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POSSIBLE SOURCES FOR EXTRACTION OF SILVER BY COMPARISON OF PARTHIAN AND SASANIAN COINS IN MEDE SATRAPS

B. Sodaei[a*], M. Hajivaliei[b] and F. Khademi Nadooshan[c]

[a] Department of archaeology, Islamic Azad University,Varamin, Pishva Branch; I.R.Iran
[b] Department of Physics, Bu-Ali Sina University, Hamedan, I.R.Iran
[c] Department of archaeology, TarbiatModares University, Tehran, I.R.Iran,

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Corresponding author: B. Sodaei (bitasodaei@yahoo.com)

ABSTRACT

Chemical composition made by PIXE and XRF of silver coins which have been minted in the Ecbatana mint houses in the Parthian period (247 BC- 224 AD) implies silver sources, which has been extracted for issuing coins. Also, it gives information about the economic and political conditions of the era under study. Fifteen Perthian and twenty two Sasanian (459 - 651 A.D.) silver coins were analyzed. The silver metal, which has been used in this Satrap, has been explored when commercial activity and population gone high, more silver has been extracted and access to the new sources was necessary by the Parthian. Here, we analytically show the number of mines for extraction of silver in this satrap and possible number of silver ore sources.

KEYWORDS: Parthian, Sasanian, Medes, coins, silver, PIXE, XRF

INTRODUCTION

Coins represent important objects of our cultural heritage and are usually of high artistic and cultural value. In relation to the iconography, the archaeological issue concerns question of dating, provenance, technology of production or authenticity. Techniques of investigation used here include energy dispersive X-ray fluorescence analysis (EDXRF) that can be applied non-destructively i.e. without sampling (Liritzis & Zacharias, 2011) and Proton induced X rays emission. (PIXE).

PIXE is one of the prevailing methods for finding the chemical composition of ancient metals (Smith, 2005; Guerra, 1995; Torkiha et al.2010; Roumie *et al.*2010; Constantinescu et al., 1999) which provided useful information on several aspects of the time period under study. This information can be used to know about economic conditions and possible sources of metals.

The XRF may give same results up to some extent, but PIXE's results for some elements are more accurate and much better than XRF (Tripathy et al.,. 2010; M.Hajivaliei et al., 2008; Weber et al 2000; Denker et al., 2004)

Moreover, XRF has a poor sensitivity for trace elements and for elements with an atomic number lower than 11(Na). The detection limits of XRF are approximately 0.1 wt. %, depending on the atomic number and the matrix composition. The detection limits of XRF depend very much upon the sample, the considered element and the experimental conditions, and detection range from 0.1 ppm to a few percentages for elements with low atomic numbers.

The sensitivity of PIXE is significantly higher compared to XRF due to the very low bremsstrahlung induced by protons. PIXE offers the maximum sensitivity for elements ranging approximately from Ar to Zr. The variation of the proton beam energy enables the characterization of layered structures at the surface (Linke, 2004). Using these analytical techniques, and being aware of all the drawbacks, we have focused our work on the provenance mines that used in period Parthian and Sasanian in Iran.

GEOGRAPHY OF SITE UNDER STUDY

After the fall of Medes their territory (Map 1) had been reduced and finally until the Achaemnenid had been changed to a satrap. Medes in the Parthian time according to of Isodore, had been divided to Ragha Medes and Upper Medes. As the Isodore has shown Upper Medes has bounded to Armenia in the north and Ragha in the east and in the west to Mesopotamia, in the south to Susa. Isodore did not mention about the governor of these two satraps, but we may conclude that the capital of Medes Ragha was a city of Ecbatana. Naturally, the several silver mines were used by Parthian as a mint house to issue many coins.

MAP 1
Parthian empire

BACKGROUND OF RESEARCH

Caley's work (Caley, 1955) on the chemical compositions of Parthian coins was one of the excellent works, which has been done on the Parthian numismatic. However, he has not referred to anything about silver mines, which had been explored by the Parthian for issuing of silver coins of Orodes II. Other scholars have done spectroscopy on the silver coins and have suggested possible sources of this metal, which may show the politico-economic condition of the era under study.

