Analysis of the chemical elements of the last hammering coins and the first machined-struck silver coins in Qajar Iran

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Abstract:
Numismatic data has always had a special place in archaeological studies. So, these documents can provide researchers with a wide range of information based on the focused point of research. The quality and quantity of elements used in coin metal can be restored by archaeometric studies. Some of these elements, such as silver, lead, copper and gold, indicate the monetary policies and metallurgy of their minting time. In this research, for the first time, 25 samples of coins in Ghajar periods were analyzed by the fast and non-destructive PIXE method with different minting techniques, and the percentage of main elements of these coins (silver, copper, lead, gold, iron, chlorine, calcium) were obtained. The results showed that silver is the mould element in this coinage and its amount is slightly different in hammering and milled coinages. Over time, the Qajars were able to gain more control over monetary policies. Also, the presence of small amounts of lead in most of the coins showed that the separation of elements has been done well by silver. And in this era, various sources have been used to supply the necessary silver for minting.

Rezumat: Analiza elementelor chimice ale ultimelor monede bătute și ale primelor monede de argint frezate din Qajar Iran
Datele numismatice au avut întotdeauna un loc aparte în studiile arheologice. Așadar, aceste documente pot oferi cercetătorilor o gamă largă de informații bazate pe punctul de interes al cercetării. Calitatea și cantitatea elementelor utilizate în monedele metalice pot fi descoperite prin studii arheometrice. Unele dintre aceste elemente, cum ar fi argintul, plumbul, cuprul și aurul, indică politicile monetare și metalurgia din timpul baterii lor. În această cercetare, pentru prima dată, au fost analizate 25 de mostre de monede din perioadele Ghajar prin metoda PIXE rapidă și nedistructivă cu diferite tehnici de batere, precum și procentul elementelor principale ale acestor monede (argint, cupru, plumb, aur, fier, clor, calciu). Rezultatele au arătat că argintul este elementul de matriță în această monedă și cantitatea sa este ușor diferită în monedele bătute cu ciocanul și cele bătute mecanic. În timpul dinastiei Qajar au reușit să câștige mai mult control asupra politicilor monetare. De asemenea, prezența unor cantități mici de plumb în majoritatea monedelor a arătat că separarea elementelor s-a făcut bine cu ajutorul argintului. Și în această epocă, s-au folosit diverse surse pentru a furniza argintul necesar pentru batere.

Key words: Qajar dynasty, silver coins, PIXE method, discriminant analysis, numismatic studies
Cuvinte cheie: dinastia Qajar, monede de argint, metoda PIXE, analiză discriminantă, studii numismatice

Introduction

Before using archaeometric methods in numismatic studies, the information extracted from these important archaeological data was limited to the classification and chronology of kings based on inscriptions and coin images. Different methods such as PIXE and XRF are used to analyze the elements of coins. Although the XRF method is less expensive and detects more elements in spectroscopy, the higher accuracy of the PIXE method can lead to the correction of the results of other methods[1]. It is possible to recover the quality and quantity of the elements used in the coinage metals at the minting time by archaeometric studies on coins. The elements revealed by this method each have different scientific importance in archaeometric studies. By studying the silver element of Macedonian coins in the era of Alexander, issued from different mints, Kallithrakas-Kontos could show the coinage policies of that period[2]. Also, Kohansal's studies conducted in 2016 on the coins of the Safavid Islamic era showed that

[1] Yousefi et al 2021; Weber et al 2000; Neyestani et al 2014.
[2] Kallithrakas-Kontos et al 2000

mints added copper elements to silver coins in some cases under the influence of economic conditions[3]. In other words, the copper element in coins with silver element has a negative balance. The remaining amount of about 1 percent of copper remains in the process of extracting copper from silver, the amount between 1 and 2 or 3 percent was added in order to harden the coin, and the amount greater than 3 percent should be considered the result of monetary and economic policies[4].

