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SEM-EDS ANALYSIS USED TO DETERMINE VALUE CHANGES IN OTTOMAN COINS BASED ON POLITICAL DEVELOPMENTS

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ABSTRACT

Coins were used to maintain the commercial activities on a specific standard. They are significant written sources that enlighten the political, economic, and cultural life of the period they were produced. It is possible to find the coin collections belonging to different periods of Turkish history in museums. One of the important groups of these coins belongs to the Ottoman period. Although there are studies covering the periods of some Ottoman sultans by using advanced analysis techniques in the literature, no scientific study has been carried out covering all periods. The most extensive information that can be found about the coins is from the Ottoman archive and inventory records. In this study, twenty-six Ottoman Empire coins from Sakarya Museum dated between the 14th-19th centuries were evaluated stylistically, physically, and chemically. The non-destructive analysis of scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) was employed to identify the elemental composition of the coins. The chemical analysis of coins showed the connection between the political situation in the Ottoman Empire and the decline in the value of the money.

KEYWORDS: Ottoman coins, coin analysis, SEM-EDS analysis, silver coin, coin minting, money

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1. INTRODUCTION

Humanity has developed the bartering method to survive until a certain period of history by the barter method. A barter economy is a cashless economic system in which services and goods are traded at negotiated rates. This system was a type of currency developed over the centuries that involved trade items like animal skins, salt, and weapons. Bartering for commodities and trade in kind evolved into increasingly complex forms of exchange using commodity currencies like bronze or copper ingots or even cowry shells. However, these were typically only useful for large-scale commercial dealings, and for smaller transactions, money was required. Ancient people sometimes introduced coins as a practical means to pay warriors, but the concept rapidly expanded to civilian life. The Silk Road was a network of historical trade routes that united the ancient globe in commerce between 130 BCE and 1453 CE. It was initially founded under the Han Dynasty of China in 130 BCE.

The barter method has some difficulties in meeting the mutual needs and paved the way for the precious metals to be used as a means of exchange. Metals evaluated depending on their weight and value were formed in various shapes and sizes and transformed into metal tokens by the end of the 7th century B.C and were used as a shopping tool. The weight of these tokens was predetermined, and value was ensured with the official stamp of the State; they were called coins (Pakalın, 1972:214; Mete, 1992:14; Tekin, 1998:2).

Although the first evaluations of the findings obtained from scientific excavations indicate that these coins were made of an alloy of gold and silver, research in recent years revealed that the first coins minted in the pre-Christian period were mainly made of silver (Yükçü-Gönen, 2014:46). The coins, which were initially used to carry out trading activities, were also a significant means of paying for municipal expenses, military expenditures, and wages. In the forthcoming period, the coins were considered a symbol of freedom and were minted by reigning states of different geographies. Each State minted coins that reflected its own belief and culture (Eagleton-Williams, 2008:23). Different names were given to the coins like denarius, drachma, and solidus for the fact that they were made of different metals like gold, silver, and bronze. Depictions of gods and goddesses, portraits of emperors, depictions of animals as national emblems, floral motifs, and rarely, inscriptions are found on the coins. These elements have significance in clarifying the period to which the coin belongs. The coins used by Islamic states were minted according to Byzantine and Sassanid models. Islamic coins made with metals such as gold, silver, and copper were called dinars, dirhams, and fals (Tekin, 2009:179). As in other states, coins continued to be considered a symbol of independence and sovereign power in Islamic states. The sultans who take over the rule of the State have a khutbah held and coins minted (Halil İnalcık, 2017:61). Although the coins of the Islamic period minted from precious and semi-precious metals contained representations in the early period, after a while, these were no longer used, and religious inscriptions replaced the figures. These coins, which contain information such as the name of the sultan, his titles, prayers, the place of minting, and the date of the enthronement of the sultan, are important cultural objects that provide information about the period in which they were produced (Tekin, 2009:179; Eagleton-Williams, 2008:125) The Ottoman Empire, which was founded as a small principality in the late 13th century and dominated the world in later years, also minted coins. The minting of coins began with the establishment of the State. When the sultans took over the administration of the State and were enthroned, they used to have coins minted with inscriptions of their names as a sign of sovereignty (Figure 1). This tradition, which began with Osman Ghazi, lasted until the reign of Sultan Vahdettin. The first currency of the State was made of silver and was called akça-i Osmani, which is also known as the white coin (asper) (Pakalın, 1971:35; Aykut, 1987:258). The Ottomans established their first mints in Bursa and Edirne (Artuk-Artuk, 1974; Mitev, 2018:189).

Figure. 1. Some selected Ottoman coins. The upper pictures show the coins minted before the 17th century without using a mold, and the bottom ones after the 17th century minted using a mold.

As the borders expanded, mints were established in nearly ninety centers in Asia, Europe, and Africa, and the molding plates were shipped from the capital Istanbul. Because the manufacturing process involved hammering, the shapes of early coins were imperfect. With mechanization in the 17th century, the shapes of the coin templates were improved, and coinage became serial. It is mentioned in written sources that the measure and fineness of Ottoman coins were not changed in the first 120 years (Pakalın, 1971:32). In this period, the first financial practice of the enthroned sultans was coin regeneration. Coin regeneration means that the new coins with the names of the sultans are put into circulation, the coins of the predecessor sultan are withdrawn, and their use is prohibited. In the following years, the political situation of the State was gradually changed, and this change had a negative effect on the economic situation because of the decrease in state revenue. The coin adulteration method was used in order to generate income for the state treasury, starting from Mehmed II (Fatih Sultan Mehmed). The purpose of coin adulteration is to reduce the carat content and weight of the coin, and the first coin adulteration was shown by reducing the weight of the coin from 6 carats (1.203 g) to 5 carats (1.052 g). During the collapse of the Empire, the value of money was reduced to one carat (0.202 g) (Pamuk, 2007:54,59). Another regulation implemented in coins during the Ottoman period was the correction procedure. It is known that in cases where the economy was stalled and the State did not intervene in time, counterfeiters either put money on the market (low setting) or stole silver by shearing existing coins. Since these circumstances resulted in a devaluation of coins, the administration minted new standardized coins and put them into circulation to eliminate this weakness (Pakalın, 1971:32; Sahillioğlu, 1989: 226,227).

It was not easy to understand the actual chemical structure of the coins from the Ottoman period in those years. Therefore, it was not possible to find out whether the minted coins were deteriorated or not. The reason for this is the lack of advanced analytical methods. Due to this situation, the only way to understand the content of the coins was through written sources. However, today's technology allows all kinds of analyses of the coins. The well-developed analytic methods facilitate the understanding of coin content and allow to identify whether the money is counterfeit or has undergone a transaction. As in previous periods, the first analysis that can be applied to coins is visual assessment. This method of analysis involves examining the inscriptions and numbers on the coins. In this method, the dating of the coin is possible by comparing it with similar coins. In addition, analysis can be done on parameters such as weight, density, and diameter of the coin. The authenticity and structural changes of coins can be revealed through advanced analytical techniques. In case the content of coins made of a particular metal or metal mixture is not known, the content of these metals can be easily analyzed through various techniques. These analytical techniques include Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), X-Ray Diffraction (XRD), X-Ray Photoelectron Spectroscopy (XPS), Neutron Activation Analysis (NAA), Proton Activation Analysis (PAA), and Particle Induced X-Ray Emission (PIXE). These techniques have advantages and disadvantages in comparison with each other. A technique that can present optimal results would be sufficient for analysis (Hajivaliei et al., 1999; Papp-Kovàcs, 2013; Valter, 2020; Felix et al., 2020; Liritzis et al., 2020). When the EDS technique is compared with other surface analysis techniques, it can be thought that techniques such as PIXE and XRF give better results in quantitative analysis. When the studies in the literature are examined, it has been shown that there is only a 0.7% difference between the results obtained from these techniques in tests performed on silver standards (Rodrigues et al., 2011).

