An Analytical Study on 12 Coins from Elymais Era Recovered at Tang-e Sulak Kohgiluyeh and Boyer-Ahmad Province, Southwestern Iran, through Particle Induced X-Ray Spectroscopy (PIXE)

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Abstract: Elymais is known as a semi-autonomous state which ruled during the Parthian period. They can be considered as a successor to the Elamite power throughout the history of Persia. Located in the southwest of Iran, Tang-e Sulak is one of the important regions where numerous Elymaisian artifacts have been discovered. In this research 12 copper coins recovered at Tang-e Sulak are examined. According to previous studies on these coins, there are evident signs of economic and political chaos from the Elymais Era. Moreover, the proportion of elements in these coins obtained from spectroscopy can argue there are at least two different mines involved. Meanwhile, this study discussed the technology by which copper was isolated from its ore over the Elymais Era. In that light, a good insight can be gained about the great importance of Particle Induced X-Ray Spectroscopy (PIXE) in archaeological studies and relevant analyses in the Elymais Era.

Keywords: Elymais, Tang-e Sulak, PIXE spectroscopy, metal mines**.**

Introduction

Given the insufficient data about the regions where Elymais people inhabited, it is crucial to investigate Elymais coins. The Elymais ruled as a semi-autonomous or autonomous state over the Parthian period. The history of Elymais can be traced back to 160 B.C. to 224 A.C. (Hosseini Sarbisheh 2015: 3). One of the challenging obstacles to studying Elymais is the unknown region and boundaries for land in which Elymais settled. Apparently, Niarkus, Admiral of Alexander the Macedonian, first mentioned Elymais as nomads settling across Zagros Mountains, known as one of the four bandit tribes alongside Mards, Oxins and Cosseens, who had borders shared with both Persis and Susa. The Elymais were non-Semitic mountain-dwelling people who made a living through war, banditry and extortion (Briant 2002; Boyce 1996: 51). Wiessbach believed that the Elymais land covered Babylon and Persis, i.e. Susiana (Weissbach 1905: 24-58). In fact, the Elymais referred to a part of ancient Ilam located between Bakhtiari

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or eastern part of Susa (Sarfaraz and Avarzamani, 2000: 58). Kahrstedt divided into four parts the Elymais land extending from the third century B.C to the second century A.D. (Kahrstedt 1950: 39). The first part covered the second century A.D., when the Elymais people were bandits, not yet ruling over Persis and Susa. The second part stretches from the second century B.C. to first century A.D., when the Elymais established a state near two rivers called Karkheh and Karun. In the third part setting out with the birth of Christ, Kahrstedt introduced Karkheh as the border between Susiana and Elymais. The coins reveal a fourth part from the second century B.C. onwards as Susa was destroyed by the Elymais (Mohammadifar *et al*. 2012: 242). In ancient sources, Elymais has been regarded as one of the roads to Susa the winter capital of Achaemenid, for passing which the Persis kings sometimes had to tribute the mountain-dwelling Elymais (*Strabo's Geography*; Olmstead 1966). Elamite sounds like a name deriving from its Hebrew version linked with the Assyrian-Babylonian word *Elamtu*. In Ptolemy's geography, the Elymais tribes lived in fertile lands with three rivers and five cities namely: Orumshir, Solore, Susa, and Gundishapur (Marquart 1901). The similarity of Solore to Tang-e Sulak is interesting and worthy of further investigation.

Alizadeh believed that the surrounding parts of Khuzestan were not merely the territory of Elymais but in fact its political capital. Thus, he deems Tang-e Sulak the capital of Elymais Kingdom rising in the second century B.C. and persisting until the end of Parthian period (Alizadeh 1985).

