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Compositional Study of Sassanian Silver Coins Using PIXE Technique

Case Study: Hormizd IV of Coins

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Abstract: Studying the elemental composition of coins does not only provide chemical information of the legal tender but provides insight into the manufacturing process, history, and economic state of the country during the minting year of the coins. The elemental composition of some Sassaian coins spanning from the years 582 to 591 AD have been analyzed using PIXE at the Bubansor physical lab of India and metallic the elements Ca, Fe, Cu, Ag, Au, and Pb were observed. The result The study of elemental composition of silver coins in Iran under the Sassanian period can help to explain the locations and identification of coins' mines. By determining not only major but also minor and trace element concentrations, the coin's compositions were used to deduce information both on the economic conditions under the different reigns. The aim of this work is to study the chemical composition of some Hormizd IV coins to show the economic situation and find any relation between the mines used for the extraction of silver and the actual silver coins minted at that time. Using the PIXE technique, the show that Hormizd IV king used almost Cerussite mines for their coins and are brought to light valuable information about the economy of the time.

Keywords: *Sassanian, Hormizd IV, Coins, Silver, PIXE, Darabgerd Mint, Iran.*

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Introduction

The Sassanid Empire was the last great pre-Islamic empire of Iran whose rule spread through the length of late antiquity. In this capacity, the Sassanid Empire was also the major foe and political rival of the Roman and Byzantine Empires in the west, as well as that of the Kushans in its early history. Throughout the more than 400 years of Sassanid rule, its King of Kings (the official title of the Sassanid empire) often had to deal with many other external threats who, like the Hephthalites, did not take the shape of traditional enemies such as the Romans. External pressures were, however, only part of the Sasanian problems, as internal challenges in form of religious movements, natural disasters, and military rebellions plagued the Sassanid much like they did the Romans. Despite all these problems, the Sassanid period can be credited as one of the most fundamental periods of Iranian history. It was a period of intensive cultural activity, including the foundation of Iranian historiography, the establishment of a state religion, and indeed the prominence of Persian as the literary language of the realm, all major features of Mediaeval and even modern Iran. It was also the period in which the ancient, partly mythical idea of "Iran" came to be applied to the physical reality of the Sassanid Empire (called in Middle Persian Ērānšahr, "the Realm of Iranians"). Hormizd IV is one of the kings of the Sassanid period. He protected the common people while maintaining severe discipline in his army and court. When the priests demanded a persecution of the Christians, he refused on the grounds that the throne and government could be safe only with the goodwill of both religions. From his father, Hormizd inherited wars against the Byzantine Empire and the Turks. Though negotiations for peace had begun with the Byzantine emperor Maurice, Hormizd declined to cede any of his father's conquests. In 588 his general, Bahrām Chūbīn, defeated the Turks but in 589 was beaten by the Romans. When Hormizd dismissed Bahrām, the general rebelled with his army; an insurrection followed. Hormizd was deposed and killed, and his son was proclaimed king as Khosrow II (Frye, 1967). Since the time of Hormizd IV was facing political problems, by examining coins, we want to examin its economic conditions. Ancient coins are often struck with a well- controlled alloy by a known mint with a date of issue and for most of them references can be found in ancient documents dealing about their typology and metrology (Ben Abdelouahed, 2010).

Analysis of the coins were carried out by Particle Induced X-ray Emission (PIXE), which is a non-destructive technique revealing the chemical composition of ancient metal (Smit, 2005, Denker, 2004, Weber, 2000) and providing highly useful information an ancient coin (Guerra, 1995, Torkih, 2010, Rumie, 2010). PIXE measures elements ranging approximately from Ar to Zr (Constantinescu,1999, Khademi Nadoshan,2011, Hajivalei,2012,) The variation of the beam energy enables the characterization of layered structures on the surface (Linke, 2004). Using PIXE as an analytical, we have focused on metals once used in the Sassanid periods in Iran. Therefore, PIXE is used to determine the elemental compositions of coins, to understand their fineness and to obtain valuable information about the economy (Beck, 2008). In this work, PIXE technique is applied to study Twenty Iran silver coins, sixteen coins belonging to Hormiz IV and four coins have been used for comparison belonging to Khosrow I and Khosrow II

