The International Journal of Ancient Iranian Studies
July 2022, VOL. 2, NO. 3: 53-73. OPEN ACCESS
https://doi.org/10.22034/pa.2022.324966.1006

PERSICA ANTIQUA

RESEARCH ARTICLE

The Elemental Analysis of Elymais Period Coins by PIXE Technique and Their Statistical Analysis by Spss Software

Behzad Hoseini Sarbisheh[1], Ali Asghar Salahshoor[2], Hamzeh Ghobadi Zadeh[3]

Abstract

Elymais had existed as a semi-autonomous and sometimes autonomous satrap, coinciding with Seleucids and the Parthians in the southwest and west Iran. This government played an active presence in political and economic domains of the region from the mid-second century BC to the advent of the Sasanian Empire. This paper tries to study the historical coins of Elymaean using archaeometry. The method is a valuable criterion for the recognition of size and weight of those coins. Elemental studies of coins give us valuable information in connection with particle size used, combinations percentage of the coins, and applied metallurgy in their manufacturing. In other words, the study provides groundwork for understanding the economic and political structures as well as commercial communications of the society. The difference in the quantity of element may provide information about the mining of these metals. As such bronze and silver coins belonging to the Elymaean have been studied using PIXE technique to know about the concentration of elements, the number of mines as well as mints through the elemental analysis and the definition of the chemical composition of metals. To achieve the mentioned goals, we analyzed 35 coins involving three periods of Elymaean (from 85 BC to 224 AD). The results showed that the percentage of elements in coins such as silver and copper in the three periods were different but have had more purity in the first period. Furthermore, the analyzed coins are minted at six places and raw materials were brought from three different mines. Lastly, the statistical analysis is performed with SPSS software.

Keywords: Elymais Coins; Ore; PIXE Technique; SPSS; Elemental Analysis.

[1] Ph.D. Candidate of Archaeology, Tarbiat Modarres University, Tehran, Iran behzadsarbisheh@gmail.com
[2] Ph.D. Candidate of Archaeology, Tehran University, Tehran, Iran (Corresponding Author) aa.salahshour@ut.ac.ir.
[3] Ph.D. Candidate of Archaeology, Tehran University, Tehran, Iran. h.ghobadi@ut.ac.ir.
Article info: Received: 16 January 2022 | Accepted: 4 March 2022 | Published: 1 July 2022
Citation: Hoseini Sarbisheh, Behzad; Salahshoor, Ali Asghar; Ghobadi Zadeh, Hamzeh. (2022). "The Elemental Analysis of Elymais Period Coins by PIXE Technique and Their Statistical Analysis by Spss Software". *Persica Antiqua*, Vol. 2 (3): 53-73.
https://doi.org/10.22034/pa.2022.324966.1006

Introduction

Elymaean are successors of Elamites and ruled during the mid-second century BC in the southwest Iran. Their main governing base was somewhere in present-day Khuzestan province and based on ancient texts, they are said to live in the northeast and southern Khuzestan. The founder of Elymais was Kamnaskires I, who according to available resources, governed between 160 and 140 BC. Elymais state until 224 AD (i.e., contemporary to the beginning of the Sasanian Empire) had had active participation in regional events (Alizadeh, 1985: 181-183). According to written sources, archaeological evidence and the late field studies, Elymaean from the north ruled on parts of Khuzestan and Chaharmahal and Bakhtiari provinces, from the east to Kohgiluyeh and Boyer-Ahmad province, from the south to the Persian Gulf and from the west to the plains of Khuzestan province (Moradi, 2012; Hojabri Nobari, et al. 2013: 60, 61).

Among archaeological resources, coins have particular importance because they have high resistance to damage, as well as showed much information about the cultural, economic, and political conditions of that period. With the typology of coins, we can acquire information about the relative chronology, art cognition, etc. Laboratory methods such as PIXE can provide additional information about the targeted society.

With the advent of modern archeology, experts of other sciences such as Archaeometry were used to study artifacts. One of the non-destructive analytical techniques in archaeometry is PIXE, a fast and sensitivity used to study coins. Today, the PIXE technique, due to its high accuracy and non-destructive nature is considered in the study of archaeometry (Tripathy, et al. 2010). In other words, this laboratory method can provide additional information about the period and the society under study. At the same time, the elemental analysis gives us valuable information about the composition of alloys as well as the source of metals (Guerra, et al. 2008). In the numismatic study, it is important to recognize original compositions of alloy used in the coins. The relative proportion of elements provides valuable information about the changes in the monetary system, economic and political conditions and technology (Beck, et al. 2004). In this paper, we try to study 35 coins of various Elymais kings using the PIXE technique. By this way, we can determine the number of mines and mints involved in their production as well as an analysis of the economic and, political conditions. Based on the coinage, their rule can be categorized into three periods: the family of Kamnaskires, the government (25-150 AD), and the state of the last king (150-221 AD).

Research Background

The first scholar who studied pre-Islamic coins of Iran was Caley (1950), an American chemist who noted the reign of Orodes, Parthian king. Hughes (Hughes & Hall 1979) not only worked on Sasanian silver metals but compared them with Roman silver utensils. Among researchers who used XRF and PIXE techniques to study the available elements in coins or metals of different historical periods can be mentioned as Khademi Nadooshan (2006) and Hajivaliei (2009). Hajivaliei with the PIXE technique surveyed the number of the silver coins of Khosrow II, a Sasanian king (Hajivaliei et al., 2008). Among those who analyzed copper coins are Vijayan, Hajivaliei and Kallithrakas-Kontos. Vijayan studied the copper coins of the Kushan period (Vijayan, 2005: 121-125), Hajivaliei studied ancient Indi-

an coins (Hajivaliei, et al. 1999) whereas Kallithrakas-Kontos (1996) analyzed the copper coins of ancient Greece. Unfortunately, the coins of Elymais were not analyzed. So this study is the first lab activity on the coins of this period, which are mostly copper and silver and some copper and gold coins.

Elymaean Coins and Mints

For a better understanding the different periods is necessary the coins attributed to the kings and the sequencing their period. The newest division of Elymaean is done by Pakzdaidan who investigated the Elymais period based on coins in three parts (Pakzadian, 2007). As mentioned, coins provide us the most important information of Elymais kings. Based on the designs of coins, alloy, weight and the concentration of different elements can give us useful information about their source as well as the economic, religious, and political aspects of that period. Elymais coins were minted from silver, bronze and, copper. The special monetary unit has not been presented for this period, but for other periods such as Parthian, there were drachms (tetradrachms and one drachm) which was divided into smaller and smaller sub-units "obol" (three obol, two obol, one obol) and also "Kalkon" (like eight Kalkon, four Kalkon, two Kalkon and, one Kalkon), in this way, each drachm was equivalent to six obol and each obol was equivalent to eight Kalkon. The normal weight of tetradrachms coins during the Parthian was 14-16 grams. Also one drachm was 3/5-5 grams and obol was one-sixth drachms. Bronze coins of Parthian and across the country were minted in different weights from 7.0 g to 14 g (Sarfaraz & Avarzamani, 2006). In this study, silver coins of Elymais were drachms and bronze coins were kalkons.