No scientific research has been conducted on Ottoman period coins, covering all periods. Rodrigues and his friends (Rodrigues et al., 2011) carried out partial research on Ottoman coins, and in this study, 416 coins were selected out of a total of 60 000 coins, and content analyses were made on these coins. These coins represent the period of three different sultans minted in different mints. The given historical information about the coins was compared with the data obtained by using real experimental results. For this purpose, the coins minted during the Ottoman Empire were evaluated physically, stylistically, and chemically. SEM and EDS technique was used for chemical analysis to find the real composition of the coins, and all these results have revealed the impact of political and economic developments in different periods on the coinage and the amount of metal used in its production.

2. MATERIALS AND METHODS

2.1. Samples

The studied coins were taken from the collection of the Sakarya Museum after obtaining official permission from the Ministry of Culture and Tourism of the Republic of Turkey, Directorate of Cultural Assets and Museums. A total of twenty-six coins minted by twenty-two sultans between the 14th and 19th centuries were analyzed. Fig. 2 shows images of both sides of these coins.

Figure. 2. Obverse and reverse images of Ottoman period coins.

2.2. *Methods*

The chemical composition of the coins brought to the central research laboratory of Sakarya University under the supervision of the museum directorate was studied using scanning electron microscopy of the JEOL model of JSM 6060 LV (SEM) at 20 kV. For each coin, different locations were scanned and the best points were selected for data analysis. The elements quantified in the coin included the main components Ag and Cu and others Pb, Hg, Pb, and Al. The spectral evaluation was performed with the system software (JEOL, SEM control user interface version 6.60). The matrix effect correction was also done using the same

software. Backscattered electron images were collected with 100X magnification and a total 1.72x1.72 mm^2 area was monitored. Interpretations have been done using the same dimensions for all the coins. The coins were not cleaned, nor were conductive layers applied. The measurements were carried out in low vacuum mode to avoid any damage. Afterward, the physical and stylistic analyzes of the coins were carried out. The inscriptions and figures on both sides of each coin were carefully examined. Only basic parameters such as the sizes, diameters, and weights of the coins were examined in physical analyses. Density measurement was not performed in order to avoid damage to cultural assets.

3. RESULTS AND DISCUSSION

It is known that the Ottoman Empire was ruled by thirty-six sultans for 600 years. In this study, twenty-six coins belonging to twenty-two sultans who ruled between 1362 and 1876 were evaluated. These coins were subjected to stylistic, physical, and chemical analysis.

3.1. Stylistic analysis

The obverse and reverse images of all the coins are shown in Fig. 2. Table 1 summarizes the name of the sultan, the year of issue, the place of minting, the category of the coin, and the information on the obverse and reverse images of the coins. As seen from the pictures given in Fig. 2 and the information given in Table 2, the coins have different sizes and weights. Their average weights range from 0.21-2.05 g, their diameters from 9.92-20.90 mm, and their thicknesses from 0.19-1.31 mm. The main reason for the differences was the size of the rods, the pressure applied to the coin mold, and the aging of the mold. The coins were cut from the rods, and the rods were not made in the same diameter. Therefore, it was not possible to produce the same size of coins. After the coins were cut from the rods, they were subjected to shaping and printing the information on them. During the shaping and printing of the appropriate information, different amounts of pressure were applied to the coins.

Table 1. Inscription and figure analyses of reverse and obverse surfaces of coins.

No	Name of Sultan	Production year (Gregorian/Muslim Calender)	Mint place	Obverse	Reverse
1	I.Murad (1359-1389)	-	-	Orhan's son Murad	May the property be overlasted
2	I.Bayezid (1389-1402)	1390 / 792	-	Murad's son Bayezid	May the property be overlasted
3	II. Murad (1421-1451)	1421 / 824	Bursa	Mehmed's son Murad	May the property be overlasted, printed in Bursa 824
4	II. Mehmed (1451-1481)	1444 / 848	-	Mehmed son of Murad Khan	May the property be overlasted, 848
5	II. Bayezid (1481-1512)	1481 / 886	-	Sultan Bayezid	May the relief be plenteous, 886
6	I. Selim (1512-1520)	-	Constantinople	Sultan Selim Shah	May the relief be plenteous, printed in Constantinople
7	I. Süleyman (1520-1566)	1520 / 926	-	Sultan Süleyman son of Selim Khan	Year 926
8	III. Murad (1574-1595)	-	Kastamonu	Murad son of Sultan Selim Khan	-
9	III. Mehmed (1595-1603)	1595 / 1003	Constantinople	Sultan Mehmed son of Sultan Murad Khan	Konstantiniyye, 1003
10	I. Ahmed (1603-1617)	1603 / 1012	Constantinople	Sultan Ahmed son of Sultan Mehmed	May the relief be plenteous, printed in Constantinople, 1012
11	I. Mustafa (1617-1618/1622-1623)	1623 / 1031	Edirne	Ahmed khan	Printed in Edirne, 1031
12	II. Osman (1618-1622)	1618 / 1027	-	Sultan Osman son of..	1027
13	IV. Murad (1623-1640)	-	Egypt	Sultan Murad son of Ahmed	May the relief be plenteous, printed in Egypt, 2
14	I. İbrahim (1640-1648)	-	-	İbrahim son of Ahmed Khan	May the relief be plenteous, printed..
15	IV. Mehmed (1648-1687)	-	-	Sultan Mehmed..	-
16	III. Ahmed (1703 -1730)	1703 / 1115	Constantinople	Sultan Ahmed's monogram	printed in Constantinople, 1115
17	I. Mahmud (1730- 1754)	1730 / 1143	Constantinople	Sultan Mahmud's monogram	printed in Constantinople, 1143
18	III. Mustafa (1757-1774)	1760 / 1174	Egypt	Sultan Mustafa's monogram	printed in Egypt, 1174
19	I. Abdülhamid (1774- 1789)	1774 / 1187	Egypt	Sultan Abdülhamid's monogram	printed in Egypt, 1187
20	III. Selim (1789- 1807)	1789 / 1203	Egypt	Sultan Selim's monogram	printed in Egypt, 1203
21	II. Mahmud (1808-1839)	1808 / 1223	Constantinople	Sultan Mahmud's monogram and Adli (nickname of Mahmud II)	printed in Constantinople, 1223
22	Abdülmecid (1839-1861)	1839 / 1255(2)	Constantinople	Sultan Abdülmecid's monogram	printed in Constantinople, 1255(2)
23	Abdülmecid (1839-1861)	1839 / 1255(3)	Constantinople	Sultan Abdülmecid's monogram	printed in Constantinople, 1255(3)
24	Abdülmecid (1839-1861)	1839 / 1255(4)	Constantinople	Sultan Abdülmecid's monogram	printed in Constantinople, 1255 (4)
25	II. Abdülhamid (1876- 1909)	1876 / 1293(2)	Egypt	Sultan Abdülhamid's monogram	printed in Constantinople, 1293 (2)
26	II. Abdülhamid (1876- 1909)	1876 / 1293	Constantinople	Sultan Abdülhamid's monogram	printed in Egypt, May the relief be plenteous, 1293

Table 2. Mint places and physical specifications of the analysed coins.