Sasanian coins were of more interest to the foreign Scholars in particular concerning their impurity (Bacharach, 1972) or because Sasanian was contemporary with the Roman empires, and their data gave more useful information until Parthian. Hajivaliei was among the first Iranian scholars to pioneer the analytical study by PIXE of Sasanian silver coins (Hajivaliei et al., 2008). Among the foreign scholars Hughes (Hughes at al., 1979), not only has worked on the Sasanian silver metals but compared them with the Roman silver metals. The cupellation which is applying for exploration of Galena after oxidation of Pb and Zn, may lead to obtain Ag. But since Au has not been separated from mines, its amount remains the same with coins. The phenomenon has been reported by both Meyers and Gordus (Meyers, 2003; Gordus, 1967). However, gold has been used for the location of mines. Gordus has used Pt group also.

However, the problem is when the Au is reeled by other Ag, of other mines the confusion arises to find the mines of Au which has been explored due to add Au when added in remolding process they shows high percentage of Au and it confuse the recognizing mines of exploration.

In another research Kontos (Kontos, 2000) which has worked on the Alexander silver coins, has showed Bi possibly may be used as the indication for mines. The same method has been applied by Guerra (Guerra, 1995; 1998; 2004; *et al.* 2008) for Au mines and coins. The hypothesis throughout the research is finding the relation between silver metals, which has been used for issuing the coins and source of metal, used for mint house of Ecbatana.

HISTORICAL BACKGROUND

Arsaces I (247-211 B.C) after defeating Androgoros, Governor of Parthia and Hyrcania had established his government till Mithradates I (171-138 BC) who had not played important role in the political history of Iran (Bivar 1983). Mithradates after conquering satrap of Mede, Susa and Seleucia had ruled on the vast territory. Naturally, their metallic issues came to the circulation in international commercial activities in Asia. Mithradates I in his political carrier, after capturing Demetrius by his generals and send them to Hyrcania, had changed the history of Selucian dynasty. Phraates II, (138-127 BC) after Mithradates I, had sat down the Parthian throne (Isodore of Charex, 1914). Antiochus VII, after invading Mede had been defeated by Phraates II (Watson. 1976). after him, Mithradates II (123-138 BC) extended Parthian territory in east and west. After him, other Parthian kings did not extend their power beyond his limit. UntillArdashir I, (138-226 AD) who had defeated last Parthian king and built Sasanian dynasty (Gobl1971) and gave the end to nearly five hundred years of Parthian dynasty. Parthian coins in the central plateau of Iran have been minted according to Attic standard of one drachma (Sellwood 1979) and done in Susa, Seleucia and Mesopotamia in a tetradrachma. They connected Indo - Greeks (250-100 BC) to the Seleucia via commercial trades. After the fall of Greeks in east, their economic activities had been concentrated in Mesopotamia routes. They issued high value of tetradrachma for this zone because of the bulk amount of commercial activities.

SELECTION OF SAMPLES

Thirty seven Parthian and Sasanian silver coins have been selected, which had been found in the archaeological excavations. These have been typologically classified. Their weights show that all of them are Drachma. The Parthian coins belong to Orodes II and Phraates IV which they were two powerful kings. All of them were minted in an Ecbatana mint house which was the capital of Medes satraps. The Sasanian coins are belonging to kings governed between years 459 - 651 A.D. These coins are of the different mint house (Istakhr, Ardeshirk-horeh, Darabgird, Ramhormuz, Bishapur, Ecbatana and Sistan). Nearly all the coins after registration in the museum cabinet have been cleaned. The methods of cleaning of coins are as follows; they were kept in 3% - 5% acid formic solution for few minutes and were scrubbed with tooth brush, and finally cleaned with alcohol cotton.

EXPERIMENTAL SETUP

A 2 MeV proton beam with a current of 2-3 nA from AEOI (Atomic Energy Organization of Iran) Van's de Graff accelerator was used to bombard the coins. They were kept in a multipurpose scattering chamber under high vacuum (10^{-5}Torr). The emitted characteristic X-rays from samples were detected by an ORTEC Si(Li) detector (FWHM 170 eV at 5.9 keV). The GUPIX software was employed to analyze the obtained spectra. The results are shown in Table 1. Major elements are those contributing 10% to overall composition of silver coins, the minor elements 0.1-10% and trace elements less than 0.1%, down to detection limits. Overall uncertainty for the PIXE method was 5% for major elements; 5-10% for minor elements and 15% for trace elements. The uncertainties are not only statistical, but they also originate from the roughness of coin surface and from the chemical corrosion and/or wearing of the objects, altering the accuracy of the results.