It is advisable to choose non-destructive methods in archaeological materials analyses. Although, various unclear techniques are used for such analyses, the proton- induced X-ray emission (PIXE) method is of special interest for archaeological specimens because the technique is not only non- destructive, sensitive and capable of simultaneous multi- elemental analysis, but also ensures that any size of sample can be quantitatively analyzed without damage (Vijayan, 2005, Guerra, 1995, 1998, Torkih, 2010, Roumie, 2010). Using Proton Induced X-ray Emission (PIXE) technique to study ancient coins is one of the prevailing methods for finding the chemical composition of ancient metals (Smith, 2005, 258-264). Such technique can be applied to make clear unknown aspects of the economy of the time. This information can be used as a means to deduce information on economic conditions and possible sources of metals. PIXE has also been applied non- destructively in order to detect trace elements (Constantinescu, 1999). 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: 127-178). The analysis of ancient coins can show the economy and the prevailing techniques of coins minting of the time (Deyell, 1990). In this work, we analyzed coins struck under the Hormiz IV in Darabgerd order to find out any relation between the mines used for extraction of silver and the actual silver coins minted at the time and economic and political circumstances at the time of their issue. Thus, In this research has dealt with Hormizd IV coins of Darabgard mint and compared with the king coins before (Khosrow I) and after (Khosrow II),to understand the economic situation of Hormizd IV period.

Backgrund of research

Many non- destructive spectroscopic methods are used to analyze silver objects, including PIXE (Smith 2005), Which in some cases provide the concentration of minor and trace elements (Uzonyi, 2000, Campbell, 2000). PIXE has advantage and disadvantage that have been thoroughly discussed in the literature (Milazzo, 2004). The first author published data on Sasanian silver (Bacharach, 1972) and compared it with Rome Silver (Hughes, 1979). Meyers (Meyers, 2003) and Gurdus (Gurdus, 1967) published data on cupellation, technique which is applied to galena to obtain Ag by oxidation of Pb and Zn. Both author reported on the presence of Au remaining in the metals used to strike coins, used as a trace element for the location of the silver origin in the case of Sassanian silver. Gordus (Gordus, 1967) also used Pt group elements. He showed an empirical relationship was independent of the thickness of the coin over a wide range of thicknesses. However, when re-melting and re-use is carried out, Au contents might not be representative of a provenance. Kontos (Kontos, 2000) showed that Bi may be used as an indicator of a silver mine location in the case of silver coins from Athens and Guerra (Guerra, 1995, 1998, 2004, et al.2008) showed that several elements may characterize Au mines and gold coins. Sodaei (Sodaei etal,2013) show that Au and Pb may be used as an indicator of a silver mine in Iran. Sodaei (Sodaei 2016) show with ratio of Fe / Cu to Silver can be studied to the economic conditions of the period.

Throughout this study we tried to fine the relation between the silver which was used for issuing coins in the Hormizd IV mints and the possible sources of metal used in this period and economic and political circumstances at the time of their issue.

Selection of Samples

Sassanian silver coins struck by Hormizd IV in Darabgerd, Darabgerd was one of the active mints of the Sassanid period which geographical location was more stable and Pahlavi epigraph (AD) was The symbol of this mint in reverse coins. these coins were selected on the basis at this time the king can be observed political and economic events. Nearly all the coins were cleaned as follows: they were kept in 3%-5% formic acid solution for a few minutes, scrubbed with a toothbrush, and finally cleaned with alcohol -soaked cotton (fig 1) (Tab 1).

Fig 1: Sasanian silver coins: Hormizd IV (samples 1-4-11-15, Khosrow I (sample18), KhosrowII (Sample 20)

Sample	King of Sassanid	Mint	Year's AD	Unit Weight	Weight (Grams)	Diameter mm
1	Hormizd IV	Darabgerd	585	Drachma	4/07	30
2	Hormizd IV	Darabgerd	585	Drachma	4/09	29
3	Hormizd IV	Darabgerd	586	Drachma	4/11	29
4	Hormizd IV	Darabgerd	586	Drachma	4/13	29
5	Hormizd IV	Darabgerd	587	Drachma	4/10	29
6	Hormizd IV	Darabgerd	587	Drachma	4/12	28
7	Hormizd IV	Darabgerd	588	Drachma	4/09	29
8	Hormizd IV	Darabgerd	588	Drachma	4/10	29
9	Hormizd IV	Darabgerd	560	Drachma	4/12	29
10	Hormizd IV	Darabgerd	560	Drachma	4/09	29
11	Hormizd IV	Darabgerd	561	Drachma	4/11	30
12	Hormizd IV	Darabgerd	561	Drachma	4/10	29
13	Hormizd IV	Darabgerd	562	Drachma	4/14	30
14	Hormizd IV	Darabgerd	562	Drachma	4/11	28
15	Hormizd IV	Darabgerd	563	Drachma	4/07	30
16	Hormizd IV	Darabgerd	563	Drachma	4/08	29
17	Khosrow I	Darabgerd	531	Drachma	4/10	29
18	Khosrow I	Darabgerd	579	Drachma	4/12	30
19	Khosrow II	Darabgerd	591	Drachma	4/12	31
20	Khosrow II	Darabgerd	628	Drachma	4/14	31