No	Mint Place	Category of coins	Weight (gr)	Diameter	Thickness (mm.)
6	Constantinople	Asper	0.61	9.92	0.83
9	Constantinople	Asper	0.31	11.25	0.29
10	Constantinople	Asper	0.92	11.28	0.58
16	Constantinople	Asper	0.4	15.07	0.3
17	Constantinople	Asper	0.56	16.8	0.53
21	Constantinople	Asper	1.08	20.9	0.53
22	Constantinople	Asper	1.48	20.44	0.68
23	Constantinople	Asper	1.28	20.76	0.63
24	Constantinople	Asper	1.34	20.62	0.59
26	Constantinople	Piastre	1.14	14.97	0.82
13	Egypt	Asper	0.27	14.42	0.34
18	Egypt	Asper	0.28	14.77	0.26
19	Egypt	Asper	0.33	15.37	0.32
20	Egypt	Asper	0.26	14.98	0.19
25	Egypt	Asper	2.05	17.85	0.94
3	Bursa	Asper	1.23	12.57	1.31
8	Kastamonu	Asper	0.37	12.35	0.54
11	Edirne	Asper	0.33	11.38	0.48
1	Unknown	Asper	1.19	15.07	0.91
2	Unknown	Asper	1.19	12.57	1.16
4	Unknown	Asper	0.95	12.07	0.75
5	Unknown	Asper	0.76	10.34	1.22
7	Unknown	Asper	0.37	10.68	0.58
12	Unknown	Asper	0.32	11.61	0.5
14	Unknown	Asper	0.21	10.77	0.37
15	Unknown	Asper	0.29	12.11	0.39

Therefore, this process changed the shape and appearance of the coins. It was not possible to use the printing molds for too long because of quick aging. Once they were aged, making coins in the same shape was difficult. Therefore, it is not easy to make a stylistic analysis of the coins of the Ottoman Empire until the 17th century. Due to this problem, the comparison of casting mold scales is considered the most consistent method of analysis. One of the distinctive features of the Ottoman coins is that there are no representations of people or animals on the coins; instead, inscriptions embroidered with Thuluth calligraphy were used. The obverse and reverse of the coins consist of the names of the sultan and his father (Murad, Bayezid, Mehmed, etc.), their titles (Sultan, Khan, Shah), the centers where they were minted (Constantinople, Egypt, Bursa, Edirne, Kastamonu), the dates of printing, and the year of the sultan's reign. There are also blessings such as "may his possessions endure; may his proceeds be plentiful." Moreover, it is seen that motifs such as stars, knot (Fig. 2 1-15) on some of the early period samples and motifs such as flowers, garland, and tughras, known as the sultan's

signature, are present on the coins belonging to the 18th century.

3.2. Chemical Analysis

The Ottoman Empire, which ruled over a wide area, established mints in cities that were near mines and were important trading points. It is known that coins of silver were minted in almost ninety mints in Constantinople, Edirne, Bursa, Novaberde, Kratov, Skopje, Egypt, Tunisia, Damascus, etc. (Artuk-Artuk, 2003; Aykut, 1987:280). The chemical analysis showed that the metal coins minted in the same or different mints are made of different metal alloys. The metals and their contents in the samples studied are shown in Table-3. As can be seen, elements other than silver (Ag) and copper (Cu) were also detected by the analysis.

Table 3. Chemical analysis results of coins minted in the reign of each sultan.

		ELEMENTS															
DATE	**SULTAN NAME**	**Cu**	**Ag**	**Mg**	**Al**	**Fe**	**Pb**	**C**	**O**	**Si**	**S**	**Cl**	**P**	**Ca**	**Ni**	**Zn**	**Hg**
1362	I. Murad	**0.46**	**90.58**	0.68	0.65	0.31	n.d.	4.16	1.54	1.38	0.23	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1390	I.Bayezid	**2.21**	**89.43**	0.85	0.71	n.d.	n.d.	4.15	1.29	1.36	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1421	II. Murad	**0.46**	**83.41**	0.75	0.29	n.d.	n.d.	5.02	1.94	1.01	5.66	1.46	n.d.	n.d.	n.d.	n.d.	n.d.
1444	II. Mehmed	**0.45**	**93.20**	0.78	0.36	n.d.	1.70	3.04	n.d.	0.48	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1481	II. Bayezid	**0.90**	**79.36**	0.55	0.36	n.d.	1.60	4.43	1.46	1.11	1.19	0.59	n.d.	n.d.	n.d.	0.63	7.82
1512	I. Selim	**0.13**	**82.57**	0.51	0.24	0.28	n.d.	2.86	n.d.	0.21	12.70	0.51	n.d.	n.d.	n.d.	n.d.	n.d.
1520	I.Süleyman	**0.33**	**79.15**	0.85	0.55	0.31	n.d.	7.50	2.71	1.32	2.61	3.17	n.d.	1.51	n.d.	n.d.	n.d.
1574	III. Murad	**0.58**	**91.50**	0.64	0.82	n.d.	n.d.	3.50	1.40	1.57	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1595	III. Mehmed	**0.87**	**83.89**	0.73	1.61	0.44	1.24	4.65	2.26	2.92	n.d.	1.39	n.d.	n.d.	n.d.	n.d.	n.d.
1603	I. Ahmed	**1.73**	**86.49**	0.73	0.94	n.d.	n.d.	3.83	2.26	3.55	0.48	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1618	II. Osman	**0.50**	**90.94**	0.76	0.81	n.d.	1.22	2.84	1.49	1.44	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1622	I. Mustafa	**2.06**	**91.50**	0.15	0.48	n.d.	1.52	2.04	1.33	0.92	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1623	IV. Murad	**2.44**	**65.94**	0.83	3.73	1.16	1.09	8.06	8.15	7.61	n.d.	n.d.	0.29	0.68	n.d.	n.d.	n.d.
1640	I. İbrahim	**1.68**	**84.12**	0.71	1.76	0.78	n.d.	4.11	3.23	3.19	0.41	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1648	IV. Mehmed	**1.80**	**85.19**	0.27	1.78	0.71	n.d.	4.26	3.18	2.76	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1703	III.Ahmed	**1.38**	**92.73**	0.67	0.29	n.d.	n.d.	2.95	0.82	0.57	0.59	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1730	I. Mahmud	**2.47**	**79.66**	0.90	2.14	0.56	n.d.	5.05	4.20	4.61	0.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1760	III. Mustafa	**6.89**	**82.13**	0.56	0.15	n.d.	n.d.	7.02	2.29	0.41	0.57	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1774	I. Abdülhamid	**24.19**	**35.88**	0.74	0.95	0.41	1.26	17.20	12.40	2.17	n.d.	2.67	0.24	1.89	n.d.	n.d.	n.d.
1789	III. Selim	**2.80**	**84.15**	0.77	1.25	0.28	n.d.	3.52	3.06	3.13	0.41	n.d.	0.30	n.d.	0.33	n.d.	n.d.
1808	II. Mahmud	**38.39**	**29.18**	n.d.	1.08	0.59	n.d.	17.64	10.10	2.58	0.32	n.d.	0.13	n.d.	n.d.	n.d.	n.d.
1839	Abdülmecid	**57.70**	**20.49**	n.d.	0.29	0.46	n.d.	14.47	4.79	n.d.	0.93	0.87	n.d.	n.d.	n.d.	n.d.	n.d.
1839	Abdülmecid	**37.79**	**41.65**	0.50	0.92	0.36	n.d.	7.22	8.03	1.89	1.20	n.d.	0.21	n.d.	0.23	n.d.	n.d.
1839	Abdülmecid	**25.77**	**62.46**	0.54	0.14	n.d.	n.d.	8.07	2.30	0.27	0.46	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1876	II. Abdülhamid	**1.68**	**84.12**	0.71	1.76	0.78	n.d.	4.11	3.23	3.19	0.41	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1876	II. Abdülhamid	**2.11**	**76.94**	0.51	0.85	0.26	n.d.	8.78	2.06	1.54	0.21	6.74	n.d.	n.d.	n.d.	n.d.	n.d.

