Indian Journal of History of Science, 38.4 (2003) 351-366

NUMISMATIC STUDY OF MĀLHAR COINS BY THE ENERGY DISPERSIVE X-RAY FLUORESCENCE (EDXRF) TECHNIQUE

Atis Chandra Mandal[1], Sumita Santra[2], Debasis Mitra[2], *Manoranjan Sarkar[2], Dipan Bhattacharya[2] and Sushmita Bose Majumder[3]

(*Received 6 January 2003; revised 15 October 2003*)

The elemental composition of a number of ancient coins (1st century BC to 4th century AD) have been obtained using the nondestructive EDXRF technique. The coins have been classified with respect to their metal contents and some tentative inferences have been drawn regarading the metallurgical produces of the minting time of the coins.

Key words: Archaeology, EDXRF, Numismatics

Introduction

Over the last three decades, the technique of Energy Dispersive X-Ray Fluorescence (EDXRF) is being successfully applied for quantitative elemental analysis in various fields of human endeavour e.g. Physics, Chemistry, Archaeology, Metallurgy, Pollution Studies etc. The special attraction of the technique lies in the fact that it is non destructive, and this property makes it highly suitable for numismatic studies, especially for determining the elemental composition of rare ancient coins. The relative concentration of metals in an ancient coins is an useful information to archaeologists and historians because it helps them to glean (i) the then value of the metals used to

1.Department of Physics, University of Burdwan, Burdwan 713104, India
2. Saha Institute of Nuclear Physics, Kolkata 700064, India; * Corresponding author e-mail : mano@amp.saha.ernet.in
3.Sanskrit College, Kolkata 700014, India

mint the coins which reflect the state of the economy of the region where the coins belong, (ii) the availability of different metals in the region, and (iii) the state of metallurgical practices of the period in which the coins were issued. Even though, on an international scenario, the use of the EDXRF technique by numismatists is quite well known; it has not yet gained popularity in India. The method of chemical analysis is destructive and hence not suitable in the case of rare and ancient coins. In this context it is worth mentioning that EDXRF is a convenient, non-destructive, multi-elemental, quick and cheap analytical technique; and the level of accuracy attainable is also quite satisfactory. Consequently, this is the most attractive technique to the archaeologist and numismatist. Besides, even trace elements can be detected up to the 'ppm' (parts per million) level by this method[1].

One of the authors of the present note (SBM) brought it to our notice that ancient (1st century BC to 4th century AD) coins from Mālhar (21.0°N, 82.2°E; situated in the Bilaspur district of the Chattisgarh state of India) would be worth investigating through the EDXRF technique. She had access to a number of coins (property of private collectors) from this region, and we got the coins from her on loan. This is the genesis of the present study. In order to attempt a comparative analysis, local as well as imperial coin samples of nearby provenances have also been included in the present study. This category includes three varieties of local coins e.g. *Tripurī, Thathārī, and Kalācūrī* and imperial coins e.g. *kuṣāṇa* copper coins, and *Śātavāhana* coins. In India we do not have much literature that can be used as historical evidence in the modern sense of the term. In quite a number of cases, however, the study of coins minted during a particular period tells us a lot about its history. For instance, the knowledge that nearly thirty Bactrian kings and queens ruled over the Punjab during 200-100 BC has come exclusively from studies of coins minted during the period[2]. For the coins under study here, we do not have the support of much ancient literature that can be used as historical evidence except some indirect and stray references in the Purāṇas. In general, the local coins from ancient India, especially those from the post-*Mauryan* era, are important to historian mainly because very often these are the only source of information available. So it is only natural that the discovery of a new series[3] of local conis at Mālhar received a warm welcome from Indian numismatists. Mālhar is an archaeologically rich site and has yielded evidence of occupation since circa 600 BC. The coins that have been studied by the EDXRF technique, and are being reported herein, have been collected by local residents from surface explorations of the site during the rainy season.