The coins of Sasanian after registration in the museum cabinet have been similarly cleaned. Elemental analyses of the selected coins were carried out by non-destructive technique of wavelength dispersive X-ray fluorescence (WDXRF) model Philips PW 2404, with a detection limit of ± 1 ppm.. The tube high voltage was 40 kV with the tube current of 30 mA

Table 1. The percentage of chemical elements present in the Parthian coins by PIXE (a: out of accuracy)

Coin No.	Name King	Mint House	Unit Weight	Weight (gram)	Ti %	Fe %	Cu %	Zn %	Ag %	Au %	Pb %	Au/Ag
1	Orodes II	Ecbatana	Drachma	4.01	0.19±0 [a]	1.4±0.1	25.3±1.3	3.1±0.3	65.2±3.3	2.2±0.2	2.6±0.3	0.034
2	Orodes II	Ecbatana	Drachma	3.35	0.0	0.1±0 [a]	5.0±0.5	0.1±0 [a]	92.1±4.6	2.0±.0.2	0.1±0 [a]	0.022
4	Orodes II	Ecbatana	Drachma	3.93	0.0	0.0	10.1±0.5	0.0	86.7±4.3	1.2±0.1	1.1±0.1	0.014
5	Orodes II	Ecbatana	Drachma	3.99	0.0	0.0	9.9±1.0	0.0	88.1±4.4	1.0±.0.1	1.1±0.1	0.011
6	Orodes II	Ecbatana	Drachma	4.09	0.0	0.0	8.2±0.8	0.0	90.2±4.5	0.8±0.1	0.8±0.1	0.009
7	Orodes II	Ecbatana	Drachma	4.00	0.0	0.0	6.8±0.7	0.0	90.8±4.5	1.0±0.1	1.4±0.1	0.011
8	Orodes II	Ecbatana	Drachma	3.91	0.0	0.0	16.5±0.8	0.0	81.2±4.0	1.1±0.1	1.2±0.1	0.014
9	Orodes II	Ecbatana	Drachma	4.03	0.0	0.0	9.1±0.9	0.0	89.5±4.5	0.7±0.1	0.7±0.1	0.008
10	Orodes II	Ecbatana	Drachma	4.50	0.0	0.0	9.6±1.0	0.0	87.7±4.4	1.1±0.1	1.6±0.2	0.012

Table 1. Continued

11	Phraates IV	Ecbatana	Drachma	3.61	0.12±0[a]	0.9±0.1	19.9±0.9	0.1±0[a]	77.8±3.9	0.6±0.1	0.5±0.1	0.008
12	PhraatesIV	Ecbatana	Drachma	3.92	0.07±0[a]	0.6±0.1	23.7±1.2	0.0	74.2±3.6	0.5±0.1	0.9±0.1	0.007
13	Phraates IV	Ecbatana	Drachma	3.94	0.0	0.1±0[a]	9.6±0.9	0.0	88.9±4.4	0.5±0.1	0.8±0.1	0.006
14	Phraates IV	Ecbatana	Drachma	3.62	0.0	0.4±0[a]	6.1±0.6	0.0	92.1±4.6	0.7±0.1	0.4±0[a]	0.008
15	Phraates IV	Ecbatana	Drachma	3.69	0.0	0.1±0[a]	12.6±0.6	0.0	86.1±4.3	0.5±0.1	0.7±0.1	0.006

Table 2. Percentage of present elements in Sasanian coins by XRF

Coin No.	King name	Regnal year	Mint house	Unit weight	Weight (gram)	Fe	Cu	Ag	Au	Pb	Au/Ag
1	Piruz	459-84	Istakhr	Drachma	4.1	0.0	2.7±0.2	96.1±4.8	0.7±0.1	0.0	0.007
2	Piruz	459-84	Ardeshirkhoreh	Drachma	3.8	2.4±0.2	1.5±0.1	94.1±4.7	1.2±0.1	0.0	0.013
3	Belash	484-8	Ardeshirkhoreh	Drachma	4.1	7.8± 0.7	1.4±0.1	89.1±4.4	0.8±0.1	0.0	0.009
4	Kavad	488-96	Istakhr	Drachma	4.0	0.3±0.0	1.0±0.1	96.3±4.8	0.9±0.1	0.0	0.009
5	Kavad	488-96	Ardeshirkhoreh	Drachma	3.6	0.3± 0.0	3.5±0.3	94.3±4.7	0.9±0.1	0.0	0.009
6	Kavad	488-96	Istakhr	Drachma	4.0	0.0	2.5±0.2	95.1±4.8	0.9±0.1	0.0	0.009
7	Kavad	488-96	Darabgird	Drachma	4.1	0.3±0.0	1.4±0.1	91.6±4.6	0.9±0.1	0.0	0.010
8	Kavad	488-96	Darabgird	Drachma	4.0	1.0±0.1	5.0±0.5	97.2±4.6	0.3±0.0	0.0	0.003
9	Kavad	488-96	Ardeshirkhoreh	Drachma	4.0	0.5±0.0	3.8±0.3	94.7±4.7	1.0±0.1	0.0	0.010
10	Xusro I	531-79	Ramhormuz	Drachma	4.0	0.7±0.1	3.7±0.3	97.4±4.7	0.8±0.1	0.0	0.008