Elymaean coins between Kamnaskires I (ca. 147 BC) and Kamnaskires III (ca. before 85 BC) are derived from the tradition of Seleucids as well as from Kamnaskires IV (ca. 82- 72 BC) until the end of this government which resembled Parthian coins. Coins are depicted with designs and political symbols like king image and symbols associated with Elymais kings (in many cases, these symbols are not interpreted correctly). On the reverse of coins, various images such as the previous king or crown prince, parallel and intersecting scattered lines, birds, etc are depicted. At the first, Greek script, and then Aramaic script (including the name of the king, sometimes king name and his epithets) are used. Also mints information and date of mintage are carved on the reverse of some of these coins (Pakzadian, 2007).

Before Kamnaskires III, Elymais coins were similar to Seleucids with Greek script, but from Kamnaskires III onward pictures on Elymais coins were changed, and tendency to the Parthian iconography is seen on Elymais coins that continued until the end of the Elymaean government, but script until kings of the second period of Elymais was Greek which gradually changed to Aramaic. During the reign of Farhad (Phraates IV) and Orodes IV, contemporary to Kamnaskires XI and XIII, Parthian mints in Susa reduced the value of drachms. This action affected the coins of the Kamnaskires dynasty and tetradrachms merely decreased to bronze sign (Ibid). In the second decade of the 2nd century AD to Kamnaskires, the founder of the third period of Elymaean government reunited Susa and Elymais. The coinage accuracy and images on coins of second and third Elymais decreased. Coins belonging to Elymais kings have been scattered throughput Khuzestan, Lorestan, Cha-

Table 1. Words and Numbers in The Dating of Coins During Elymais (Pakzadian, 2007)

A	B	Γ	Δ	E	Σ	Z	H	Θ	I	K	Λ	M	N	Ξ
1	2	3	4	5	6	7	8	9	10	20	30	40	50	60
O	II	Q	P	[illegible]	T	Y	Φ	X	Ψ	Ω				
70	80	90	100	200	300	400	500	600	700	800				

harmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, Bushehr and Fars provinces to the east of Saudi Arabia, reflecting the role played by Elymaean in regional and trans-regional trade. Regional developments, particularly the conflicts between Parthians and the Romans influenced the economic situation of Elymaean. As far as the sources have pointed out, Elymaean capitals have been Ayapir (Izeh), Susa (Seleucia-by-the-Eulaios) and Seleucia-on-the-Hedyphon. The reason for this change is not yet known, but Susa as the key city has been important throughout the Elymais dynasty. When Susa was dominated by Parthians and Seleucids, their capital was moved to another city (Yarshater, 1989; Pakzadian, 2007). The studying signs on the Elymais coins shows the name of seven cities of Elymais.

In the early period of Elymais, Ayapir and Susa mints were active. After decades of silence, Elymaean in another place, probably in the first half of the first century BC minted coin in Hedyphon again and the capital was moved there. After Kamnaskires III, a group of coins has been affected by Parthian coins and, apparently, former mint of Ayapir has been closed or dominated by Parthians.

Elymais coins could be minted in Susa after 75 AD, but before, they were minted in Seleucia-on-the-Hedyphon that implies the capital was probably moved from Seleucia to Susa in 75 AD. Elymaean territory during their several hundred years of rule has constantly been changed from its size and extent. Mint signs on the coins of Elymais are varied, but their position is not often specified. The study of written signs on Elymaean coins, the name and signs of seven cities are identified. Before King Kamnaskires IV and Queen Anzaze, mints of Ayapir and Susa were main coinage centers. Then onward, Susa and Seleucia-on-the-Hedyphon were the main mints (Vanden Berghe and Shippman, 1985; Pakzadian, 2007). Unfortunately, the mintage date is missing on the first coins of Elymais Kings and on the coins contemporary to the Parthian ones, dates are rarely seen. Method of engraving on these coins like Seleucid and Parthian are with Latin alphabets which are read from left to right. For example, ΕΛΣ date in the Table 1 is equal to 235 of Seleucid or 78 BC of Parthian (Pakzadian, 2007).

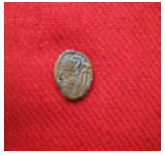
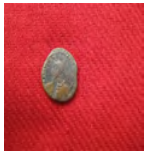
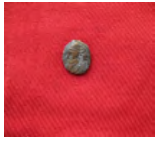
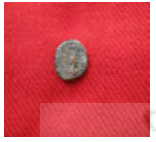
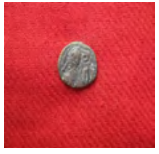
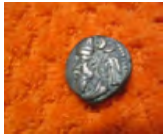
Samples Preparation

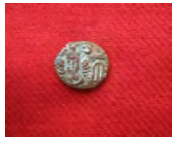
The analysis using the PIXE technique is one of the most accurate ones in finding small elements. This study uses this technique for the elemental analysis of Elymais coins. By studying the composition and metal contents of coins can explain and analyze historical events, place of mint, and their mines. The same method can also identify fake, imitation or suspicious coins. The coins of this research are selected from the personal collection of Mohammad Saffar. They include 2 silver and 33 copper coins which were placed

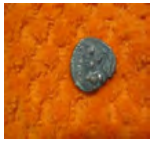
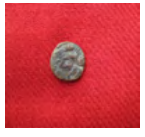
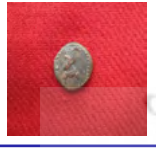
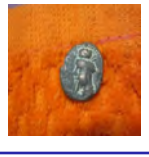
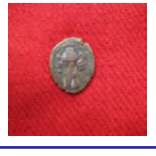
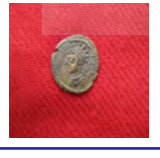
Table 2. The Analyzed Coins by PIXE Technique

No	Reverse	Obverse	Explanations of Coins					
1			Reference	Mint	Weight (gr)	Diameter (cm)	Material	Coins of King Kamnaskires IV and Queesn Anzaze A
			Pakzadian 2007	Kan-gavar	1/567	1.7	silver	
2			Reference	Mint	Weight (gr)	Diameter (cm)	Material	Coin of Kamnaskires VIII I
			Ibid	?	3/468	2	silver	
3			Reference	Mint	Weight (gr)	Diameter (cm)	Material	Coin of Kamnaskires XI O
			Ibid	?	1/835	1.8	billon	
4			Reference	Mint	Weight (gr)	Diameter (cm)	Material	Coin of Kanaskires XII V
			Ibid	?	12/839	3.2	billon	
5			Reference	Mint	Weight (gr)	Weight (cm)	Material	Coin of Kanaskires XIII T
			Ibid	?	15/518	3.3	billon	