Some of these elements, especially the metallic ones, are most likely elements mined with silver. Non-metallic elements are either the impurities on the coins or the elements such as oxygen (O) and sulfur (S) that react with other metals on the coins. Carbon (C), one of the most common elements on coins, is one of the organic impurities that appear on money over the years, and accordingly, some of the oxygen may come from these organic compounds. Since metals other than silver are generally in the form of oxides, some of the oxygen will also come from oxide compounds. As can be seen in Table 3, Cu, aluminum (Al), magnesium (Mg), and silicon (Si) in particular are found in many coin analyses, and since these four elements are in the form of oxides, the analytical result of oxygen is also due to these metal oxides on the surface of the coins. Sulfur (S) was also found in the analysis. It is in the same group as oxygen and can form some compounds with metals. The most interesting coins were minted during the period of Bayezid II. In the analysis of this coin, unexpected elements such as zinc (Zn), aluminum (Al), and mercury (Hg) were found in high ratios. Fig. 3A shows the SEM image, the EDS analysis, and the elemental contents of the coins. Hg has the third-highest percentage (8.53 %) in the coin. Mercury was observed in only one sample. This situation brings up the idea that mercury was added to the coin for a specific purpose. Because the mercury-silver technique was used for silver coating on Roman coins (Vlachou-Mogire et al., 2007; Romano et al., 2012; Beck et al., 2017; Uhlir et al., 2016; Ingo et al., 2017) in this technique, the Hg-Ag amalgam was applied to the surface of the coins and then exposed to heat to remove the mercury by evaporation, but the analysis results showed that 3% mercury still remains on the surface of coins. In the study, the detected mercury amount was 8.53 %, which is higher than the expected mercury amount. This specific coin was produced during the Beyazid II period and minted in the Bursa mint. Analysis of the other coins, which were minted before and after production of this specific coin in the same mint, did not show any evidence of mercury. This result shows that the Hg-Ag technique was not used in the production of these coins and confirms the idea that mercury was added to the silver as amalgam without any purpose. The presence of these elements on coins is most likely related to the place of the minting. Probably, other metals were being processed in the same place, or they were already present in the raw material. Other common elements such as calcium (Ca), phosphorus (P), and chlorine (Cl) are the impurities collected on the

coins over the time. In Fig. 3B, another interesting result could be seen. The coin was minted in the sultan Murad IV period, and it was found a high content of Si, Al, C, and O in the analysis. In the SEM picture, many impurities and rough surfaces were seen on the surface of the coin. Some of these impurities may adhere to the coin during or later in the minting process.

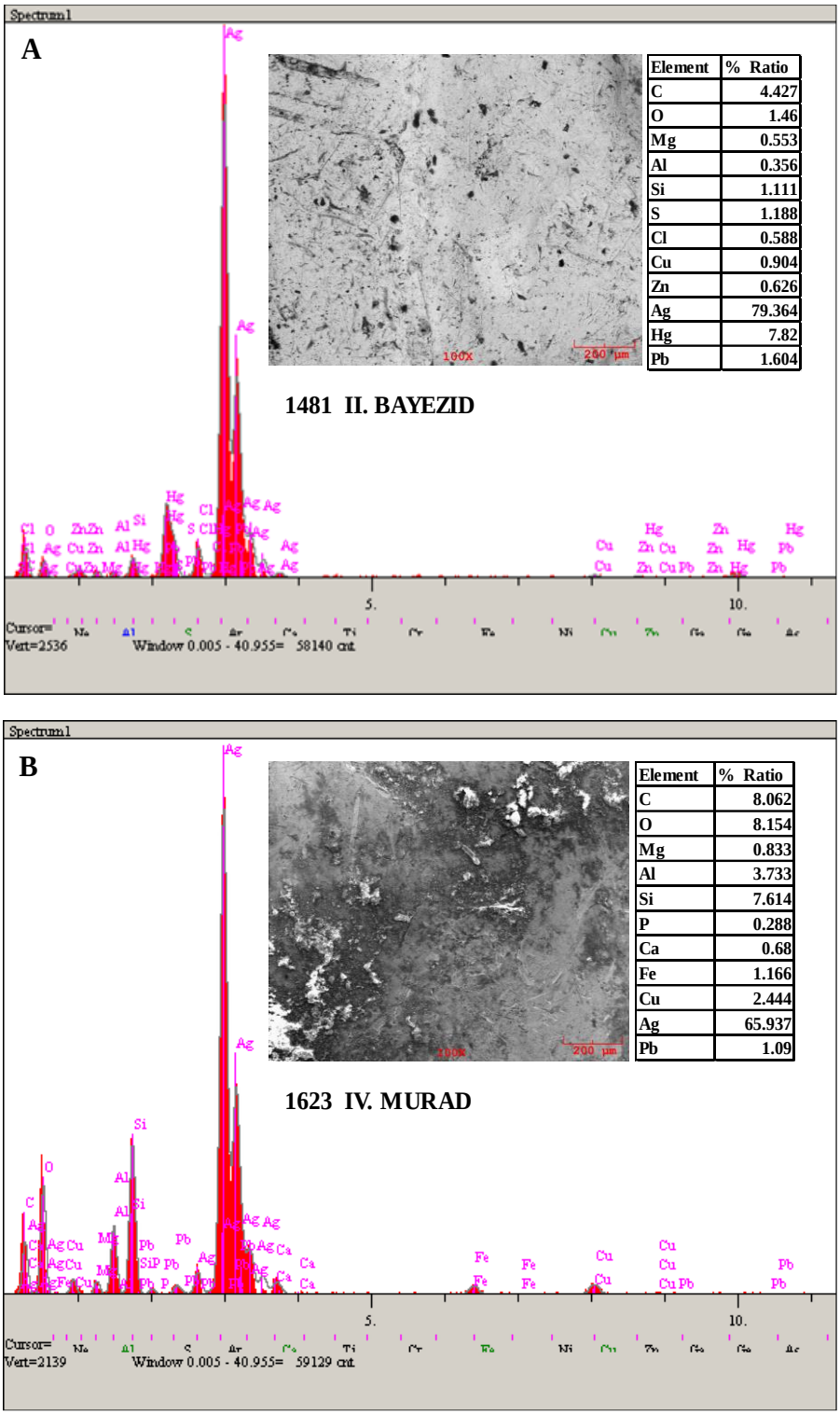

Figure. 3. SEM, EDS, and element analyses of coins, including different elements than other coins. (A) BAYEZID II period, (B) MURAD IV period.

In SEM and EDS analysis of coins, the scanned area was one mm². Figs. 4A and B show two different coin analyses, including SEM, EDS, and the element content of the coins. The reason for selecting these two coins is the ratio of silver and copper contents in them.

While the silver content is high in Fig. 4A, the copper content is high in Fig. 4B. The surface of the coins also shows the difference in terms of roughness and the number of pits. The pits may form due to the air bubbles trapped in the coins during the production step, and they may also form later due to the corrosion of the metal oxide particles. The corrosions may bring different problems for the analysis of silver on the surface of the coins. One of the main problems is the enrichment of silver that may occur on the upper surface of the coin because of corrosion over time. The silver enrichment of the coins was well studied in the literature (Hrnjić et al., 2020). This study also focused on the silver analysis, and it is normal to think about silver enrichment on the coins. As seen in Fig. 2, the selected coins are not much corroded, and during the analysis, specific points were selected on the coins. Since the coins used in this study are cultural heritage and borrowed from the museum, no cleaning work could be done on the coins. If it were possible, sections of sample samples could be taken, and analysis of the interior could be made for a better result.