11	Xusro I	531-79	Istakhr	Drachma	3.4	0.0	2.8±0.3	96.3±4.8	0.9±0.1	0.0	0.009
12	Xusro I	531-79	Bishapur	Drachma	3.5	0.0	10.9±1.0	88.3±4.4	0.8±0.1	0.0	0.009
13	Hormuz IV	579-90	Bishapur	Drachma	4.1	1.4±0.1	0.8±0.1	96.2±4.8	0.8±0.1	0.8±0.1	0.008
14	Xusro II	590	Istakhr	Drachma	4.1	0.0	6.3±0.6	92.1±4.6	0.7±0.1	0.8±0.1	0.008
15	Xusro II	590	Ecbatana	Drachma	4.0	0.0	0.9±0.1	98.1±4.9	1.0±0.1	0.0	0.010
16	Xusro II	590	Ardeshirkhore	Drachma	4.1	1.3±0.1	2.3±0.2	95.7±4.8	0.8±0.1	0.0	0.008
17	Xusro II	590	Sistan	Drachma	4.1	0.0	2.0±0.2	97.0±4.8	1.0±0.1	0.0	0.010
18	Xusro II	590	Sistan	Drachma	4.0	0.0	3.3±0.3	95.6±4.8	1.1±0.1	0.0	0.011
19	Kavad II	629	Ecbatana	Drachma	4.1	0.0	2.1±0.2	97.1±4.8	0.7±0.1	0.0	0.007
20	Ardeshir III	628-9	Istakhr	Drachma	4.2	0.2±0.0	1.4±0.1	97.5±4.5	0.9±0.1	0.0	0.009
21	Ardeshir III	628-9	Bishapur	Drachma	4.1	0.0	2.1±0.2	97.0±4.8	0.9±0.1	0.0	0.009
22	Yazdgird III	632-51	Sistan	Drachma	4.0	0.3±0.0	6.4±0.6	91.6±4.6	0.8±0.1	0.9±0.1	0.009

RESULTS AND DISCUSSION

The ratio of Ag with respect to Au shows in the Satrap of Mede several sources of Ag have been used for exploration and issuing the coins. Presence of Cu not only is for hardness of coins but presence of other metals in minor amount like Zn along with Cu, may show exporting of Cu to the Parthian territory had been banded.

The changing of percentage of Cu in the Ag coins of Orodes II shows his reign faced many eco-political problems but analysis of Phraates IV coins of Parthian coins has given less difference among the coins, and it proves that in the era of this king eco- political variation was less, and he had more stable government in compare to Orodes II.

Possibly, about the half of the silver metals are produced today from Lead ores and in the antiquity were more (Hugges et al., 1979). Obtained results, which have been shown in Tables1 and 2, show that only Cerussite (PbCO3) mines have been explored for extraction of silver in Satrap of Medes (Figure 1).