Elements such as lead were influenced by the technology of extracting silver from metal ore in such a way that the lower the amount of lead in the composition of coins, the higher the quality of silver separation from lead[5]. A specific percentage of gold in silver can also indicate the mines used for silver extraction[6]. The review and study showed that no archaeometric study has been done on the silver coins of the Qajar period. As a result of this research gap, we do not have detailed information on how monetary policies were applied and what sources supplied silver and the metallurgy of this period. In this research, for the first time, spectroscopy was used for 25 coins belonged to coinages of the Qajar era by the PIXE method to study their chemical composition. There are 15 samples of coins with the hammering method that were minted in 11 mints of Tehran, Isfahan, Shiraz, Kerman, Kermanshah, Tabarestan, Tabriz, Mashhad, Hamedan, Rasht and Kashan during the era of Fath-Ali Shah (1797-1834 AD), Mohammad Shah (1834-1848 AD) and Naser al-Din Shah(1848-1896 AD). 10 other samples are coins with milled coinage technique related to Naser al-Din Shah and Muzaffar al-Din Shah Qajar. Mohammad Ali Shah and Ahmad Shah are kings of Qajar, all of them minted in Tehran mints. (Fig. 1).

Fig. 1. The studied coins

[3] Kohansal Vajargah 2016.
[4] Kantarelou et al 2011; Hajivaliei and Khademi Nadooshan 2012
[5] Masjedi et al 2013a; Tripathy et al 2010, Kohansal Vajargah 2016.
[6] Meyers 2003.

Historical background:

By the death of Karim Khan Zand, Agha Mohammad Khan Qajar (1779-1797 AD), the founder of the Qajar dynasty, became the king after many wars with the survivors of Zandiye in 1779 AD[7]. The emergence of the Qajar dynasty in the late 18th century began with the same common monetary system of the Safavid era, which was in trouble between the invasion of Afghans and the rise of the Qajar dynasty. At the beginning, coins were minted and issued in about 40 mints in big cities in hammered form, like the first coins minted in Iran in the middle of the first century BC. (Fig. 2). In 1863 AD/1279 AH, Naser al-Din Shah Qajar ordered to purchase milled coinage (machine-struck coinage) under the influence of Europeans and following regulatory and economic problems and for the purpose of monetary reforms. But the modern mints lasted about 14 years to start working with the help of Europeans. These mints could mint coins until the end of the period of the last four kings of this dynasty (Naser al-Din Shah, Muzaffar al-Din Shah, Muhammad Ali Shah and Ahmad Shah Qajar)[8]. However, despite the command to collect and replace, hammered coins were used in a limited amount until the end of the Qajar era. Governments supplied the metal needed for minting coins from three sources: extraction from mines, booty through military campaigns and trade.

In this era, due to the weakness of technology and the lack of a strong military force, the third item, trade, was more important[9]. The studied hammered coins (Fig. 1, 1-15) are nominal units of Rial, Qerans, Shahi and Toman. Milled coins (Fig. 1, 16-25) are Shahi, Toman, Qerans and Dinar, which are minted in different weights and units. (Table 1) (for more information on standard weights and monetary units, refer to Farah Bakhsh's 1975 guide to Iran's minted coins).

Materials and methods:

A number of 25 samples were randomly selected from the Qajar period coins from a collection among silver coins minted in different mints with different minting techniques (Table 1). All the samples were selected and transferred to the Vandograph Laboratory of Amirabad Atomic Energy Organization, Tehran, to remove possible

