	Romanus III (1028-1034)	Au-Ag
51	Romanus III (1028-1034)	Au-Ag
52	Romanus III (1028-1034)	Au-Ag
53	Romanus III (1028-1034)	Au-Ag
54	Romanus III (1028-1034)	Au-Ag-Cu-Fe

55	Romanus III (1028-1034)	Au-Ag
56	Romanus III (1028-1034)	Au-Ag-Cu-Fe
57	Romanus III (1028-1034)	Au-Ag-Fe
58	Romanus III (1028-1034)	Au-Ag
59	Romanus III (1028-1034)	Au-Ag
60	Romanus III (1028-1034)	Au-Ag
61	Romanus III (1028-1034)	Au-Ag-Fe
62	Romanus III (1028-1034)	Au-Ag-Cu
63	Romanus III (1028-1034)	Au-Ag
64	Romanus III (1028-1034)	Au-Ag
65	Romanus III (1028-1034)	Au-Ag
66	Romanus III (1028-1034)	Au-Ag
67	Romanus III (1028-1034)	Au-Ag-Cu
68	Romanus III (1028-1034)	Au-Ag-Fe
69	Romanus III (1028-1034)	Au-Ag-Fe
70	Romanus III (1028-1034)	Au-Ag
71	Romanus III (1028-1034)	Au-Ag
72	Romanus III (1028-1034)	Au-Ag
73	Romanus III (1028-1034)	Au-Ag-Cu
74	Constantine Ducas X (1059-1067)	Au-Ag-Cu
75	Constantine Ducas X (1059-1067)	Au-Ag-Cu
76	Constantine Ducas X (1059-1067)	Au-Ag-Cu
77	Constantine Ducas X (1059-1067)	Au-Ag-Cu
78	Romanus Diogenes IV (1068-1071)	Au-Ag-Cu
79	Romanus Diogenes IV (1068-1071)	Au-Ag-Cu
80	Romanus Diogenes IV (1068-1071)	Au-Ag-Cu
81	Michael Ducas VII (1071-1078)	Au-Ag-Cu

**Please see the references [3], [10], [11], [12] for the details.*

Table 2. Presence of Au, Ag, Cu, Fe in the solidus and hollow coins (continued).

SPSS No	**Emperor***	**Au, Ag, Cu, Fe**
82	Michael Ducas VII (1071-1078)	Au-Ag-Cu
83	Michael Ducas VII (1071-1078)	Au-Ag-Cu
84	Michael Ducas VII (1071-1078)	Au-Ag-Cu
85	Michael Ducas VII (1071-1078)	Au-Ag-Cu
86	Michael Ducas VII (1071-1078)	Au-Ag-Cu
87	Michael Ducas VII (1071-1078)	Au-Ag-Cu
88	Michael Ducas VII (1071-1078)	Au-Ag-Cu-Fe
89	Michael Ducas VII (1071-1078)	Au-Ag-Cu
90	Michael Ducas VII (1071-1078)	Au-Ag-Cu
91	Michael Ducas VII (1071-1078)	Au-Ag-Cu
92	Michael Ducas VII (1071-1078)	Au-Ag-Cu
93	Michael Ducas VII (1071-1078)	Au-Ag-Cu
94	Michael Ducas VII (1071-1078)	Au-Ag-Cu
95	Michael Ducas VII (1071-1078)	Au-Ag-Cu
96	Michael Ducas VII (1071-1078)	Au-Ag-Cu

97	Michael Ducas VII (1071-1078)	Au-Ag-Cu
98	Michael Ducas VII (1071-1078)	Au-Ag-Cu
99	Michael Ducas VII (1071-1078)	Au-Ag-Cu
100	John II (1118-1143)	Au-Ag-Cu
101	John II (1118-1143)	Au-Ag-Cu

**Please see the references [3], [10], [11], [12] for the details.*

4. Conclusions

When all the coins in the study are evaluated from a numismatic point of view, it could be seen that the samples show the characteristics of the period they belong. As an example, it is possible to talk about the depiction of Jesus sitting on a throne with a backrest, which was first seen on Byzantine coins during the Romanus III period. In addition, the present research has provided a detailed archaeometric data basis for the coins. The results were initially evaluated for the Romanus III coins and then discussed with the other solidus and hollow coins in order to make a comparison in terms of chemical composition. The main element was gold detected as 93.89% in average, and silver was the most abundant element after gold, but the highest silver rate did not exceed 9% (5.25% in average). Copper and iron were identified respectively in 12 coins (Cu: 1.05-2.46%) and 18 coins (Fe: 0.87-6.5%). Manganese, nickel, titanium, lead, iridium and osmium were seen in one sample each. The ignorable amounts of these elements were attributed to possible contaminations on the coins' surfaces which may occur during the delivery of the coins to the museum.

Considering all the coins of the emperors who ruled in different periods, the highest gold content was seen in the Leo I period solidus with 99.81%, and the lowest in the Michael Ducas VII period hollow coin with 43.08%. While the gold average is 93.89% in the samples of Romanus III period, this rate is 97.82% in the solidus samples belonging to the pre-Romanus III period. The average value of gold is 59.95% for the hollow coins. While the highest silver rate with 47.28% is seen in the Michael Ducas VII period hollow coin, it is possible to show a total of three solidus samples, two of which belong to the Leo I period and one belonging to Mauricius Tiberius, as the lowest rate, in which no silver was found in the analysis. The negative correlation between gold and silver (in general) indicated that there were no significant changes in coin material in each emperor's own period, but there were fluctuations in the use of precious metals in coins, especially in hollow coins, as the emperor changed. In the comparison made between the coins of the Romanus III period (studied in the present research) and the coins of the other imperial periods, it should be noted that the samples belonging to the period of six emperors, who were on the throne between 457-695 AD, were composed of solidus, while the others were made of hollow coins.

In this archaeometric research, the portable XRF has been successfully applied on the gold coins as a non-destructive method which is also an in-situ analysis technique allowing the users to analyze the samples on-site. This kind of portable devices are frequently preferred for the artifacts in the museums and the immovable building materials such as stone, plaster, mortar and tile. It is predicted that the analytical data of the coins and use of p-XRF in this work would be a good reference for the further archaeometric investigations.

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Contributions of the Authors

Murat Bayazit; application of p-XRF analysis, statistical analyses, interpreting the results, editing. Nesrin Şeker; application of p-XRF analysis, interpreting the results.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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