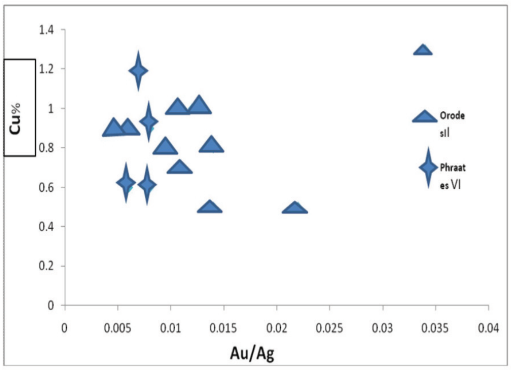

Figure 1. Percentage of Au/Ag Vs. Cu in the silver coins by PIXE

It means all the Parthian silver coins, which had been minted an Ecbatana mint house have been extracted from Cerussite mines. According to Meyers, if the silver were produced from Cerussite, then the gold content varies from approximately 0.2 to 1.5 percent, which is true in our case. Furthermore, it can be said that the concentrations of trace element of Au in the silver coins are same as in the mines which has been extracted. In the spectra which had been obtained from PIXE technique, the Au is as trace element. Meyers (2003) has shown at least one of two traces of Au and Ir possibly related to the sources of silver metals. The total amounts of Au in the silver coins show (Figure 1) that several mines of Cerussite type have been explored for issuing coins. In the case of coin number 1 with more Zn, it seems that either the cupellation process was not used or this coin may be forged one. Naturally, Cu is not dissolved in cupellation process and remains as base metal in the Ag (Hughes at al. 1979). However, its amount more than 1% is used as the hardness and retained standard in silver metals. Standard deviations of Cu in the Parthian silver coins are higher than the Sasanian coins. The same applies for Ag and Au elements, but for Pb element the standard deviation in Sasanian coins is less than Parthian coins, which may imply that the method of extraction of silver from ores were well improved.. Fig.2 gives Silver coins of Sasanian and the concentration of Au/Ag Vs. Cu%

The presence of Ca in the Ag coins (not given in the table) is due to the inability of removing it during the metallurgical process. Furthermore, in case of Fe and Br it can be said that they are due to surface at contaminations. Comparisons between Figure 1 and 2 of Parthian and Sasanian Ag coins, which minted in the Ecbatana mint house of Mede Satrap, show some similarity, but the Medes in Parthian period are wider than in Sasanian period. The correlation among Orodes II silver coins have been studied and observed that there is a strong negative correlation between Ag-Cu which means the more Ag, the less Cu will be. Moreover, negative correlation between Ag and Pb is observed.

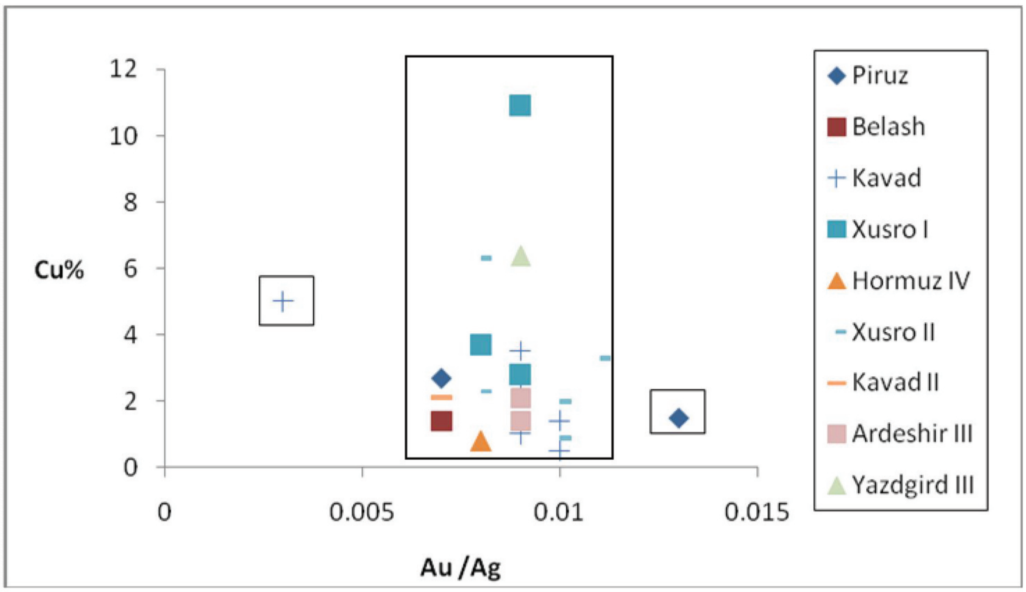

Figure 2. Silver coins of Sasanian and the concentration of Au/Ag Vs. Cu% with WDXRF technique

In Phraates IV silver coins, the same trend for Cu and Ag is seen. Furthermore, negative correlation between Au and Pb is observed. The reliability of the analysis is checked for Cu and Au. The reported and measured results for the copper foil from Merck and Suisse fine gold is given in Table 3. The pictures of some Parthian coins are given in Figure 3.

Table 3. Reported and measured concentration for copper foil and Suisse fine gold

Standard	Cu foil (Merck Art.2700	Au (Suisse fine gold)
Reported (%)	>99.70	99.99
Measured (%)	99.90	99.91

a) Orodes II

b) Phraates IV

Figure 3. Obverse and reverse of Parthian coins (a) Orodes II (b) Phraates IV

CONCLUSION

According to above- mentioned results and historical evidence, we can say that only the cerussite mines were being used by Parthian, as well as, the Sasanian kings, but these mines were different with respect to the observed gold in them. These mines can be classified in three categories in both Parthian and Sasanian periods.

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