6			Reference Ibid	Mint ?	Weight (gr) 3/324	Diameter (cm) 1.9	Material billon	Coin of Kamnaskires XII G
7			Reference Ibid	Mint ?	Weight (gr) 3/52	Diameter (cm) 1.8	Material copper	Coin of other kings of Kamnaskires dynasty F
8			Reference Ibid	Mint ?	Weight (gr) 14/691	Diameter (cm) 3.2	Material bilon	Coin of other kings of Kamnaskires dynasty S
9			Reference Ibid	Mint ?	Weight (gr) 3/392	Diameter (cm) 2.1	Material copper	Coin of other kings of Kamnaskires dynasty R
10			Reference Ibid	Mint ?	Weight (gr) 2/936	Diameter (cm) 1.9	Material copper	Coin of Phraates I C3
11			Reference Ibid	Mint ?	Weight (gr) 3/042	Diameter (cm) 1.9	Material copper	Coin of Phraates I I9

12			Reference Ibid	mint ?	Weight (gr) 2/993	Diameter (cm) 1.9	material copper	Coin of Orodes II F 6
13			reference Ibid	Mint ؟	Weight (gr) 3/295	Diameter (cm) 2	Material copper	Coin of Orodes II E 5
14			Reference Ibid	Mint ?	Weight (gr) 2/306	Diameter (cm) 2.1	Material copper	Coin of Orodes II B 2
15			Reference Ibid	Mint ?	Weight (gr) 3/546	Diameter (cm) 1.9	Material copper	Coin of Orodes II M13
16			reference Ibid	mint ?	Weight (gr) 3/897	Diameter (cm) 1.8	material copper	Coin of Orodes II N14
17			Reference Ibid	Mint ?	Weight (gr) 2/989	Diameter (cm) 1.8	Material copper	Coin of Phraates II G 7

18			Reference Ibid	Mint ؟	Weight (gr) 3/025	Diameter (cm) 2.5	Material copper	Coin of Kamnaskires-Orodes I D 4
19			Reference Ibid	Mint ?	Weight (gr) 3/290	Diameter (cm) 2	Material copper	Coin of Kanaskires – Orodes I Q
20			Reference Ibid	Mint ?	Weight (gr) 13/801	Diameter (cm) 3.2	Material billon	Coin of Kamnaskires-Orodes IW
21			Reference Ibid	Mint ?	Weight (gr) 4/096	Diameter (cm) 2.3	Material copper	Coin of Kamnaskires Orodes II P 15
22			Reference Ibid	Mint ?	Weight (gr) 2/713	Diameter (cm) 1.9	Material billon	Coin of Kamnaskires-Orodes II H 8
23			Reference Ibid	Mint ?	Weight (gr) 2/51	Diameter (cm) 1.9	Material copper	Coin of Kamnaskires-Orodes II H

24			Reference Ibid	Mint ؟	Weight (gr) 2/809	Diameter (cm) 1.7	Material copper	Coin of Orodes V and Olfan L
25			Reference Ibid	Mint ?	Weight (gr) 3/233	Diameter (cm) 2.2	Material copper	Coin of Orodes V and Olfan K 11
26			Reference Ibid	Mint ?	Weight (gr) 2/16	Diameter (cm) 1.9	Material copper	Coin of Orodes VII E
27			Reference Ibid	Mint ?	Weight (gr) 2/727	Diameter (cm) 1.9	Material copper	Coin of Orodes VII J10
28			Reference Ibid	Mint ?	Weight (gr) 2/588	Diameter (cm) 2	Material copper	Coin of the third unknown king/Orodes VIII J
29			Reference Ibid	Mint ?	Weight (gr) 2/739	Diameter (cm) 2	Material copper	Coin of the third unknown king/ Orodes VII

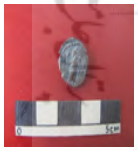
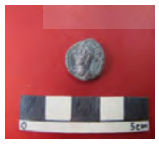
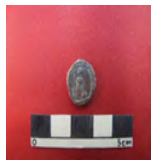
30			Reference Ibid	Mint ?	Weight (gr) 3/319	Diameter (cm) 2.1	Material copper	Coin of the third unknown kin/ Orodes VII gN
31			Reference Ibid	Mint ?	Weight (gr) 2/93	Diameter (cm) 1.9	Material copper	Coin of the third unknown / Orodes VII‹ B
32			Reference Ibid	Mint ?	Weight (gr) 2/653	Diameter (cm) 1.7	Material copper	Coin of the fifth unknown king E L12
33			Reference Ibid	Mint ?	Weight (gr) 2/784	Diameter (cm) 2	Material copper	Coin of the sixth unknown king C
34			Reference Ibid	Mint ?	Weight (gr) 2/528	Diameter (cm) 1.7	Material copper	Coin of the sixth unknown king D
35			Reference Ibid	Mint ?	Weight (gr) 2/806	Diameter (cm) 1.9	Material copper	Coin of the seventh unknown king (G)P

Table 3. Elymais Coins of Different Kings

Coin	Number of Coin	Timeframe of Government	Elymais Kings
1	1	82/81- 72/71 BC	King Kamnaskires IV and Queen Anzaze
2	1	50- 48 BC	Kamnaskires VIII
3	1	44-28 BC	Kamnaskires XI
4-6	3	The late 1st century BC	Kamnaskires XIII
7-9	3	The early first century AD, before 30 AD	Other kings of Kamnaskires dynasty
10 and 11	2	ca. 35- 50 AD	Phraates I
12-16	5	ca. 50- 70 AD	Orodes II
17	1	ca. 70- 85 AD	Phraates II
18-20	3	ca. 100- 110 AD	Kamnaskires- Orodes I
21-23	3	ca. 110- 120 AD	Kamnaskires- Orodes II
24 and 25	2	ca. 140- 150 AD	Orodes V and Olfan
26-27	2	ca. 155- 160 AD	Orodes VII
28-31	4	The second half of 1st century AD	The third unknown king/ Orodes VIII
32	1	The Second half of first century AD	The fifth unknown king (E)
33 and 34	2	The Second half of 1st century AD/ Early 3rd century AD	The sixth unknown king (F)
35	1	The second half of 1st century AD/ Early 3rd century AD	The seventh unknown king (G)