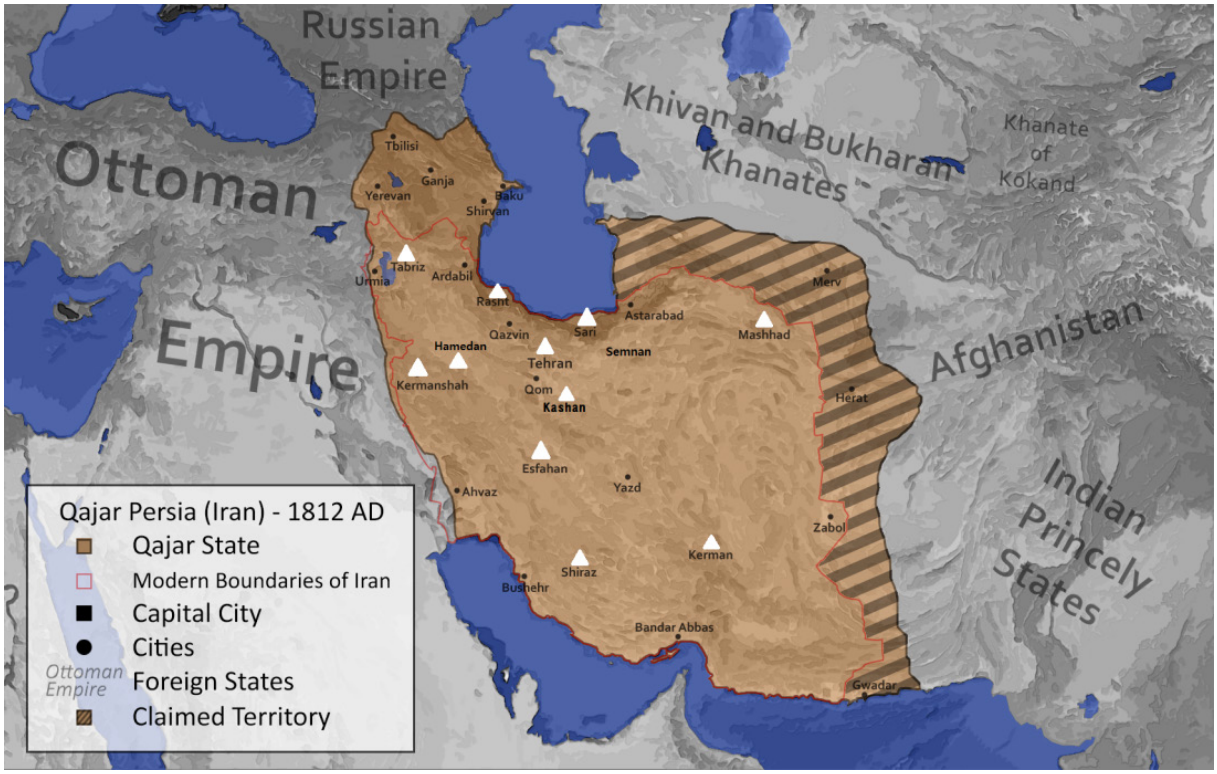

Fig. 2. Mints in Qajar era

[7] Avery et al 1991
[8] Mathee et al. 2013
[9] Mathhee, Floor & Clawson, 2013: 33-34.