Artifacts related to the Elymais State in Kohgiluyeh and Boyer Ahmad

Kohgiluyeh and Boyer Ahmad is a province spanning 264.16 square kilometers of southwestern Iran from N 30° 9' to 31° 32' and E 49° 57' to 50° 42' with an altitude of 1880 meters above sea level. This province is surrounded by Chaharmahal and Bakhtiari in the north, Khuzestan in the West, Fars and Bushehr in the South and Fars and Isfahan in the East (Zehbari *et al*. 2014: 54). The Elymais artifacts recovered in Kohgiluyeh and Boyer Ahmad include several reliefs on four separate pieces of rock, depicting twelve scenes and carved subjects as well as eight inscriptions (Rajabi *et al*. 2010). These reliefs are located at Tang-e Sulak, to which the coins in this study are attributed based on what was discussed above. Other findings cautiously attributed to the Elymais Era in the province include burial artifacts found in villages of Puleh and Khorramrah. There are a total of six burial artifacts recovered to date (Zehbari *et al*. 2014: 54). Tang-e Sulak is situated along the southern slopes of Zagros mountain ranges stretching from northeast to southeast splitting the flat and low plain of Khuzestan from rugged plateau of Iran. There are multiple prolific valleys parallel to each other, one of which is known as Tang-e Sulak lying within highlands of Hatam in southwest of Iran. As a geological outcrop, Tang-e Sulak is limited by Hatam and Maghar in the north and east, Kat and Likak plains in the south and Maghar Valley in the west. This valley is 12 kilometers northwest of Likak, central city of Bahmaei, and southwest of Kohgiluyeh and Boyer-Ahmad.

Research Background

The first elemental analysis on Parthian coins can be traced back to Caley's studies (Caley 1955). Similarly, Khademi carried out numerous spectroscopy investigations on Parthian coins, obtaining certain findings on metal mines attributed to the coins (Khademi Nadooshan *et al*. 2005). In recent years, coins have been widely explored through PIXE method, including a study by Sodaei on 20 Parthian coins, by which she delved into the historical developments of Elymais Era (Sodaei 2010). In another paper, 30 Sassanid coins from Hamedan Museum were studied to gain a better insight on the political history in a certain part of the Sassanid Era (Hajvaliei *et al*. 2009: 147). Another instance is the elemental analysis of Achaemenid and Parthian silver coins through PIXE conducted by Oliaiy and her colleagues, who finally based on the coin grades pointed out certain facts concerning the political and economic issues in those eras (Oliaiy *et al*. 2015: 51). In this regard, a recent study on the economic and political situation in part of the Parthian period was conducted on a number of silver coins through PIXE (Khademi Nadooshan *et al*. 2015).

Materials and Methods

PIXE involves a nondestructive, elemental, accurate and powerful analysis applied in various fields including archeology (Khademi Nadooshan *et al*. 2015: 58). In this procedure, proton beams collide with coins at an angle of 90 degrees, leading to the ionization of atoms in the coins and emission of X-ray emission characteristic of a given element (Hajvaliei *et al*. 2009: 144). For this purpose, the coins are first cleansed with alcohol and acetone. Then, they are kept in a testing chamber. Using a two mechanical and diffusion pumps, the vacuum in the chamber is raised to 20×10-5 Torr. The elemental concentrations of samples are measured through proton beams with energy of 2 MeV and current of about 2-3 nA. The required proton beams were generated by 3-MV Van de Graaff accelerator at the Institute of Physics and Accelerators (Oliaiy *et al*. 2015: 43). The spectrum analysis was performed through GUPIX, which is an application software used everywhere for quantitative analysis of PIXE spectrum. PIXE is regarded a relatively quick technique to test data (Linke and Schreiner 2004: 173). In addition to determining the chemical composition and production methods, PIXE can be employed to figure out the origins of ancient metals

Fig. 1: Elymais coins under study

Sample number	weight/ gram	diameter/centimeter
291	3.44	1.4
292	3.42	1.3-1.5
293	3.13	1.3-1.4
294	3.68	1.4
295	3.27	1.3-1.5
296	3.56	1.3-1.5
297	3.55	1.5
298	3.65	1.5
299	3.30	1.5-1.4
300	3.66	1.5
301	4.33	1.5
302	3.79	1.5-1.6

Table. 1: Diameter and weight of coins under study

(Khademi Nadooshan and Khazaie 2011). At the end, SPSS can be used to statistically analyze the coins.

Artifacts under study

This study involved 12 coins from Elymais Era (Figure 1). The diameter and weight of coins have been displayed in Table (1). It is extremely difficult and even in some cases impossible to precisely pinpoint the kings minting the Elymais coins due to lack of inscriptions in most of the specimens and excessive erosion in their design. Given the style of patterns and inscriptions visible on a few of the coins, these specimens can be attributed to the Elymais days. The prominent patterns engraved on these coins depict an anchor, star and crescent. Additionally, the back of a few coins have been engraved in Aramaic letters with the names of two kings ruling at Tang-e Sulak called Second Orod and Kamenaskir. Given such evidence, the coins recovered from smugglers at Tang-e Sulak, most of which kept at Yasouj Museum, can be attributed to the Elymais Era.