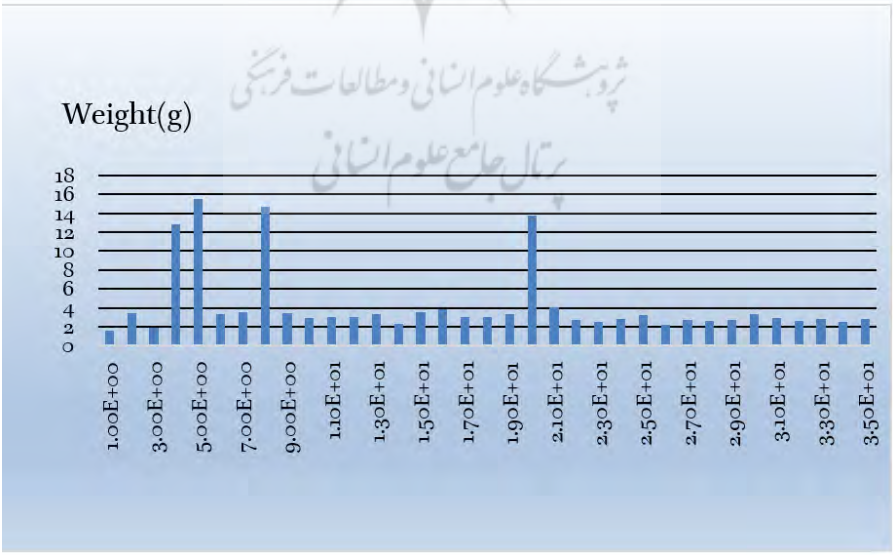


Fig. 1. The Weight of the Analyzed Coins of Elymais

in acetone by authors for 24 hours and then cleaned with distilled water. After drying in the open air, the collection was transferred to the "Van de Graaff" lab of the Atomic Energy Organization of Iran and was analyzed by the PIXE technique.

We performed the spectrum analysis using Gupix software that offered us a parametric method for quantitative analysis and is routinely used to analyze the whole PIXE spectrums. To analyze, we should identify the target Matrix meaning which element has the highest percentage. In this paper, the largest element is silver. Finally, three to five percent error caused by a fundamental parameter of calibration and lack of cleanliness of the coin is expected (Hajvalaiei, 2009). The studied coins are tested by PIXE of the Atomic Energy Organization of Iran. Then, in order to determine the technology of silver extraction from copper and zinc mines, and the differences in its extraction in Seleucid and Parthian kingdoms, the results of the spectrometry were processed by the SPSS statistical method.

Discussion

In this paper, 35 Elymais coins were analyzed by the PIXE technique. Because of a lengthy period of Elymaean government, various kings, lack of precise date, and the sequence of the date of reigning kings, we could not examine all of the coins, but at least tried to analyze samples of different coins to achieve the desired results. 2 silver and 33 copper coins were analyzed (Table 2). After the analysis, it was determined that among 33 coins, seven are of billon (an alloy of a precious metal with majority base metal content) and 26 coins are copper. The oldest analyzed coin in this study is related to Kamnaskires IV and Queen Anzaze (82 / 81- 72/71 BC) while the newest analyzed coin is related to the seventh unknown king of the Elymaean era (ca. late 1st or early 2nd century AD, Table. 3). Four analyzed coins from 35 mentioned samples weighed as much as tetradrachms, but they were not made of silver. Two coins were copper and two coins were billon. The approximate weight of these coins was between 12 and 16 grams. The weight of some silver and some billon coins were less than 2 grams. The weights of other silver and billon coins were 2-4 grams. The weight of the analyzed Elymais coins is shown in Figure 1.

Before experiment, the analyzed coins were classified into two groups of silver and billon, but after the analysis, they were classified into three groups: 1. Silver coins: with more than 50 percent silver content, 2. Billon coins: coins with silver between 3 and 49/9 percent. 3. Copper coins: coins with less than 3 percent silver (Hajvalaiei, personal correspondence). The increase of lead more than 2 percent was to reduce the melting point of copper and it is mostly seen in copper coins. Iron oxide and copper oxide represent that silver coins are counterfeit. Chlorine and calcium compounds represent that coins had long been underground or in the mintage process for preventing sticking of molten material into the mold had been pouring salt on the coins (Table 4) (Khademi Nadooshan & Moosvai, 2006).

The amount of tin (Sn) and zinc (Zn) in silver coins was probably because of the shortage of bronze, brass and, copper (Cu) at the time of re-melting. The copper element causes the hardening of coins. During the extraction of silver, copper remains less than 1 percent. The amount of copper more than 1 percent represents that coins have been minted in various mines. The high percentage of iron (Fe) indicates that the added copper

Table 4. Available Elements Concentration in The Elymais Coins by PIXE Technique

No	Sample	SI	CL	Ca	Ti	Fe	Ni	Cu	Zn	Ag	Sn	Pb	K	p	Al	others	King
1	A	0.24	1.51	0.68	.	0.05	.	4.23	.	91.56	.	1.05	.	.	.	Au:0.59	Kamnaskires IV and Anzaze
2	I	.	1.43	0.65	.	.	0.13	24.47	.	71.92	.	1.4	.	.	.	.	Kamnaskires VII
3	O	5.98	0.65	2.36	0.18	0.76	0.24	47.74	.	41.28	.	2.88	.	.	0.93	.	Kamnaskires XI
4	V	.	0.66	0.53	.	0.13	0.42	71.41	.	22.33	2.89	1.63	.	.	.	.	Kamnaskires XIII
5	T	0.25	0.68	0.29	.	0.06	0.49	81.66	.	11.1	3.47	2	.	.	.	.	Kamnaskires XIII
6	G	0.29	0.66	0.69	.	0.08	0.17	54.66	.	39.74	.	3.71	.	.	.	.	Kamnaskires XIII
7	F	0.68	0.31	0.61	.	0.13	0.46	90.82	0.56	0.93	2.71	2.79	.	.	.	.	late Kamnaskires successors
8	S	0.32	4.67	0.57	.	0.11	0.34	62.6	.	7.97	11.43	11.6	.	0.39	.	.	lateKamnaskires Successors
9	R	.	0.45	.	.	0.05	0.44	81.68	.	.	5.81	11.57	.	.	.	.	lateKamnaskires Successors
10	C 3	3.51	1.44	1.08	.	0.16	0.38	62.69	.	.	1.69	29.05	.	.	.	.	Phraates I
11	I 9	3.23	0.75	0.45	0.07	0.24	0.48	75.71	.	.	1.27	17.8	.	.	.	.	Phraates I
12	F 6	4.15	1.61	1.45	.	0.28	0.37	57.05	0.23	3	.	31.62	0.47	.	.	.	Orodes II
13	E 5	4.29	1.63	1.01	.	0.18	0.36	64.46	0.46	.	6.73	21.09	.	.	.	.	Orodes II
14	B 2	4.16	0.91	2.05	0.05	0.28	0.48	79.31	.	.	.	12.48	0.05	.	.	.	Orodes II
15	M13	4.47	1	0.46	2.91	0.06	0.41	0.43	73.16	.	2.97	14.13	0.46		.	.	Orodes II
16	N 14	6.77	3.14	2.65	0.07	0.56	0.31	54.71	.	.	10.23	21.56	.	.	.	.	Orodes II
17	G 7	5.79	1.01	1.65	.	0.37	0.45	65.75	.	.	1.81	22.73	0.44	.	.	.	Phraates II
18	D 4	5.77	0.98	1.88	.	0.51	0.37	73.88	.	1.3	7.82	7.03	.	.	.	.	Kamnaskires - Orodes I
19	Q	0.65	0.54	0.67	.	0.07	0.39	68.97	0.31	1.63	6.98	19.79	.	.	.	.	Kamnaskires - Orodes I