Table 1. Characteristics of the studied coins

Sample	King	nominal	coinage	Technique coinage	Mint	sampel Weight	standard Weight
1	Fathali Shah	One rials	1232-1219	hammered	Tehran	9.45	10.36
2	Fathali Shah	One rials	1232-1241	hammered	Rasht	8.60	9.21
3	Fathali Shah	One rials	1245-1241	hammered	Esfahan	6.87	6.90
4	Fathali Shah	One rials	1245-1241	hammered	shiraz	6.70	6.90
5	Mohammad Shah	One qerans	1252-1251	hammered	Kermanshahan	6.25	6.33
6	Mohammad Shah	Ten shahi	1258	hammered	Tabarestan	2.60	2.68
7	Mohammad Shah	One qerans	1255-1264	hammered	Kerman	5.10	5.37
8	Mohammad Shah	Ten shahi	1255-1264	hammered	Tehran	2.66	2.68
9	Naser-aldin Shah	One qerans	1289	hammered	Tabriz	4.85	4.99
10	Naser-aldin Shah	One qerans	1289	hammered	Tabriz	4.90	4.99
11	Naser-aldin Shah	One qerans	1278	hammered	Mashhad	4.62	4.99
12	Naser-aldin Shah	One qerans	1293-1272	hammered	Hamedan	4.85	4.99
13	Naser-aldin Shah	One qerans	1293-1272	hammered	Rasht	4.90	4.99
14	Naser-aldin Shah	One qerans	1293-1272	hammered	Kashan	4.58	4.99
15	Naser-aldin Shah	One toman	1293-1264	hammered	Hamedan	3.40	3.45
16	Naser-aldin Shah	1000dinars	1296	mechanical	Tehran	4.9	4.6
17	Naser-aldin Shah	2000dinars	No data	mechanical	Tehran	9.2	9.2
18	Naser-aldin Shah	1000dinars	No data	mechanical	Tehran	4.6	4.6
19	Naser-aldin Shah	2000dinars	1314	mechanical	Tehran	9.2	9.2
20	Mozafar-aldinshao	shahi	No data	mechanical	Tehran	0.74	0.74
21	Mohamadali shah	two qerans	1326	mechanical	Tehran	9.2	9.2
22	Mohamadali shah	Two qerans	1327	mechanical	Tehran	9.2	9.2
23	Ahmad shah	1000dinars	1330	mechanical	Tehran	4.6	4.6
24	Ahmad shah	1000dinars	1332	mechanical	Tehran	4.8	4.6
25	Ahmad shah	1000dinars	1332	mechanical	Tehran	4.6	4.6

contamination from the entire surface of the coins, cleaned and dried with acetone and a soft brush, then the coins were immersed in a 10% solution of formic acid for 24 hours, and finally dried it with air[10].

Test conditions:

On two occasions and in every test, 10 and 15 samples were placed in the test chamber. Chamber vacuum is provided up to 2 x 10^{-5} Torr by a rotary mechanical pump and a diffusion pump. An energy of 2 MeV and a current of about 2-3 nA were used to bombard study samples with a proton beam, which is produced by the PIXE device active in the Atomic Energy Organization in Amirabad. After bombarding the surface of the samples with a proton beam at an angle of 90 degrees, X-rays are emitted, which is measured by the Si(Li) ORTEC detector at an angle of 45 degrees. The characteristic X-ray energy collected in the detector results in signals of varying intensities. The type of elements and the number of X-rays with a certain energy determine the concentration of the elements in the samples. Cupix program has been used to quantitatively reveal the constituent elements of coinages. Also, a Mylar filter with a thickness of 175 microns has been used to reduce low-energy X-rays caused by light elements and to better reveal heavy metals (Fig. 3).

[10] Vijayan et al. 2005.