Discussion

As can be seen in Table (2), the constituent elements of Elymais coins at Tang-e Sulak include Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ag, Sn and Pb. which represent the elements chlorine, potassium, tin, silver, zinc, copper, nickel, cobalt, iron, manganese, chromium, vanadium, titanium, calcium and lead, respectively. Figure

Sample	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ag	Sn	Pb
291	0.85	0.22	0.81	-	0.01	-	-	0.25	0.02	0.05	75.47	-	0.48	7.3	14.54
292	1.76	0.81	4.06	0.13	0.02	0.01	0.02	2.61	0.05	0.11	50.96	0.32	4.13	5.9	29.11
293	1.21	0.68	2.06	0.14	0.02	-	-	0.76	0.02	0.06	56.99	-	0.79	7.19	30.08
294	1.55	0.42	2.41	0.07	0.02	-	0.01	0.41	-	0.03	32.31	-	-	3.36	59.41
295	1.19	0.6	2.49	0.14	-	-	-	1.08	0.03	0.06	70.2	-	1.21	4.09	18.91
296	1.74	0.69	1.74	0.09	0.05	-	-	0.86	0.03	0.07	67.13	-	1.06	19.25	7.29
297	1.32	0.46	1.82	0.06	-	-	-	0.49	-	0.04	74.5	-	1.76	7.7	11.85
298	1.42	0.51	1.63	0.05	-	-	-	0.49	-	0.06	74.64	-	2.95	7.99	10.26
299	1.72	0.75	4.17	0.14	0.04	-	0.02	1.02	-	0.04	62.26	-	4.32	13.45	12.07
300	1.08	0.56	2.27	0.1	-	0.01	-	0.6	0.02	0.15	71.76	0.43	5.24	10.84	6.94
301	1.29	0.35	4.34	0.06	-	-	-	0.54	0.05	0.05	70.68	-	-	9.35	13.29
302	2.1	1.1	10.68	0.13	0.01	-	0.02	1.06	0.02	0.05	52.72	0.16	0.51	1.84	29.6

Table. 2: Percentages of constituent elements in the Elymais coins.

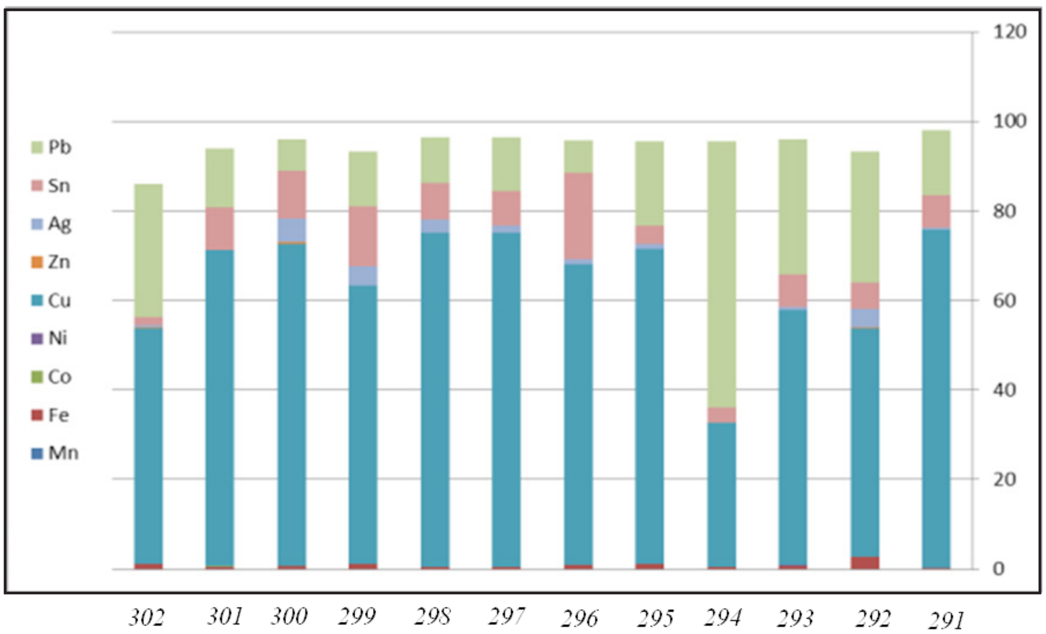

Fig. 2: Comparison of elements in coins under study.