20	W	0.38	9.54	0.44	.	0.09	0.39	68.34	.	6.45	2.57	10.83		0.36	.	S: 0.63	Kamnaskires - Orodes I
21	P 15	1.51	17.4	0.54	.	0.12	0.17	40.1	.	.	4.46	35.7	.	.	.	.	Kamnaskires - Orodes II
22	H 8	3.65	0.94	0.65	.	0.12	0.36	69.3	.	4.33	5.75	14.9	.	.	.	.	Kamnaskires - Orodes II
23	H	0.42	1.19	0.3	.	0.81	0.33	63.31	.	.	2.72	30.92	.	.	.	.	Kamnaskires - Orodes II
24	L	0.24	0.47	0.26	.	.	0.39	77.27	.	.	3.58	17.79	.	.	.	.	OrodesV&UlPhan
25	K 11	3.21	1.19	1.45	.	0.17	0.31	64.72	.	.	10.16	18.79	.	.	.	.	OrodesV&UlPhan
26	E	0.37	0.73	0.89	.	0.08	0.36	56.99	.	.	5.04	35.54	.	.	.	.	Orodes VII
27	J 10	2.1	6.32	0.51	.	0.25	0.23	38.77	.	.	1.3	50.52	.	.	.	.	Orodes VII
28	J	1.06	0.56	2.07	0.1	0.26	0.68	74.61	.	.	2.41	18.25	.	.	.	.	Third unkhown King (C)
29	A 1	4.66	1.53	0.95	0.08	0.44	0.31	55.97	.	.	.	35.59	0.37	.	.	.	Third unkhown King (C)
30	N	0.48	0.45	0.5	.	.	0.35	52.99	.	.	.	45.23	.	.	.	.	Third unkhown King (C)
31	B	1.54	0.35	1.93	..	0.28	0.46	71.2	1.04	.	.	23.2	.	.	.	.	Third unkhown King (C)
32	L 12	5.53	2.61	1.08	.	0.15	0.32	40.19	.	.	.	49.84	0.28	.	.	.	Fifth unkhown King (E)
33	C	0.38	1.83	0.47	.	.	0.46	77.9	.	.	.	18.96	.	.	.	.	sixth unkhown King (F)
34	D	0.78	0.62	0.52	.	0.13	0.41	70.83	0.5	.	7.61	18.6	.	.	.	.	sixth unkhown King (F)
35	P	0.25	2.76	0.37	.	.	0.33	66.86	.	.	2.77	26.43	0.23	.	.	.	Seventh unkhown King (G)

to silver has not been extracted well and iron is impure. Gold (Au) is an associated element in silver coins, but the lack of gold element in silver coins cannot be indicated that the coin is fake, because in ancient times, mines were used that lacked gold element. The existence of small amounts of lead (Pb) in silver coins represents a great technique of extraction in that period. Gold, silver, copper and, lead are heavy or original metals and titanium (Ti), iron, manganese (Mn) are not part of heavy metals and are seen the slag or impurity on the surface of the coin (Hajvalaiei, 2009). In the classification of coins based on the place of coinage and identification of their mines, the combination containing copper and bismuth (Bi) can be used; especially when archaeological features are ambiguous. Based on the elements of gold and iridium (Ir) can be identified as mines of coinage (Meyers, et al. 1973) (Figures 2-7).

Table 5 examines the amount of elements in these coins and the results are listed in terms of percentage. As shown, the elements of copper and lead are used in full (100 percent) in all 35 analyzed coins in this table, and in contrast, metals such as silver are used in 13 coins (37.1 percent). The amount of lead and silver in the coins is noteworthy. In this way, these two metals have been used in 100 percent in the coins analyzed.

In Table 6, the high percentage of these elements in the sections of mean and median is seen correctly, and in the standard deviation section, which examines the available fluctuations in the use of these elements, the most fluctuated use of copper (20.10027), zinc (36.29327), silver (29.59663) and lead (13.64781) is seen. This indicates the amount of differences in the use of these elements in the different periods of Elymaean rule. But in the case of other elements, which are not the main ones, their fluctuations are very small.

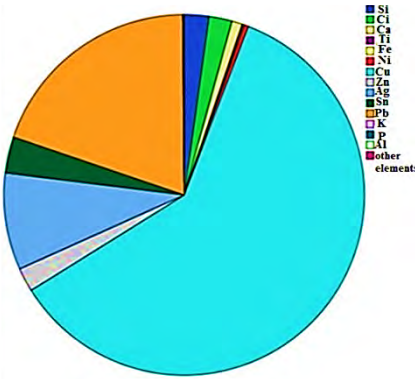


Fig. 2. The Percentage of Used Elements in the Analyzed Coins

As seen in Table 6 and Figure 8, the ratio of mean and the distribution of these two elements in the analyzed coins is very high, which indicates the economic weakness of the period. Another indicator that is very important in the study of coinage technology and therefore the economic status of the study is the ratio of silver to lead, the lower ratio indicates the use of the better technology to separate lead from the silver mine. As seen in Table 6, in the standard deviation section, as well as in Figure 8, this distribution is very large and indicates the weakness of lead extraction technology from silver mines. This distribution and inequality have been the reasons of high fluctuations during the reign of Elymaean kings, which had a profound effect on coins of that period.