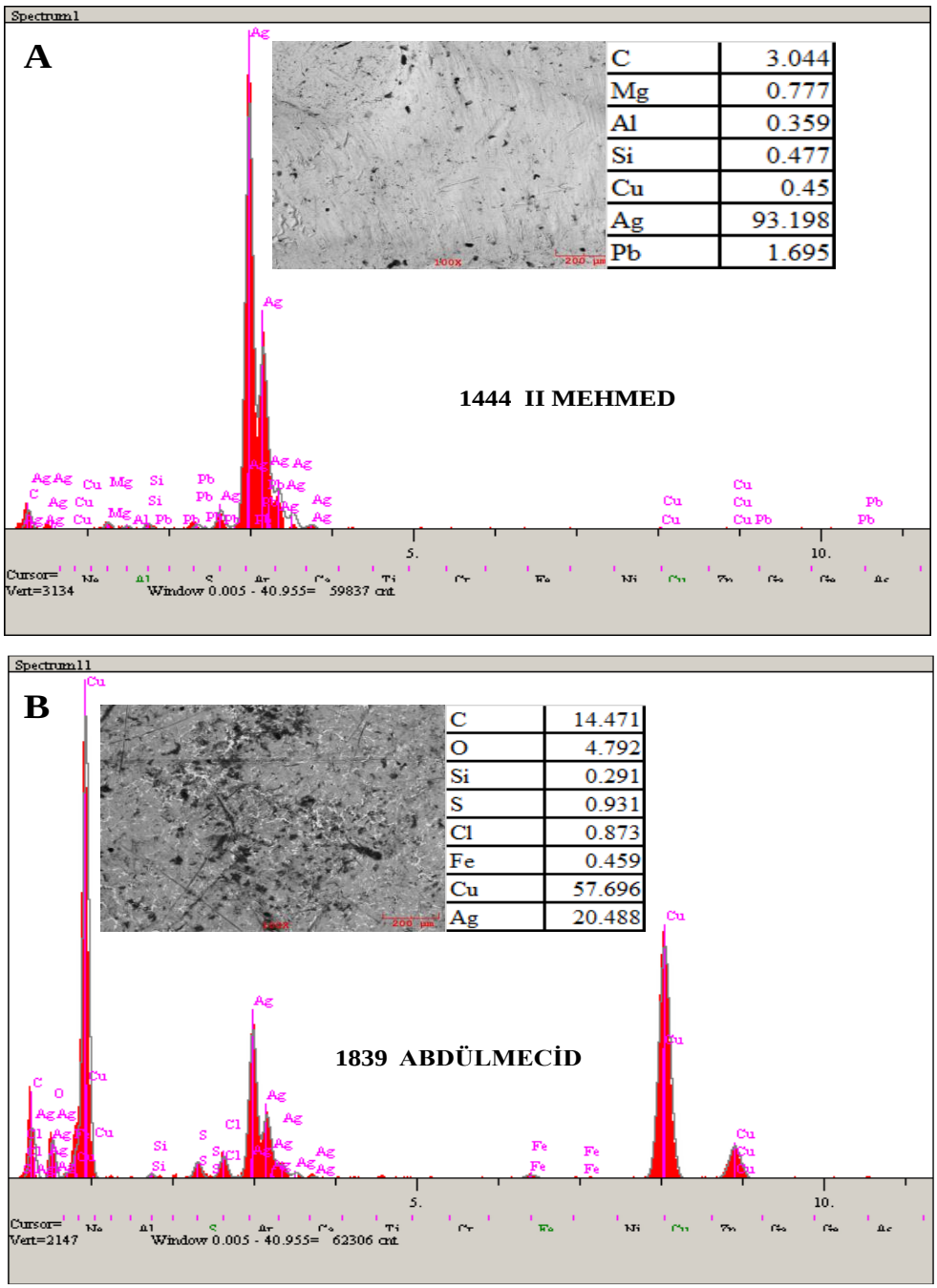

Figure. 4. SEM and EDS analysis results of two different coins with high silver content (A) of *MEHMED II period, and high copper content (B) of ABDULMECİD period.*

In SEM picture analysis of coins, some of them have granular structures on their surface, as seen in Fig. 3B and Fig. 4B. Deep traces of the forging technique are clearly visible on some coins. The lines and depressions created by hammering hold organic and inorganic pollution on the surface. The presence of organic matter-based elements in the analysis confirms this situation.

All of the above comments and explanations have been made in accordance with Table 3. Although the coins were selected carefully, some organic-based elements were also found during the analysis of the coins. These are the contaminations due to the usage or may come from where they were recovered over the history. The amount of those elements is not so high, so those determined amounts were distributed to those main elements depending on their percentage ratio by the software. Table 4 shows the results obtained after the amount correction was made on the main elements. The instrument uses % 100 normalizations for the elimination of minor elements. In the historical assessment, Table 4 was used for the comparison of written documentation and experimental results.

When the silver content changes made on the coins are considered historically, it is observed that the copper content in coins increased during specific periods. Although elements other than copper and silver were also seen in the analysis, only silver and copper proportions were evaluated in periodic economic analysis. Figs. 5A and B show more clearly the variation of silver and copper percentage of Ottoman coins in relation to historical change. While Fig. 5A shows the histogram profile of the most abundant elements throughout history, Fig. 5B shows only the variation of silver and copper over the years.

3.3. Classification of Ottoman State coins by centuries

3.3.1 14th Century coins

The first coin belongs to Murad I (Fig. 2.1). The sultan had three different coins minted, on which the minting place and date are not inscribed. Only one of them was examined in this work. The words composing the blessing on the reverse side are separated by three lines.

Table 4. Elemental analysis of coins after excluding low percentage elements and some common organic contaminations.

		ELEMENTS							
Date	**NAME OF SULTAN**	**Cu**	**Ag**	**Pb**	**Cl**	**O**	**Hg**	**S**	**Zn**
1362	I. Murad	**0.50**	**99.50**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1390	I.Bayezid	**2.4**	**97.60**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1421	II. Murad	**0.51**	**93.14**	n.d.	n.d.	n.d.	n.d.	6.35	n.d.
1444	II. Mehmed	**0.47**	**97.77**	1.76	n.d.	n.d.	n.d.	n.d.	n.d.
1481	II. Bayezid	**0.99**	**88.04**	1.75	n.d.	n.d.	8.53	n.d.	0.69
1512	I. Selim	**0.14**	**86.56**	n.d.	n.d.	n.d.	n.d.	13.31	n.d.
1520	I.Süleyman	**0.37**	**92.92**	n.d.	3.68	n.d.	n.d.	3.03	n.d.
1574	III. Murad	**0.63**	**99.37**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1595	III. Mehmed	**1.00**	**97.58**	1.41	n.d.	n.d.	n.d.	n.d.	n.d.
1603	I. Ahmed	**1.96**	**98.04**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1618	II. Osman	**0.54**	**98.16**	1.30	n.d.	n.d.	n.d.	n.d.	n.d.
1623	I. Mustafa	**2.16**	**96.25**	1.59	n.d.	n.d.	n.d.	n.d.	n.d.
1623	IV. Murad	**3.47**	**95.02**	1.50	n.d.	n.d.	n.d.	n.d.	n.d.
1640	I. İbrahim	**1.96**	**98.04**	n.d.	n.d.	3.23	n.d.	0.41	n.d.
1648	IV. Mehmed	**2.06**	**97.94**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1703	III.Ahmed	**1.46**	**98.54**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1730	I. Mahmud	**3.00**	**97.00**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1760	III. Mustafa	**7.64**	**92.34**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1774	I. Abdülhamid	**37.73**	**60.34**	1.92	n.d.	n.d.	n.d.	n.d.	n.d.
1789	III. Selim	**3.22**	**96.78**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1808	II. Mahmud	**55.62**	**44.39**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1839	Abdülmecid	**72.93**	**27.07**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1839	Abdülmecid	**47.10**	**52.90**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1839	Abdülmecid	**28.85**	**71.15**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1876	II. Abdülhamid	**1.96**	**98.04**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1876	II. Abdülhamid	**2.66**	**97.34**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