Tab 1: Specifications of the studied coins

Experimental setup:

Analyses were carried out in the van de Graff accelerator at the Bubansor physical lab of India. A 2 MeV proton beam with a current of 2-3 nA was used to bombard the coins. Then coins inserted in a multipurpose scatter chamber maintained in high vacuum (10-5 Torr). The emitted characteristic X- rays were detected with an ORTEC Si (Li) detector (FWHM 170 eV at 5.9 keV). GUPIX takes in to account; the energy loss of the 3 MeV incident protons, the variation of X-ray production cross- sections with the decreasing proton energy, the absorption of X- rays from different depths in the target and the elemental effect, also used all the inputted specification of the Si X-ray detector to generate a theoretical curve for its efficiency and allows for the escaps peak, sum peak and low energy tailing of X- ray (Ben Abdelouahed, 2010, Campbell et al. 2000). The results are shown in Table 2, 3. Major elements are those contributing with more that 10% to overall composition, 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 corrosions and wearing of objects, altering the accuracy of the result (Hajivalaei 2011,2012, Sodaei 2013)(fig 2).

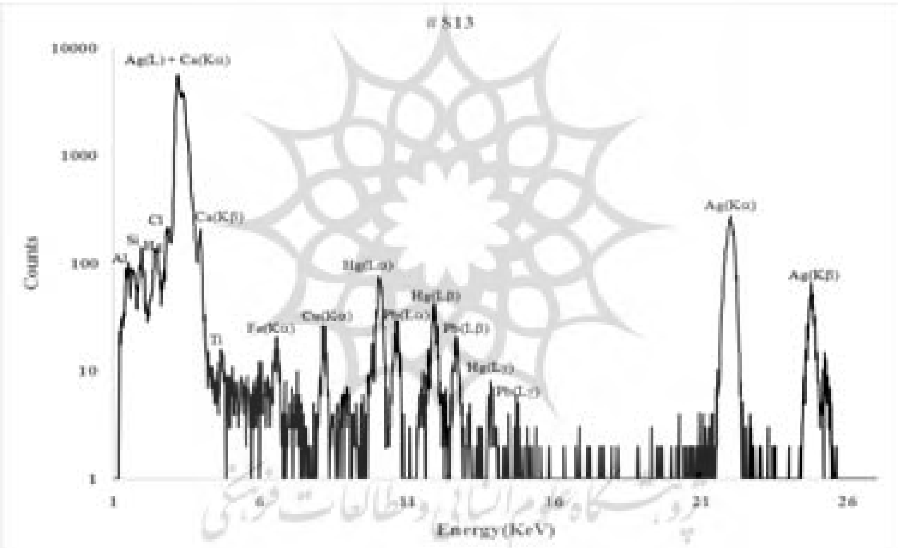

Fig 2: A taypical PIXE spectrum of analysed silver coins

Result and discussion

The metallic elements Ag, Au, Pb, Cu, Fe, Cl, Ca, S, Si , Zn, and S were observed in The studied coins (Tab 2, 3). According to the results, important elements for us are Cu, Ag, Au, Fe and Pb that observed in the coins along with the silver as major component. The percentage of Ag varies between 95/15 % to 96.42% (Tab 2).

The amount of silver in coins of Hormizd IV, Khosrow I and Khosrow II are between 95% to 96%, the elemental spectrum in coins of Hormizd IV and Khosrow I includes Fe, Pb, Ca and Cl and, this elemental spectrum in coins of Khosrow II includes Ag, Au and Cu (Tab 2). Considering that the removal of additional elements in the process of purifying the metal of coins has a high cost and has a great impact on the quality of existence of coins, Therefore, it can be seen that in the Hormizd IV period, additional elements were not removed to reduce the cost of coinage, and this resulted in the low quality of the coins. While in the time of Khosrow II, the quality of the coin metal was very important, so that the amount of iron, which has always