Conclusion

The analyzed coins of Elymais can be studied in three time frames. The first is related to the Kamnaskires dynasty i.e., coins from 80 BC to 25 AD. The analyzed coins of Elymaean are made of silver (2), copper (26), and billon (7). An analysis of the percentage of available elements is to understand the economic situation,

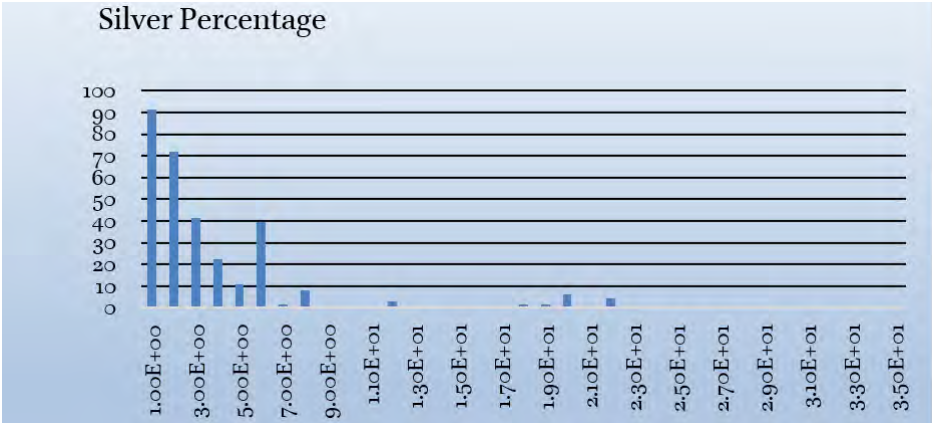


Fig. 3. Silver Percentage in the Analyzed Coins

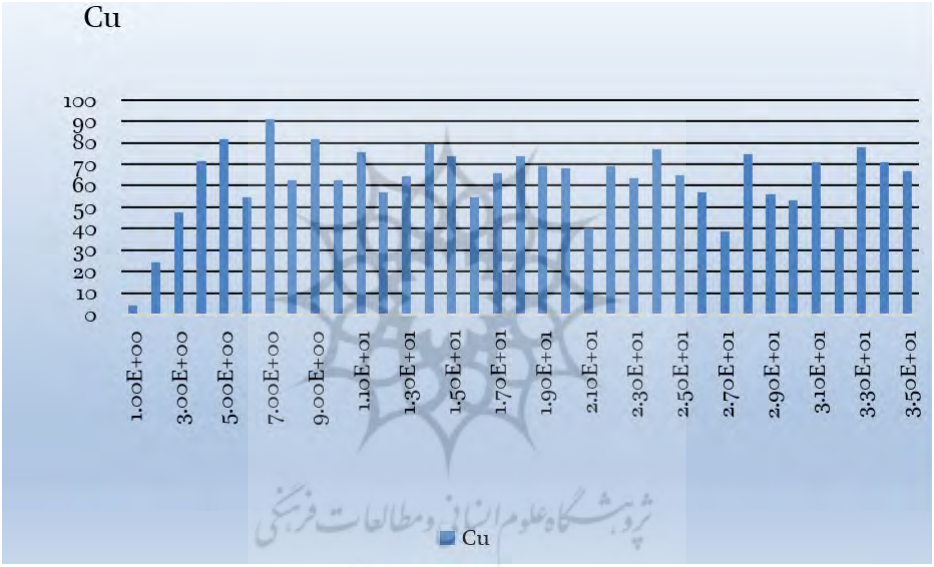


Fig. 4. Copper Percentage of the Analyzed Coins

the number of mints and mines. The percentage of silver during first kings is high, but there was no silver during the second and third periods or it was very rare (Figure 3). This subject can be an indicator of better economic situation during the first kings of Elymais toward the second and third periods. Two of 35 analyzed coins are silver (Coins 1 and 2), belonging to Kamnaskires IV, in which silver percentage is high. Although one or two coins are not enough for analysis, it can be said that increasing the percentage of silver and coins impurity indicate that the economic situation of the reign of this king was suitable and reducing the amount of silver and increasing of impurity in the reign of Kamnaskires VIII indicate the worsening economic situation. In addition to the copper, the silver percentage in coins of Kamnaskires XI and Kamnaskires XIII are high. Billon coins have had more value than copper or because of the precipitance in coinage and metallurgy they are not of good quality. Also, there was a small per-

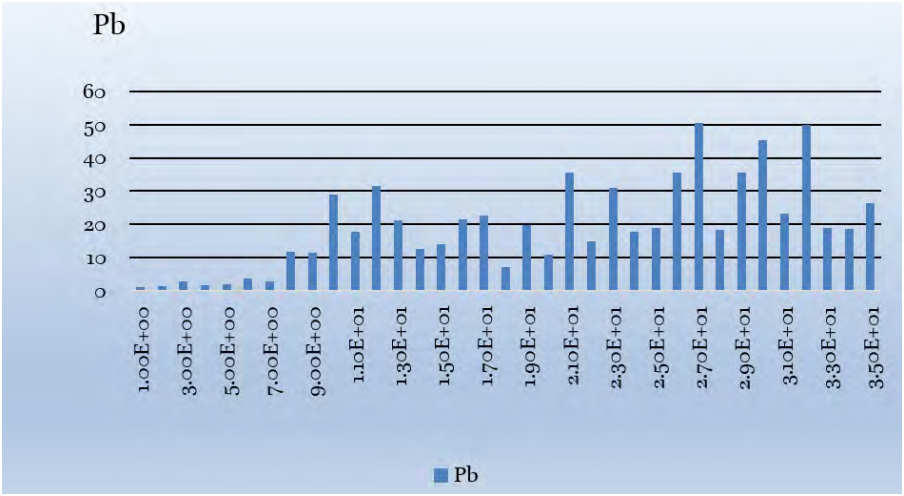


Fig. 5. Lead Percentage of Analyzed Coins

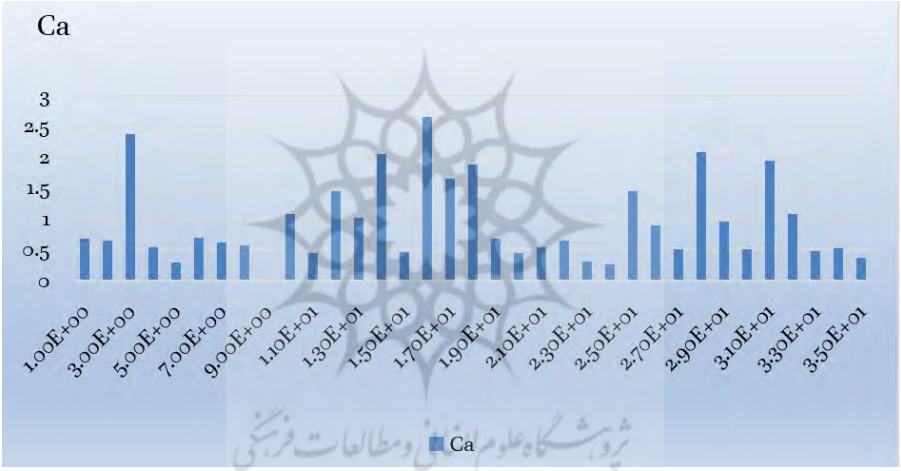


Fig. 6. Calcium Percentage in Analyzed Coins

centage of silver in copper coins during other kings of the Kamnaskires dynasty. About the subject of whether or not this style of coinage was used during the first kings of Elymais, we cannot say certainly, but in copper coins, we can see this style. During Kamnaskires- Orodes I and Kamnaskires- Orodes II, we can see the percentage of silver in copper coins again. Since the percentage of copper to lead in these coins are different, this can be confirmed by different mints and may be proposed the popularity of this style of coinage (Billon) for Elymaean. After the reign of the first kings of Elymais, this style cannot be seen during Parthian successors. In the time of Kamnaskires I who linked Susa and Elymais perfectly together, billon is seen once again. It can be said that this style of coinage was a native and local for mountain dwellers of Elymais. So that Elymaean in the plains of Khuzestan had diffused this style. This ethnic duality in the history of the area and even pre-history can be studied. Of course, we need the analysis of more Elymais coins to confirm or reject this hypothesis. Also, the subject of superficial