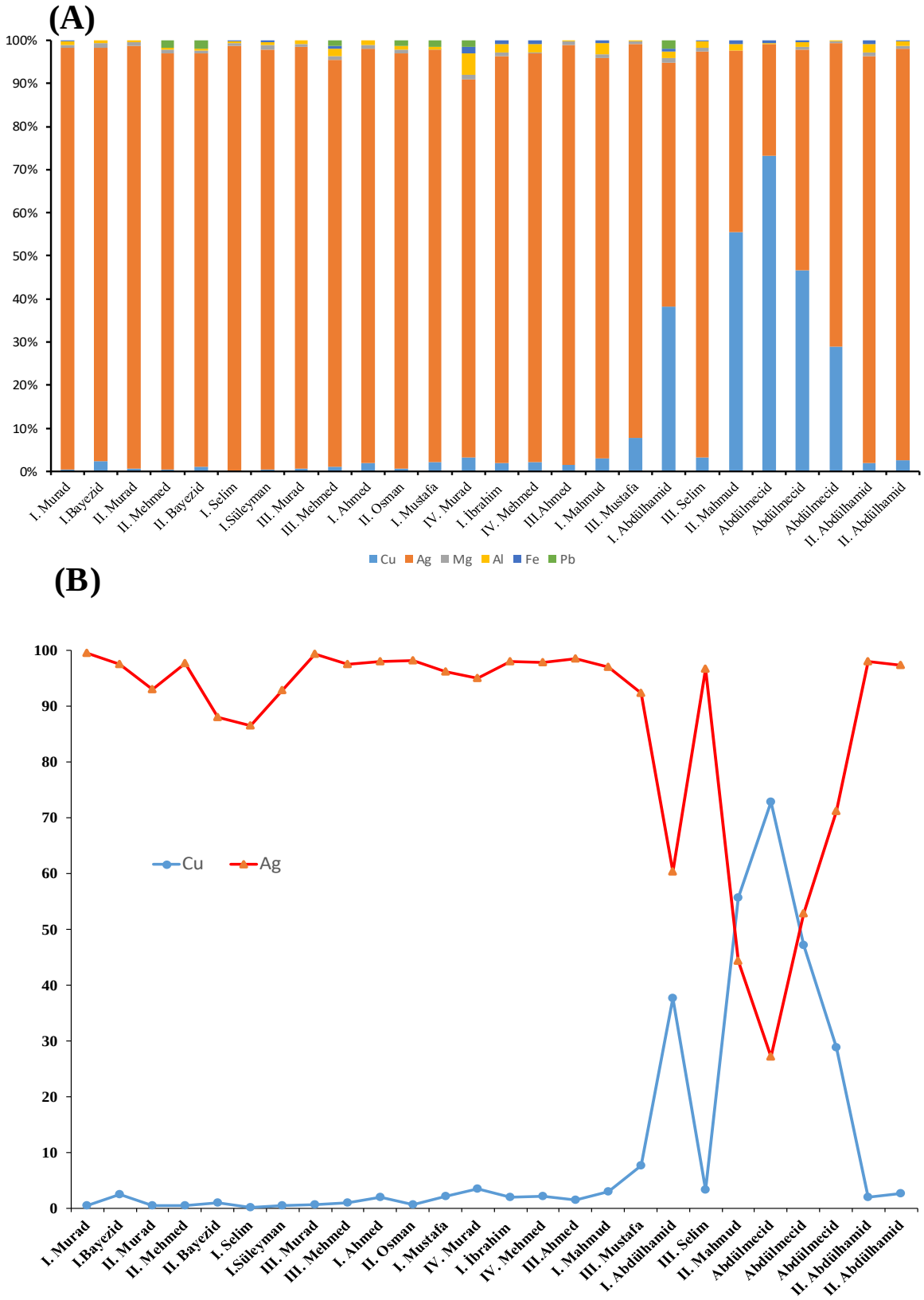

Figure. 5. Percentage of most frequent elements in coins, according to periods (A) and percentage of copper and silver contents (B).

The second coin (Fig. 2.2) was minted by Bayezid I. Although Sultan Bayezid mints one type of coin, they are divided into six groups in terms of the shapes embroidered on their surface. The date of minting was engraved on the coins for the first time in this period

(Aykut, 2002:1529). These coins have inscriptions on the front and a line in the middle. Although the written documentation explains that the coins belonging to the 14th century were made of pure silver weighing 1.203 g (6 carats) (Pakalın, 1971:32), both their weight and purity were found to be different from the stated values. The weights of the coins were found to be 1.190g. This could be due to erosion that occurred during the time they were in circulation or the lack of sensitive weighing devices at those times. Based on EDS analysis, the silver and copper content of the coins were found in the range of 97.60-99.50% and 0.50-2.40%, respectively (Table 4). Although there are statements in the written documentation that the coin settings did not change in the first 120 years (Pakalın, 1971:32), it is obvious that the silver and copper content started to change in the period of Bayezid I. This difference may come from either silver source difference or coin adulteration that started already in those days by adding some copper in the coins.

3.3.2. 15th Century coins

Murad II, Mehmed II, and Bayezid II coins belong to this group (Figs. 2.3-5). The weights of the coins vary between 1.203-0.751 g. The growing Empire brought with it some economic problems in this century, and the first process of adulteration was undertaken by Mehmed II to generate revenue for the treasury. The coin weight was reduced from 1.203 g (6 carats) to 0.902 grams (4 carats) (Pakalın, 1972: Aykut, 2002, 1987). This change, which drew the reaction of the Janissaries, led to the Bucuktepe revolt, and Mehmed II returned the throne to his father Murad II. In the comparison of the coin values in both periods, although Mehmed II reduced the weight of the coins, the amount of silver was higher than the coins minted in the period of Murat II. Based on the results of the analysis, the proportion of silver in the periods of Murad II and Mehmed II was 93.14% and 97.77%, respectively. Although the content of silver is lower in the Murad II term, this is because of the high S amount (6.35%) on the surface of the coin. The black color on the surface of the coins is the result of a chemical reaction between the silver and sulfur-containing substances in the air. If we assume that this S amount is added to the silver amount, the content of silver in both periods would be the same. Although the proportion of silver was the same in both Mehmed II and Murad II periods, the value of money decreased by 10% during this period. In the Bayezid II period, the coin weight was reduced to 0.751 g (3.75 carats) (Aykut, 1987: 281). In EDS analysis of Bayezid II period coins, 88.04% silver was found. It is obvious that adulteration of coins happened in both the weight and value of the coins. In this period, adulteration was made by using a different metal other than Cu. Hg does not react with most acids, but it dissolves many metals such as gold and silver to form amalgams. This phenomenon was known in those days, and most probably, mercury was added to the silver on purpose. The results show that the first serious adulteration happened in the Bayezid II period.

3.3.3. 16th Century coins

Coins of the 16th century are shown in Fig. 2. 6-9. In this century, the timar system, which provided unpaid soldiers to the State, began to disintegrate, and this led to an increase in the number of paid soldiers for whom the State was responsible. For this reason, the use of adulteration continued this term. In addition, the importation of a lot of cheap silver from America caused a further decrease in the value of the coins (Ay, 1991:319). As a result of the devaluation, the Janissaries rebelled and attacked the palace and murdered the Rumelia Governor Dogancı Mehmed Pasha, whom they believed to be responsible, and the incident was recorded in the archival records as the Beylerbeyi Case (1585) (Kütükoğlu, 2006:174). In this period, the reported weight of the coins was between 0.701 g (3.5 carats) - 0.400 g (2 carats) (Pakalın, 1971:33). EDS analysis of the coins showed that while the silver percentage varies from 86.56-97.58%, the copper percentage varies from 0.14-1.00 %. Although the percentage of silver increased at the end of the 16th century, the weight of coins decreased compared to the previous century by 57%. These results clearly show the economic problems facing the Empire in this century.

3.3.4. 17th Century coins

In this century, the financial crises of the Empire increased more, and this situation influenced the governmental functions. In earlier times of the Empire, wars were a significant source of income, but in the 17th century, they were the main reason for great expenses. The Ottoman State finance was deeply influenced because of the wars with Austria, Russia, and Iran on the one hand and civil rebellion known as Celali rebellions on the other (Kodaman, 2007:17). In addition to these factors, the quarterly paid soldier salaries and accession baksheesh (culus) distributed due to the changes in the sultan are other factors that put pressure on the treasury. As the treasury was unable to cover the expenses, measures such as additional taxes and domestic borrowing were resorted to, and adulteration was continued in order to increase the state income. The adultery created dissatisfaction in the army, and the soldiers rebelled. As a result of the revolt, thirty people who were held responsible for the deterioration of the coinage were hung on plane trees in Sultanahmet Square, and the event

went down in history as the Çınar Case (Vak'ai Vakvakıyye) (Aktepe, 1993:302). During this period, the weight of coins was reduced to 0.225-0.220 g (1.25 carats) (Pakalın, 1971:33). Based on the sources, the silver content of the coins in the period of Ahmet I was 80%, and this content was reduced to 50% in the period of Mehmed IV. As a result of EDS analysis, the proven silver content in Ahmet I and Mehmed IV periods is 98.04% and 97.94 %, respectively. It is considered that the silver percentages of the coins are close to each other, and the amounts of silver stated earlier are no longer valid. In this century, the Europeans introduced coins with low silver content into the Ottoman market (Karta, 2013:169), and this situation forced Osman II to correct the coins. After this correction, the silver content of the coins was increased in this period, and this increase was verified as 98.16% according to EDS analysis. The lowest silver content was found to be 95.02 % in the period of Murad IV, and this amount was reported as 75% in written sources. These results indicate that the silver amount in the coins decreased by around 5%, and in total, this amount brings a considerable amount of value decrease. If the weight decrease and silver content decrease were thought together, it could be understood that the Empire had a tough economic situation. The coins of this period are shown in Fig.2.10-15.