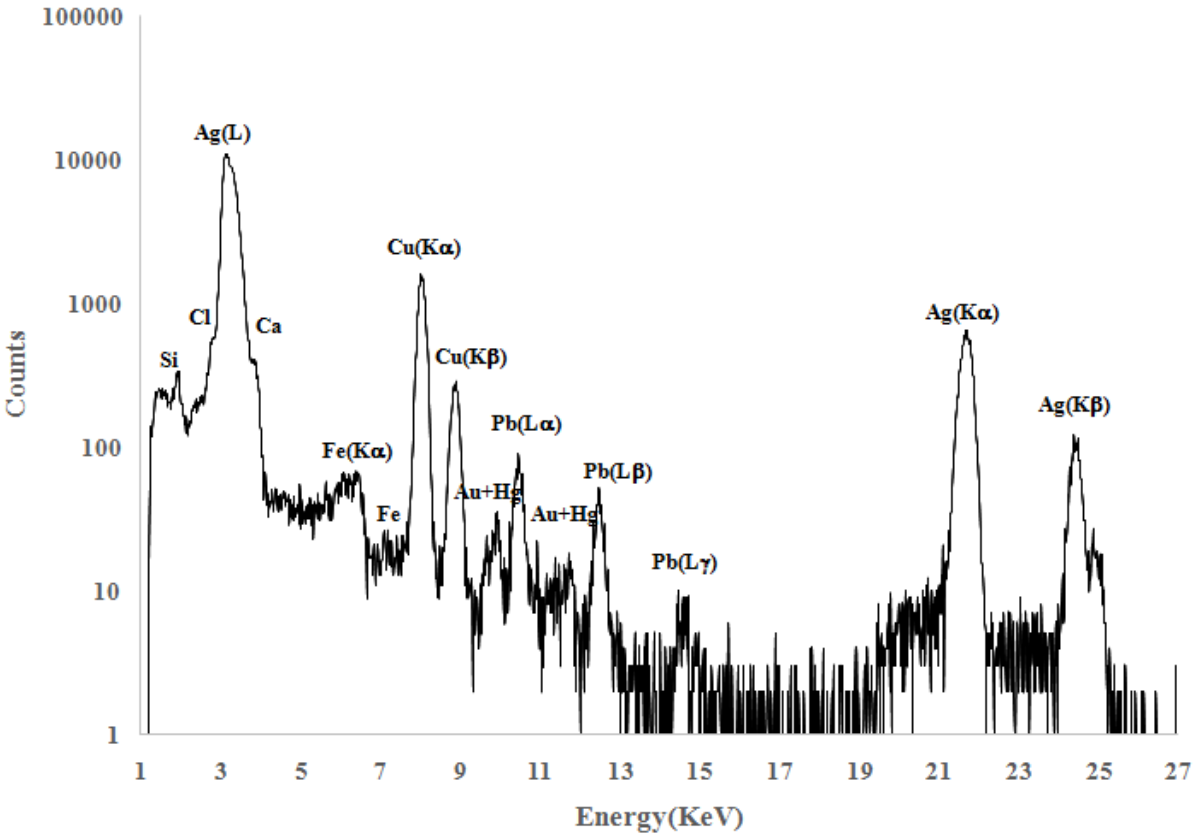

Fig. 3. Spectra sample of coin 1

Conclusion and discussion

In this research, 25 silver coins of six Qajar kings, including 15 samples of coins with the classical minting technique of Iranian coins and 10 samples of milled coinages, were analyzed via spectroscopy techniques (Fig. 1). In this collection, four coins (1-4) of Fath Ali Shah (1797-1834 AD) were minted in Rasht, Tehran, Isfahan and Shiraz mints. Four coins (5-8) of Mohammad Shah Qajar (1834-1848 AD) were minted in Tehran, Kerman, Kermanshah and Tabarestan mints. Seven samples (8-15) of Naser al-Din Shah (1848-1896 AD) were minted in Tehran, Tabriz, Mashhad, Hamedan, Rasht and Kashan mints (Table 1). Also, among the collection of Qajar milled coinages minted in Tehran, three samples of Naser al-Din Shah (No. 16, 17 and 18), two samples of Muzaffar al-Din Shah (No. 19 and 20), two samples from Mohammad Ali Shah (No. 21 and 22) and three samples of Ahmad Shah, the last king of Qajar dynasty (No. 23, 24 and 25) were tested.