Table 5. Comparison of the Used Elements in the Coinage Based on Their Percent

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Silicon	32	91.4%	3	8.6%	35	100.0%
Chlorine	35	100.0%	0	0.0%	35	100.0%
Titanium	7	20.0%	28	80.0%	35	100.0%
Iron	20	57.1%	15	42.9%	35	100.0%
Calcium	34	97.1%	1	2.9%	35	100.0%
Nickel	34	97.1%	1	2.9%	35	100.0%
Copper	35	100.0%	0	0.0%	35	100.0%
Zink	4	11.4%	31	88.6%	35	100.0%
Silver	13	37.1%	22	62.9%	35	100.0%
Tin	24	68.6%	11	31.4%	35	100.0%
Lead	35	100.0%	0	0.0%	35	100.0%
Potassium	7	20.0%	28	80.0%	35	100.0%
Phosphorus	2	5.7%	33	94.3%	35	100.0%
Aluminum	1	2.9%	34	97.1%	35	100.0%
Other elements	2	5.7%	33	94.3%	35	100.0%

Table 6. The Percentage of Elements in the Analyzed Coins

		Si	Cl	Ca	Ti	Fe	Ni	Cu	Zn	Ag	Sn	Pb	K	P	Al	Othrt elements
N	*Valid*	32	35	34	7	20	34	35	4	13	24	35	7	2	1	2
	Missing	3	0	1	28	15	1	0	31	22	11	0	28	33	34	33
Mean		2.4097	2.0720	.9606	.4943	.2145	.3691	60.3309	18.7225	23.3492	4.7575	19.6286	.3286	.375	.9300	.6100
Median		1.5250	1.0000	.6600	.0800	.1300	.3700	64.7200	7.500	7.970	3.5250	18.6000	.3700	.3750	.9300	.6100
Std. Deviation		2.17853	3.24988	.66128	1.06607	.19632	.10581	20.10027	36.29327	29.59663	2.99852	13.64781	.15334	.02121		.02828

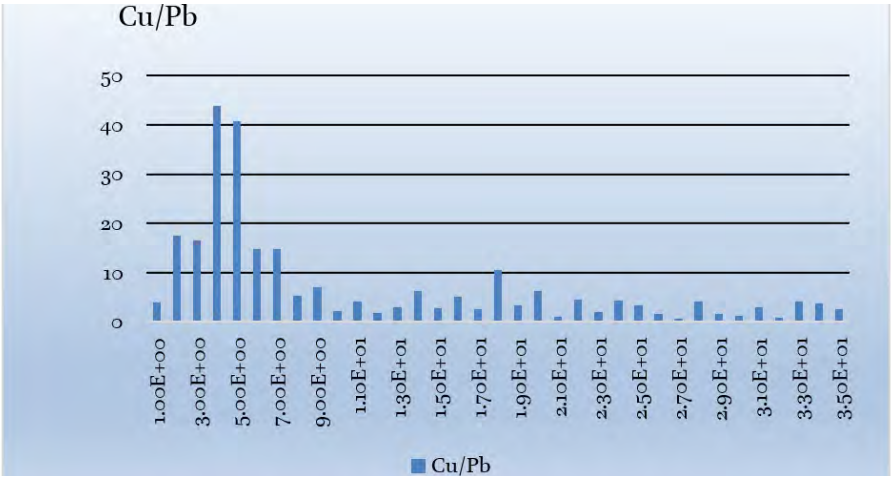


Fig. 7. The Amount of Copper to Lead in Coins

difference between this type and copper coins requires an independent investigation.

The copper percentage in coins of the first Elymais kings is more than those in second and third periods, and the amount of copper in the second period coins has more stability (Figure 4). The percentage of copper increased in the coins of KamnaskiresVII. Also, the percentage of copper increased in the billon coins of Kamnaskires XI, Kamnaskires XIII and, other kings. The amount of copper in coins of the first period is more than 80 percent and the percentage of impurity and lead is rare. In the second period of Elymais, the percentage of copper is between 50 and 80 percent. The amount of copper in the third period of Elymais has been between 35 and 80 percent. Thus, the percentage of copper in coins had a decreasing trend, that may have indicated the economic changes in these three periods (more purity of copper coins indicates stronger economy).

The low lead percentage indicates good metallurgy. Low melting temperature and resistance to the corrosion are good properties of this metal for coinage. In silver and billon coins of the first Elymais period, the percentage of lead is low, however, at the end of this period, the lead percentage increased. In the second Elymais period, lead content has been between 10 and 30 percent, while in the third period, it is between 10 and 50 percent. This increase indicates changes because of the diminution of available copper mines or the need for rapid coinage and or re-melting of coins (Figure 4). Of the analyzed coins, we cannot speak about the exact location of their coinage, since signs of mints are uncertain. Based on the numismatic analysis and concerning the copper percentage to lead in coins, it can be said that the analyzed coins were minted at six places.

The percentage of copper to lead in the coins of the first period kings is more than the second and the third periods. The amount of copper to lead has been 10-45 percent, 1-10 percent, and 1-5 percent in the three periods, respectively. The study shows that some coins were produced at one mint which are categorized as follows: coins 7, 6, 3, and 2; coins 34, 33, 31, 28, 25, 24, 22, 19, 16, 13, 11, 8, and 1; coins 20, 14, and 9; coins 35, 31 , 33, 30, 29, 26, 25, 23, 21, 19, 17, 15, 13, 12, and 10; coins 32, 30, 29, 27, 26, 21, and 12; coins 5 and 4. Some of the coins of Elymais kings minted at one place include: Coins