3.3.5. 18th Century coins

This was a period in which Ottoman finance was more deeply influenced as a result of wars with Russia, England, and France. The State, which has been weakening day by day and shrinking due to the loss of land, has become unable to meet its needs from its own lands (Karta, 2013:169). Adulteration was used to save the situation, and the money depreciated even more. The fake and low-setting coins, which were deliberately introduced to the market by western merchants, greatly reduced the value of the Ottoman currency (Akdağ, 1949:520). The weight of the coins given in Fig.2.16-20 is between 0.300-0.200 g (1.5-1 carats) (Pakalın, 1971:34), and their silver amounts were reported between 80-50% in the written sources. Considering the EDS analysis of coins in the century, it is seen that there is a gradual decrease in the content of silver (from 98.54% to 92.3 %) till Abdulhamid I term and a significant decrease in his period (60.34 %). Although some correction actions were taken in the reign of Abdulhamid I, EDS analysis of coins minted in this term showed the depreciation of money.

3.3.6. 19th Century coins

In addition to the continued poor situation, budget revenues fell, the foreign trade deficit and foreign debt increased during this term. Furthermore, the inability to adapt to the industrial revolution in the West caused the economy to falter (Ay, 1991:313). In this bad economic situation, the officials at various levels of the State did not do their job without bribery, and it became mandatory to change the silver amount in the coins. After this change, the value of the money decreased significantly. The pictures of 19th-century coins are given in Fig. 2.21-26. The bad economic situation could be understood by the EDS analysis of coins printed in the Mahmud II term. The amount of silver and copper was found as 44.39% and 55.62%, respectively. The bad economic situation continued till the first period of Abdulmecid, and the content of silver was decreased by around 27.07%. The high amount of copper in coins reflects the bad economic situation. As it is indicated in the written sources, Sultan Abdulmecid prevented the value decrease by increasing the silver content in coins (Ay, 1991:327), and this act could be seen in the EDS analysis of coins. During his period, three different coins were minted, and the content of silver increased from 27.07 % to 71.15 %. The taken measures provided a slight increase in the money's value, and this contributed to the economy of the State. The analyses indicate the economic situation of the Empire in different periods, and the 19th century is the worst period in empire history. This bad economic situation could be seen obviously in Figs. 5A and B.

3.4. Analysis according to mint place

The elemental compositions of the coins, classified by mint place, are presented in Tables 2 and 3. The analysis of EDS shows that each coin produced in the same or in different mints consists of different quantities of elements. As it is shown before, the first changes in the size and silver quantity of the coins were made during the time of Mehmed II, and the value of the money decreased significantly in the following period. Although it is known that the State minted coins in nearly ninety mints, it is obvious that the mints of Constantinople and Egypt stand at the top among them. In addition to these, there are three coins minted in the mints of Bursa, Edirne, and Kastamonu, which are listed in Tables 1 and 2. The mints of eight coins could not be identified because of the abrasions on their surfaces.

There are ten coins minted at the Constantinople mint, listed in Table 2 and numbered as 6, 9, 10, 16, 17, 21, 22, 23, 24, and 26. There are differences in the percentages of major, minor, and trace elements of the coins. Other than trace elements, mainly copper and silver were used in coins. While the percentage of copper ranges from 0.14 % to 72.93%, silver percentage varies from 20.49 % - 92.73 %. The coins minted in Constantinople show the biggest variations in silver and copper amounts. These results also reflect the

economic situation of the Empire throughout Ottoman history. Apart from the two major elements, various elements like Mg, C, O, Pb and Hg are also present in the coins, and enough information has been given in the chemical analysis section about these elements.

The minting place of five coins is Egypt, and the samples were numbered as 13, 18, 19, 20, and 25 in Table 2. While four coins have a silver content of over 90%, coin number 13 shows the lowest amount of silver (60.34%). In the comparison of coins minted in Constantinople and Egypt, the coins minted in Constantinople show a bigger variation in the content of silver. Constantinople had the highest number of mint, and also, most of the economic trading was happening there.

As seen in Table 2, three different coins were minted in Bursa, Kastamonu, and Edirne mints, numbered 3, 8, and 11. While the coin minted in Kastamonu has the highest silver content at 99.37 %, the one minted in Bursa has the lowest amount of silver. The silver amount variations of coins are similar to the coins minted in Constantinople at the same term. The minting places of eight coins could not be recognized, as explained in the previous section (samples numbered 1, 2, 4, 5, 7, 12, 14, and 15 in Table 2). Although there are differences in the percentages of trace elements, the high percentage of silver makes them valuable. The silver contents of these coins found by EDS analysis range from 88.04%-99.50%, and the copper contents range from 0.47%-2.16%. The economic reflections of these results were discussed in the previous sections; therefore, it is not given in here.

4. CONCLUSIONS

This study covers the analysis of the chemical composition of coins minted during all periods of the Ottoman Empire, which ruled for 600 years on three continents. In this study, SEM / EDX analyses were carried out on 26 Ottoman Empire coins borrowed from the Sakarya Museum collection. After evaluation of written documentation and EDS experimental results, it became clear that the political, commercial, and economic collapses experienced by the Ottoman Empire also affected coin production. The content of silver in coins was high in the first quarter of the 14th and 17th centuries, and the use of copper increased in the period from the second quarter of the 17th century until the collapse of the Empire. Although various improvements were attempted to be made in the coins, based on the results and resources obtained, it could not be successful, and the Ottoman currency lost value day by day. The results show that sometimes the written documents do not reflect the real history as in this study. The historical artifacts can be investigated by scientific methods to enlighten the past and identify the historical truth.

REFERENCES

Abdel-Kareem, O., Al-Zahrani , A., Khedr , A., Harith, M.A. (2016). Evaluating Laser Cleaning of Corroded Archaeological Silver Coins, *Mediterranean Archaeology and Archaeometry*, Vol. 16 (1), pp. 135-143.

Akdağ, M. (1949). Osmanlı İmparatorluğu'nun Kuruluş ve İnkişafı Devrinde Türkiye'nin İktisadi Vaziyeti, *Belleten*, Vol. XIII/51, Ankara, pp. 498-568.

Aktepe, M. (1993). Çınar Vak'ası, *İslam Ansiklopedisi*, Vol. 8, İstanbul, pp. 301, 302.

Akyıldız, A. (2007). Para, *İslam Ansiklopedisi*, Vol. 34, İstanbul, pp. 163-166.

Al-Saad, Z., Rababah, M. (2020). A Systematic Analysis for the Detection of Forged Copper Based Coins, *Scientific Culture*, Vol. 6 (2), pp. 11-22.

Artuk, İ., Artuk, C. (1974). *İstanbul Arkeoloji Müzeleri Teşhirdeki İslami Sikkeler Kataloğu*, Vol. II, İstanbul.

Artuk, İ., Artuk, C. (2003). Bazı İslam Şehirlerinde Hangi Devletler Sikke Kestirmiş ve Bu Şehirlere Ne Gibi İsimler Verilmiş, *Belleten*, Vol. LXVII/249, Ankara, pp. 421-446.

Ay, H. (1991). Osmanlı Devleti'nde Mali Bunalım ve Nedenleri, *İzmir Journal of Economics*, Vol. 6/2, İzmir, pp. 312-332.