Sample	Ag	Au	Cu	Fe	Pb	Ca	Cl
1	95.22	0/94	3.24	0/6	-	-	-
2	95.19	0/98	3/08	0/75	--	--	--
3	95/21	0/84	3/10	0/62	0/23	-	-
4	95/21	0/91	3/27	0/68	--	--	--
5	95/27	0/88	3/22	0/63	--	-	-
6	95/27	1/03	2/78	0/59	--	0/15	0/18
7	95/22	0/97	3/16	0/65	--	--	--
8	95/31	0/90	3/11	0/68	--	--	--
9	95/28	1/09	3/12	0/51	--	--	--
10	95/30	0/89	2/87	0/58	0/36	--	--
11	95/37	0/82	3/21	0/60	--	--	--
12	95/32	0/86	3/29	0/53	--	--	--
13	95/33	0/84	2/57	0/56	0/28	0/20	0/22
14	95.19	0/89	2/81	0.50	0/22	0/18	0/21
15	95/15	0/86	4/23	0/57	--	--	--
16	95/20	0/81	3/7	0/61	0/61	--	--
17	95/31	0/83	2/99	0/51	--	0/16	0/20
18	95/39	0/90	2/83	0/55	--	0/20	0/23
19	96/38	1/22	2/40	---	--	---	--
20	96/42	1/27	2/31	--	--	--	--

Tab 2: Percentage of current elements in Sassanian coins by PIXE

been one of the main elements, has reached zero (Tab 2). Copper is naturally present in coins with amounts less than 2%, but if the amount of this element is more than 2%, it cannot be considered natural and must have been an optional alloy to adjust the coin tablets (Hughes & Hall, 1979: 321-344). The coins of this study contain 2.31- 4.23% copper, which has an average the amount of copper in coins of Hormizd IV is between 2/31 to 4/23, and coins of khosrow I and Khosrow II is 2/83 to 2/31, which can indicate Hormizd IV the optional alloying of this metal to reduce the purity of silver. Usually there is a small amount (less than 1%) of iron in their structure due to surface contamination of the coin burial environment (Flament & Marchetti, 2004: 179-184), But if a certain amount of iron is added to the coins, it can be considered as a sign to adjust the coin tablet size. The purity of iron in these coins is between 0.50-0.75 %, which this can indicate the uptake of iron from surface contaminants or the presence of that element in the ore structure and the separation process is not well done. Iron isn't observed in the coins of Khosrow II which indicates a well done extraction (tab 3).

	Ag	Au	Cu	Fe	Pb
Minimum	95/15%	0.81%	2.31%	0.51%	0.22%
Maximum	96.42%	1.27%	4.23%	0.98	0.61%

Tab 3:the minimum and Maximum amounts of the main metal elements in the studied coins

Possibly, about half of the silver metals are produced from Lead ores (Tylecote, 1962) while in antiquity lead ores were largely exploited to produce silver the proportion must have been much higher (Hughes & Hall, 1979). The cupellation which was largely used in ancient times to obtain the silver fineness cannot be considered as very precise (Webber, 2000). It is commonly accepting that silver metallurgy developed out of lead smelting technology and that the metal silver was extracted from silver- bearing lead ores (Meyer, 2003). Recently, there is a consensus that in the earliest stages oxidized ores such as cerussite (PbCO3) may have been the primary source for silver (Craddok, 1995). It is also assumed that among the various lead ores argentiferous galena (PbS) was the main sours in antiquity for the production of silver (Meyer, 2003). The presence Pb in the alloys, which indicates that usage of lead and zinc in minting coins (Uzonyi, 2000); and Lower Pb content in some of the coins can indicate the good silver refining process (Tripathy, 2010). Our results, which are shown in Tables1, that cerussite (PbCO3) mine have been explored for extraction of silver in the Hormoz IV period (table 1). The ratio of Ag with respect to Au shows in the mint house in Sasanian several sources of Ag have been used for exploration and issuing the coins. According to Meyers (Meyers, 2003), if the silver were produced from cerussit, then the gold content would vary approximately from 0.25 %- 1.0% which is true for our case (Harper and Meyer 1981, Meyer 1993). So, correspond to the ratios that should be found for the ores from which silver was extracted. In the spectra obtained by PIXE technique, the Au is as trace element. According to our results, the comparison of Au/Ag ratio against the Cu content of coins show that mines of cerussite type have been explored for issuing coins by Hormozd IV king. The presence of Ca and Cl in the silver coins is due to the fact that its removal was impossible at that time during the metallurgical process. Furthermore, the presence Fe may be attributed to the surface contaminations (Kantarelou, 2011, Flament & Marchetti, 2004).

CONCLUSION

The elemental composition of twenty (20) Sassanian coins (Darabgerd Mint) have been analyzed 1.7 MV pellet on accelerator using PIXE spectrometry. The result show, the content of silver in the studied coins is 95 to 96 percent but there is an elemental spectrums coins of Hormozd IV and Khosrow I includes Fe, Cu, Pb,Ca and Ck that has reduced the quality of the coin metal. Probably due to reduced costs, additional elements were not removed in Darabgerd mint, but in the time of Khosrow II extraction was done well. According to above- mentioned results and historical evidence, we may conclude that the cerussite mine were used in Darabgerd mint (Sasanian Kings).

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