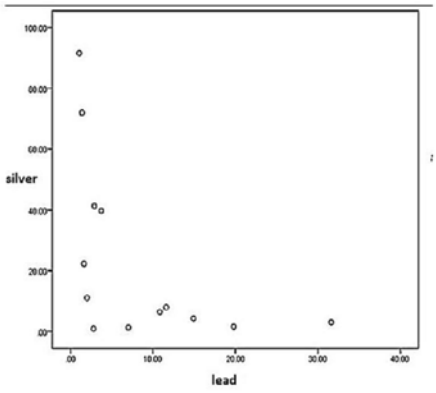


Fig. 8. The Amount of Silver to Copper in the Analyzed Coins

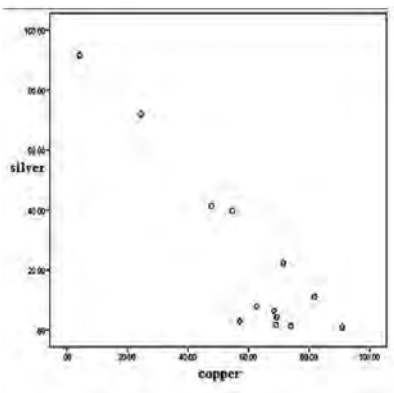


Fig. 9. The Amount of Silver to Lead in the Analyzed Coins

Table 5. The Hypothetical Location of 35 Analyzed Coins that Were Probably Multiplied in a Mint

A Mint	B Mint	C Mint	D Mint	Mint E	Mint F
Coins No.	Coins No.	Coins No.	Coins No.	Coins No.	Coins No.
2 ,3 ,6 ,7	33, 31, 28, 25, 24, 22, 19, 16, 13, 11, 8, 1	20, 14, 9	30, 31, 33, 29, 26. 25, 23, 21, 19, 17, 15, 13, 12, 10	32, 30, 29, 27,26, 21, 12	5, 4

8 and 11 belonging to the other lineage of Kamnaskires; Coins 13 and 16 related to Orodes II; Coins 24 and 25 attributed to Orodes V and Olfan; Coins 12, 13 and 15 related to Orodes II; Coins 21 and 23 related to Kamnaskires–Orodes II; Coins 20, 30, and 31 belonging to the third unknown king and the coins 33, 31, and 28 are related to the same king that this may be confirmed the coinage of this king in two mints (Table 7).

Given the percentage of calcium (Figure 6) in the coins of first period kings, they can be divided into two groups, the coins of the second period kings into three and the coins of the third period kings into two groups. Totally, based on the percentage of calcium, 35 coins can be divided into three categories: between 0 and 1 percent, between 1 and 2 percent, and between 2 and 3 percent. As such, it can be stated that Elymaean have used three different mines to extract ore for these coins. Unfortunately, we cannot talk now about their name and place. To determine the mines, samples need to be analyzed separately to identify them. Based on the elemental analysis, it can be concluded that during the first period kings of Elymais (Kamnaskires and his successors) toward the kings of the second period (in the Parthian era) and the third period of Elymais (last kings), coinage had more important and the coin impurity was lesser. This subject implies that the political and economic conditions of the first period kings of Elymais have been better than the later periods.

Acknowledgment

We would like to thank authorities of Van de Graaff laboratory of the Atomic Energy Organization of Iran (AEOI), especially Mohammad Lamei Rashti and Parvin Ovliyaei for their help in analyzing coins in the course of our study. Also, we are indebted to Mohammad Saffar for providing his valuable personal collection of coins for this research.

Bibliography

Alizadeh, A., (1985). "Elymaean occupation of lower Khuzestan during the Seleucid and Parthian periods, A Proposal". *Iranica Antiqua* 20: Pp. 175-187.

Caley, E. R., (1950). "Notes on the chemical composition of Parthian coins with special reference to the drachms of Orodes I". *Ohio Journal of Science* 50: Pp. 107-120.

Grant, J., S.Gorin & N. Fleming, (2002). *The Archaeology Course Book an Introduction to Study Skills, Topics and Methods*, London: Routledge

Guerra M. F., M. Radtke, I. Reiche, H. Riesemeier & E. Strub, (2008). "Analysis of trace elements in gold alloys by SR-XRF at high energy at the BAM Line. *Nuclear Instruments and Methods in Physics Research Section B Beam Interactions with Materials and Atoms 266* (10): Pp. 2334–2338.

Hajivaliei, M., (2009). "Analyzing and studying 30 silver coins of Hamedan museum; using PIXE technique". *Iranian Studies* 16, (in Persian).

Hajivaliei, M., M. L., D. K. Garg Handa, K. L. Govil, T. Kakavand., V. Vijayan, K. P. Singh & I. M.Govil, (1999). "PIXE analysis of ancient Indian coins, nuclear instruments and methods". *Nuclear Instruments and Methods in Physics Research Section B Beam Interactions with Materials and Atoms 150* (1-4): Pp. 645-650.

Hajivaliei, M., Y. Mohahmmadfar, K. Ghiyasi, B. Jaleh, M. Lamehi-Rashti & P. Oliaiy, (2008). Application of PIXE to study ancient Iranian silver coins: Pp. 1578–1582.

Hojabri Nobari, A., N., Moradi, F. Khademi Nadooshan, M. Moosavi, (2014). "Elymais rock reliefs of Hung- e Azhdar II and its comparison with other Elymais rock reliefs". *Baghe Nazar Journal*, Vol. 25, Pp: 58-69.

Hughes, M. J & J. L. Hall, (1979). "Roman and Sasanian silver plate". *Archaeological Science* 6 (4). X-ray fluorescence analysis of late: Pp. 321–344.

Khademi Nadooshan, F. & S. Moosavi, (2006). "Spectroscopic study of Phraates IV silver coins to identify Parthian coins issuance Standard". *Bulletin of Parthian and Mixed Oriental Studies*:Pp. 18-26.

Meyers, P., L. van Zelst & E. V. Sayre, (1973). *Interpretation of Neutron Activation Analysis Data of Ancient Silver*, Upton, N.Y. (USA): Brookhaven National Lab.

Moradi, N., (2012). 'Archaeological analysis of Elymaean art'. PhD. Thesis, Tarbiat Modares University, Tehran.

Pakzadian, H., (2007). *Coins of Elymais*. Tehran (in Persian).

Sarfaraz, A. A. & F. Avarzmani, (2006). *Iranian Coins from the Beginning to the Zand era*, Tehran: Samt, (in Persian).

Sodaei, B. (2010). "The archaeological analysis of historical and economic developments of Parthian based on the coins during 247-50 BC", PhD. Thesis, Tarbiat Modarres University, Tehran, (in Persian).

Tripathy, B., Tapash, B., Rautray, R., Rautray, A. C., Vijayan, V., (2010). "Elemental analysis of silver coins by PIXE Technique", *Applied Radiation and, Isotopes*, Vol. 68, No. 3, Pp. 454-458.

Vanden Berghe, L. & Shippman, K., (1985). *Les Reliefs rupestres d'Elymaïde (Iran) de l'opoque Parthe*. Gent: Iranica Antiqua.

Vijayan, V., (2005). *Analysis of Metallic Compositions of Kushan Copper Coins of Orissa State Museum*. Institute of Physics. Bhubaneswar, India-751 005.

Yarshater, E., (1989). *The History of Iran from the Seleucid Empire until the Fall of the Sasanid State*, Tehran: Amir Kabir, (in Persian).