As shown in Table 2, The PIXE Spectrometer device totally identified 8 elements among the studied coins, including silver, copper, lead, gold, iron, chlorine, calcium, and silicon and determined their quantity (Table 2). Among these two elements, silver and copper have the highest amount. Silver element shows the amount of 98.07%- 95.70% in the three kings' hammered coins (Table 2), which is considered a very high and considerable amount of silver. The difference in the purity of silver is very small and even incalculable during the reign of these three kings in 11 mints. The average purity of silver is 97.38 in the coins of this period. Compared to the average amount of silver in the coins tested during the Ilkhanid era, which was 84%[11] and Safavid era (1531-1736 AD), which was 88%[12], we see a very high percentage of silver averagely. It can be said that there has been an organized supervision on maintaining the quality of coins by limiting the sources of monetary metal supply. As mentioned above, with the increasing importance of trade in order to provide monetary resources, the presence of high-quality and valuable money in different regions is necessary for trading. Contrary to the almost identical carat, the weights of the studied coinages are different compared to the standard weight of that period. Due to the almost identical carat, it can be said that the weight of coins was very important in determining the value of transactions in this period. Probably, the suggestion of using the weight of silver coins for transactions, which surprised Rabino, was based on this[13]. Also, the policy of

[11] Sodaei and Kashani 2013.
[12] Kohansal Vajargah, 2016.
[13] Rabino, 1892, 37.

keeping the value of coins at the same level could neutralize Gersham's law, according to which bad quality coins take good coins out of circulation, and also prevent the minting of fake coins[14]. In 15 samples of hammered coins, the copper element shows a percentage between 0.60 % and 3.44 %. Also, the amount of silver in machine-struck coins is between 94.79 and 98% with an average of 96.29 (Table 2). On average, the difference in silver percentage between machined and hammered coins is only 1 %. In samples 17, 18, 19, 24, and 25, the amount of copper is higher than the standard amount determined (3%) in previous researches. But still, there is standard weights in all samples (Table 1). The partial weight difference in several milled coinages (16, 20, 22, 23) is related to new changes on the coins.

The combination of the high amount of silver and the observance of the standard weight could increase the government's involvement in monetary policies. The lead present in most of the samples of both groups of hammered and milled coinages (except for the samples of the last king) indicates that they were extracted from lead and zinc mines[15]. The low amount of lead present in all these samples (Table 2) shows that the silver purification process was done well and almost in the same way, which seems to be an attempt to refine as much silver as possible. A different amount of gold (0.00-2.01 %) in some samples is the result of the use of various silver ores[16]. Meyers's work on ancient silver in 2003 showed that a certain amount of gold in silver could indicate the

Table 2. The amount of elements in the coins

Sample	Si	Cl	Ca	Fe	Cu	Au	Ag	Pb	King	Mint
1	0.45	0.09	0.22	0.08	0.98	0.04	97.84	0.3	Fathali Shah	Tehran
2	0.39	0.19	0.14	0.07	0.91	0.2	98	0.1	Fathali Shah	Rasht
3	0.45	0.09	0.16	0.1	0.79	0.31	97.80	0.3	Fathali Shah	Esfahan
4	0.49	0.02	0.03	0	0.60	0.83	97.93	0.1	Fathali Shah	Shiraz
5	0.14	0.11	0.25	0.09	1.16	0.05	98.07	0.13	Mohammad Shah	Kermanshahan
6	0.76	0.23	0.23	0.01	0.99	0.06	97.64	0.08	Mohammad Shah	Tabarestan
7	0.10	0.07	0.25	0	1.20	0.25	98.01	0.12	Mohammad Shah	Kerman
8	0.77	0.21	0.26	0.03	0.82	0.13	97.40	0.38	Mohammad Shah	Tehran
9	0.58	0	0.01	0.00	3.44	0.01	95.76	0.2	Naser-aldin Shah	Tabriz
10	0.44	0.23	0.26	0.03	1.45	0.03	97.42	0.14	Naser-aldin Shah	Tabriz
11	0.22	0	0.31	0.02	1.87	0.03	97.2	0.35	Naser-aldin Shah	Mashhad
12	0.01	0.2	0.01	0.02	2.03	2.01	95.70	0.02	Naser-aldin Shah	Hamedan
13	0.07	0.01	0.11	0.01	1.44	1.29	96.97	0.1	Naser-aldin Shah	Rasht
14	0.45	0.09	0.14	0	1.81	0.01	97.4	0.12	Naser-aldin Shah	Kashan
15	0.11	0	0.39	0	1.37	0.23	97.6	0.30	Naser-aldin Shah	Hamedan
16	0.34	0.35	0.30	0.01	3.00	-	95.69	0.31	Naser-aldin Shah	Tehran
17	0.42	0.32	0.56	0.08	3.65	-	94.83	0.14	Naser-aldin Shah	Tehran
18	0.33	0.02	0.01	0.00	4.65	-	94.79	0.10	Naser-aldin Shah	Tehran
19	0.42	0.22	0.41	0.00	3.95	-	94.87	0.13	Mozafar-aldinshao	Tehran
20	0.06	0.2	0.22	0.01	2.29	-	97.19	0.05	Mozafar-aldinshao	Tehran
21	0.08	0.2	0.18	0.00	2.45	-	97.05	0.04	Mohamadali shah	Tehran
22	0.14	0.14	0.22	0.05	0.78	-	98.6	0.07	Mohamadali shah	Tehran
23	0.56	0.23	0.29	0.09	0.83	-	98.00	0.00	Ahmad shah	Tehran
24	0.19	-	0.19	0.08	3.61	-	95.93	0.00	Ahmad shah	Tehran
25	0.37	-	0.23	-	3.45	-	95.95	0.00	Ahmad shah	Tehran