(2) illustrates an example of PIXE spectroscopy graph on the coins, where high levels of copper, lead and silver are visible for Sample 299. Figure (3) displays the frequency of each element in the coins. According to this graph, copper is the most abundant element, while lead is the most abundant element only in Sample 294, to the extent it can no longer be called a copper coin

Comparison of nickel (Ni) versus copper (Cu) in Figure (4): Nickel is a metal available to some extent in the copper ore, proportion of which to copper can potentially reveal the mine where the copper coins originate from. According to Figure (4), it can be argued that the coins were minted by metals from at least 2 different mines. In fact, Samples 292 and 300 belong to a mine different from those of other coins. It should also be noted that in the process of extraction from lead mines, calcium cannot be recovered. That is why it has always been accompanied by lead, proving useful for detecting various lead mines where coins originate from. In Figure 5, the calcium to lead ratios were calculated in 12 samples. The graph indicates there are at least 2 different lead mines from which the Elymais coins were minted. It should be noted, however, Sample 296 is far remote from the other two categories. Hence, it was excluded as an outlier at this stage. Nonetheless, investigations into a greater number of Elymais coins would reveal more lead mines for minting the coins, under which Sample 296 could fall.

The next source of data concerning the process of and technology of isolating iron (Fe) from copper ore (Cu) can be the comparison of Fe/Cu ratio. In fact, higher Fe/Cu

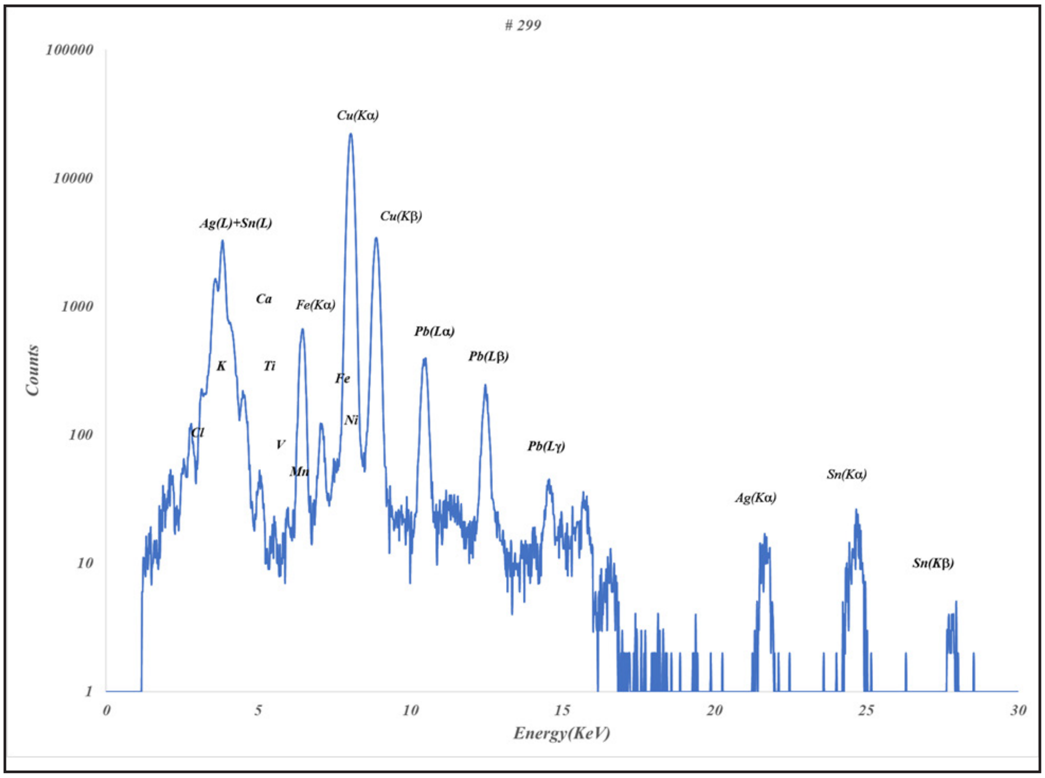

Fig. 3: PIXE spectroscopy performed on Sample 299 and significant percentage of silver in that coin.