Aykut, N. (1987). Osmanlı İmparatorluğu'nda Sikke Tecdidleri, *Turkish Journal Histo*ry, İstanbul, pp. 257-282.

Aykut, Ş. N. (2002). Osmanlı Sikkeleri, *Türkler*, Vol. 10, Yeni Türkiye Pub., Ankara, pp. 1528-1561.

Beck, L., Alloin, E., Vigneron, A., Caffy, I., Klein, U. (2017). Ion Beam Analysis and AMS Dating of the Silver Coin Hoard of Preuschdorf (Alsace, France), *Nuclear Instruments and Methods in Physics Research B*.

Eagleton, C., Williams, J. (2008). *Paranın Tarihi* (Translator Fadime Kâhya), İstanbul.

Felixi, V. S., Pereiara, O. M., Freitas, R.P., Aranha, P. J. M., Heringer, P. C. S., Anios, M., Lope, R. (2020). Analysis Of Silver Coins From Colonical Brazil by Hand Held XRF and Micro-XRF, *Materials Sciences*, 166, pp. 1-9.

Hajivaliei, M., Garg, M. L, Handa, D.K, Govil, K.L. (1999). PIXE Analysis of Ancient Indian Coins, *Nuclear Instruments and Methods in Physics Research* B 150, pp. 645-650.

Hrnjić, M., Hagen-Peter, G. A., Thomas Birch, Barfod, G. H., Sindbæk, S. M., Lesher, C. E. (2020). Non-destructive Identification of Surface Enrichment and Trace Element Fractionation in Ancient Silver Coins, *Nuclear Instruments and Methods in Physics Research* B 478, pp.11–20.

Ingo, G. M., Riccucci, C., Faraldi, F., Pascucci, M., Messina, E., Fierro, G., Carlo, G. D. (2017). Roman Sophisticated Surface Modification Methods to Manufacture Silver Counterfeited Coins, *Applied Surface Science*, Vol. 421, Part A, pp.109-119.

İnalcık, H. (2017). *Devlet-i' Aliyye. II*, İstanbul.

Karta, N. (2013). "17. ve 18. Yüzyılda Osmanlı Devleti'nin Avrupa İle İktisadi İlişkileri", *Turkish Studies - International Periodical For The Languages, Literature and History of Turkish or Turkic*, Volume 8/11 Fall, Ankara-Turkey, pp. 163-173.

Kodaman, B. (2007). Osmanlı Devleti'nin Yükseliş ve Çöküş Sebeplerine Genel Bir Bakış, *SDU Faculty of Science and Literature Journal of Social Science*, Vol. 16, Isparta, pp. 1-24.

Kütükoğlu, B. (2006). Murad III, *İslam Ansiklopedisi*, Vol. 31, İstanbul, pp.172-176.

Laskaris, N., Varalis, I., Tsodoulos, C., Dolmas, C. (2020). Evıdence of Au – Hg Gilding Process in Post Byzantıne Ecclesıastıcal Sılverwares (Chalices) of Eastern Thessaly by PXRF, *Mediterranean Archaeology and Archaeometry*, Vol. 20 (1), pp. 189-203.

Liritzis, I., Laskaris, N., Vafiadou, A., Karapanagiotis, I.; Volonakis, P., Papageorgopoulou, C., Bratitsi, M. (2020). Archaeometry: An overview, *Scientific Culture*, Vol. 6 (1), pp. 49-98.

Masjedi, P., Khademi, F., Hajivaliei, M., Kouhpar, S. M. M., Neystani, J. (2012). Elemental Analysıs of Sılver Coins of Seljuk's' of Rome by Pıxe: A Case Study, *Mediterranean Archaeology and Archaeometry*, Vol. 13 (2), pp. 181-187.

Mete, Z. (1992). *Bursa Dârbhane ve Rüsûm-ı İhzâriye Mukata'ası Teftiş Defteri*, Master thesis (İstanbul University Department of Turkish Economic History), İstanbul.

Mezzasalma, A. M., Mondio, G., Serafino, T., De Fulvio, G., Romeo, M., Salici, A. (2009). Ancient Coins and Their Modern Fakes: An Attempt of Physıco-Chemical Unmasking, *Mediterranean Archaeology and Archaeometry*, Vol. 9 (2), pp. 15-28.

Mıtev, N. (2018). "Early Ottoman coıns (14th – 15th C.) from the Region of Varna, Bulgaria", *Нумизматика, Сфрагистика и Епиграфика* 14, Табло XLVII, pp. 189-199.

Pakalın, Z. (1971). *Osmanlı Tarih Deyimleri ve Terimleri Sözlüğü 1*, Ankara.

Pakalın, Z. (1972). *Osmanlı Tarih Deyimleri ve Terimleri Sözlüğü 3*, Ankara.

Pamuk, Ş. (2007). *Osmanlı İmparatorluğu'nda Paranın Tarihi*, İstanbul.

Papp, Z., Kovács, I. (2013). Surface Analysis of a Modern Silver Coin: Sem/Eds Measurements, *Revue Roumaine de Chimie*, Academıa Română, 58(1), pp. 65-67.

Rodrigues, M., Schreiner, M., Guerra, M., Salomon, J., Radtke, A. M., Schindel, N. (2011). Characterization of the Silver Coins of the Hoard of Beçin by X-ray Based Methods, *Nuclear Instruments and Methods in Physics Research B* 269, pp. 3041–3045.

Romano, F.P., Garraffo, S., Pappalardo, L., Rizzo, F. (2012). In situ Investigation of the Surface Silvering of late Roman Coins by Combined use of High Energy Broad-Beam and Low Energy Micro-Beam X-ray Fluorescence Techniques, *Spectrochimica Acta Part* B 73, pp.13–19.

Saad, Z. A., Rababah, M. (2020). A Systematic Scientific Analysis for the Detection of Forged Copper Based Coins, *Scientific Culture*, Vol. 6 (2), pp. 11-22.

Sahillioğlu, H. (1989). "Akçe", *İslam Ansiklopedisi*, Vol. 2, İstanbul, pp. 224-227.

Salem, Y., Abd Allah, E. (2021). Archaeometallurgical Investigation Manufacturing Technique and Conservation Processes of a Coptic/Byzantine Age Hoard of Unstruck Coins Flans, *Scientific Culture* 7 (3), pp. 65-77.

Sodaei, B. (2016). Pixe Analysis Of Silver Coins from Ilkhanid and Safavid Dynasties in Iran: A Case Study, *Mediterranean Archaeology and Archaeometry*, Vol. 16 (3), pp. 207-211.

Tekin, O. (1998). *Eski Çağ'da Para*, İstanbul.

Tekin, O. (2009). "Sikke", *İslam Ansiklopedisi*, Vol. 37, İstanbul, pp. 179-184.

Uhlir, K., Padilla-Alvarez, R., Migliori, A., Karydas, A.G., Mihalić, I. B., Jakšić, M., Zamboni, I., Lehmann, R., Stelter, M., Griesser, M., Schindel, N., Alramg, M. (2016). The Mystery of Mercury-Layers on Ancient Coins-A multi-analytical Study on the Sasanian Coins under the Reign of Khusro II, *Microchemical Journal*, 125, pp.159–169.

Vajargah, H. K. (2016). An Overview of the Economic Status of the Safavid Era on the Basis of Silver Coins, Case Study: Shah Abbas II And Sultan Hussein, *Mediterranean Archaeology and Archaeometry*, Vol. 16 (2), pp. 119-125.

Vlachou-Mogire, C., Stern, B., McDonnell, J. G. (2007). The Application of LA-ICP-MS in the Examination of the Thin Plating Layers Found in Late Roman coins, *Nuclear Instruments and Methods in Physics Research B Beam Interactions with Materials and Atoms* 265 (2), pp. 558–568.

Yükçü, S., Seçkin, G. (2014). Anadolu'da İlk Paranın Ayar ve Alaşımı, *Muhasebe ve Finans Tarihi Araştırmaları Dergisi* 7, İstanbul, pp. 28-48.