[14] Mathhee, Floor and Clawson 2013, 39-40.
[15] Uzonyi et al. 2000.
[16] Kallithrakas-Kontos et al., 2000; Masjedi et al., 2013b.

use of Sarv Site (0.2% to 1.5%) and Galena (less than 0.2%) mines[17]. Accordingly, the source provided for silver in samples 2, 3, 4, 7, 13, and 15 is from Sarv Site mines and samples 1, 5, 6, 9, 10, 14, 8, and 11 are from Galena mines. It is known that both ores mentioned have been frequently used during the eras of Fath Ali Shah (1797-1834 AD), Mohammad Shah (1834-1848 AD) and Naser al-Din Shah (1848-1896 AD).

The element of gold, perhaps as a feature of Iranian silver coins, can always be seen in most of the examined samples since the beginning of coinage[18]. It's a phenomenon that is generally not observed in the samples of machine-struck coins. This can indicate the supply of silver from new and different sources than before. The silver used in recent coins is either from minerals without gold as an accompanying element, or the gold element has been completely separated from it during the purification process of the silver metal.

In the last three samples of this research (23, 24 and 25) related to the era of Ahmad Shah Qajar, no traces of lead and gold can be observed. Since silver is always extracted as an accompanying metal from various mines, the absence of this accompanying element indicates the use of a different and more advanced technology (silver refining in Iran has been usually done by the method of cupellation, which always leaves some traces of the accompanying metal in the examined samples). This can indicate the use of a more advanced technology for silver purification. A document shown issuance of an order to import silver coins from London during the minting of machine-struck coins related to this king directly refers to this issue (Document ID 240/10362-Iran National Document Archive). The low amount of iron (0.01-0.1) shown in some samples in Table 2 is probably the source of external contamination such as dust on the surface of the coins[19]. The rest of the elements do not provide a specific pattern in relation to the subject.

Conclusion:

According to the above results and historical documents, it can be said that although the hammered coins are in very good condition in terms of silver purity, they were valued in the form of ingots and were used in transactions, and on this basis, the Qajars could not have a positive impact on monetary politics and there usually was difficulty and slowness in trade and exchanges. Most of the silver in hammered coins had been extracted from lead and zinc mines. The two mines of Sarv Site and Galena, with high amount of silver, were the main suppliers of silver for minting during the era of the first three kings. At the end of this era, the needs of the central mint was supplied by importing silver metal. Although machine-struck coins have a lower percentage of silver than hammered coins, they all have a standard weight, which accelerated and facilitated domestic trade and transactions.

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