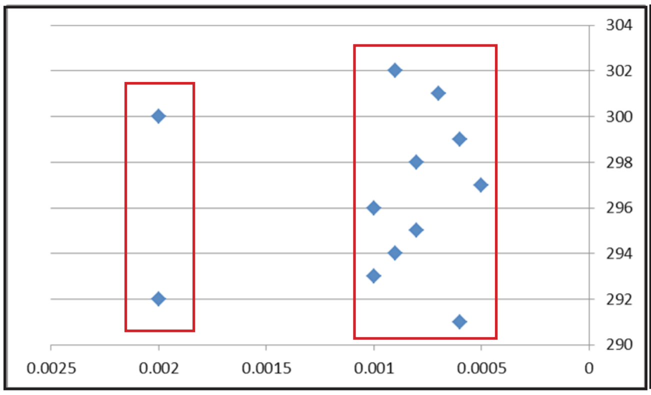

Fig. 4: Comparison of Ni/Cu ratio

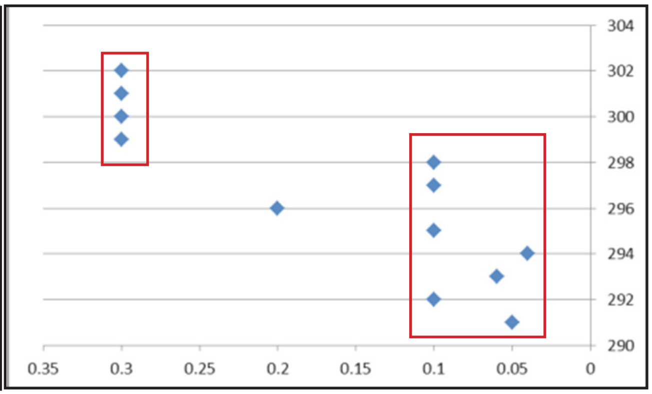

Fig. 5: Comparison of Ca/Pb ratio

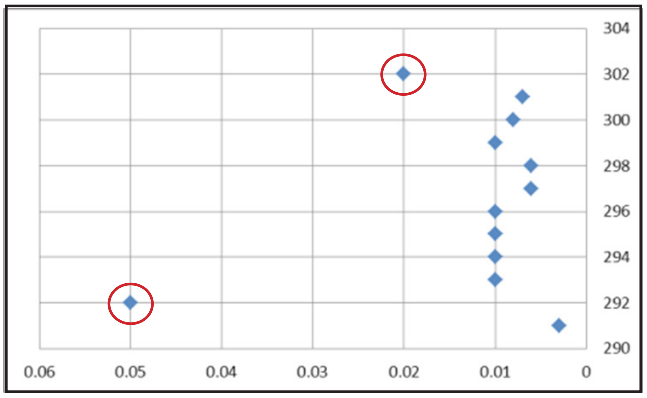

Fig. 6: Comparison of Fe/cu ratio

rates indicate poorer technology of isolating iron (Fe) from copper ore (Cu). According to Figure (6), Samples 302 and 292 indicate higher values than other coins, which implies the adoption of poorer technologies for isolation of metals in the two coins. Moreover, Samples 302 and 292 with 14 and 15 elements contained the highest concentrations of elements among all coins. This was again a telltale of poorer technologies for isolation of elements from copper ore in those coins.

The differential concentration of these elements in the coins can be detected by calculating the standard deviation of copper and its numeric value. This in turn can determine the extent to which the Elymais state monitored the minting of copper coins. In other words, the lower the mean standard deviation of copper in coins, the closer the percentages of copper in coins, the more meticulous monitoring of the state on minting and inclusion of copper in the coin composition can be inferred. As for the coins under study, the standard deviation was calculated to be 12.98. This is a huge number representing a wide gap in the numerical concentration of copper applied in the coins. This in turn could imply a not-so-powerful and accurate monitoring of the Elymais state over the minting of copper coins.

Conclusions

Given the above mentioned facts, Tang-e Sulak is evidently one of the most important sites where valuable data from the Elymais Era have been obtained. This Elymais region can be the same as the ancient Solore mentioned in historical sources. This argument can be raised with regard to the similarity between the names of Sulak and Solore as well as abundant evidence from the Elymais Era across the region. This era can be investigated based on the coins recovered. According to a study on 12 Elymais coins found at Tang-e Sulak through spectroscopy, the elemental compositions in each coin were revealed. Given the study conducted on the relative percentages of elements, it can be argued there are at least two different copper and lead mines from which the coins were minted. At the same time, the technology of isolating copper from its ore was discussed. Finally, it should be stated that the isolation technology was not identical in the coins, but varied under different circumstances. This could be associated with the place where the coins were minted during that era. It can also be reported that the Elymais state exercised inadequate monitoring over the minting of these coins. This could be due to political and economic turmoil during the Elymais Era, where the semi-autonomous state during the Parthian period was in a conflict with the central state.

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