The Mālhar coins that we have studied here lack the evidence of stratiography since all of them come from surface exploration made by private coin collectors in the area concerned. On an earlier occasion[3] these coins had been studied and arranged chronologically on the basis of paleography of the coin legends. From the paleographic study it has been found that the coins of Mālhar belong to different chronological sequences ranging from c. 1st Century BC to c. 4th Century AD. Most of the coins of Mālhar bear a symbol (as shown in Fig. 1) which stands for the identity of the place (since the symbol is constant and the dynasties that come to power from time to time in this region had used this particular symbol on their coins; it may be safely inferred that the symbol denoted the identity of the place i.e. Mālhar). To appreciate the importance of the EDXRF analysis and its significance in the reconstruction of the regional history of the area concerned, it would be relevant to give a brief introduction to the rulers and dynasties that reigned in this region. The earliest known ruler is Śilaluśirī who can be placed in c.1st Century BC. On the basis of paleographical evidences and typological similarities coins of two more rulers named Āchādaśirī and Dhamabhāda can be attributed to the same dynasty to which Śilaluśirī belonged. Then the *Magha* dynasty of Mālhar came to power sometime in the 2nd Century AD.

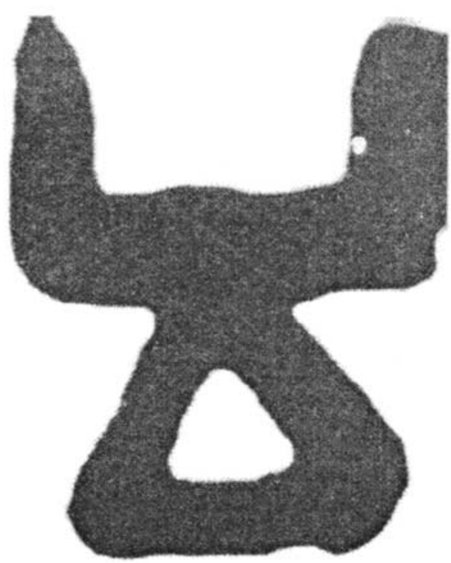

Fig. 1: Symbol of Mālhar found on many of the coins.

The *Purāṇas* mention the reign of nine *Magha* rulers over Kośala.[3] Out of these nine, four are known to us from their coins and one from two clay sealings. They are *Maghaśirī, Śirīyamagha, Śivamagha, Paramagha and Yuga or Yugaramagha.* To the next dynasty belong *Bhaliga* and possibly also *Śivaśirī, Śilaluka.* The coins of the above mentioned rulers bear an elephant on the obverse and the reverse motif is either a tree in railing or a peacock. In some cases, however, the reverse is blank. The next series of coins are somewhat different in character from the *dynastic-city issues* as we gradually see the discontinuation of the use of the Mālhar symbol. On some coins of the above mentioned series we find meaningless legends, whereas some others bear only dots reminding us of the occurrence of legends and finally we have the un-inscribed coins of this variety. These have been termed as *Elephant : Deity (ED)* series on the ground that they bear a distinct stylized elephant on the obverse, different from those depicted on the earlier issues, and the figure of a deity on the reverse. Photographs of some of the coins analysed here are shown in Fig.2.

In this study we have endeavoured to classify the studied coins with respect to their elemental composition. This would, perhaps, throw some light on the level of maturity of the metallurgical practices prevalent in ancient Mālhar. The present study, we hope, would help to corroborate the inferences drawn earlier from the paleographic study.[3]

Experimental Details

The experimental set up used in this was the same as has been used earlier[4]. The main X-ray source was a 60 watt Kevex X-ray tube imported from the USA. The bremsstrahlung from the tungsten anode is made to fall on a secondary target, here a Mo foil, kept at an angle of 45° to the X-ray beam direction. Mo foil emits K X-rays which can be taken as almost monochromatic having an energy of 17.8 keV. The coin samples are placed at an angle of 45° both with the direction of the incoming Mo X-rays and the outgoing fluorescent X-rays reaching the detector. In the present case, the X-rays detector was an ORTEC LEPS (HEGe) having an energy resolution of 160 eV at 5.9 keV. The tube voltage was 35 KV and the current was 0.35 mA. Coins were of various size and shape and an arrangement was made so that any of the coins could be placed in the target holder. Three typical spectra are shown in Figs. 4,5 and 6 which are obtained from coin no.2 (Table 1), coin no. 19 (Table 1)

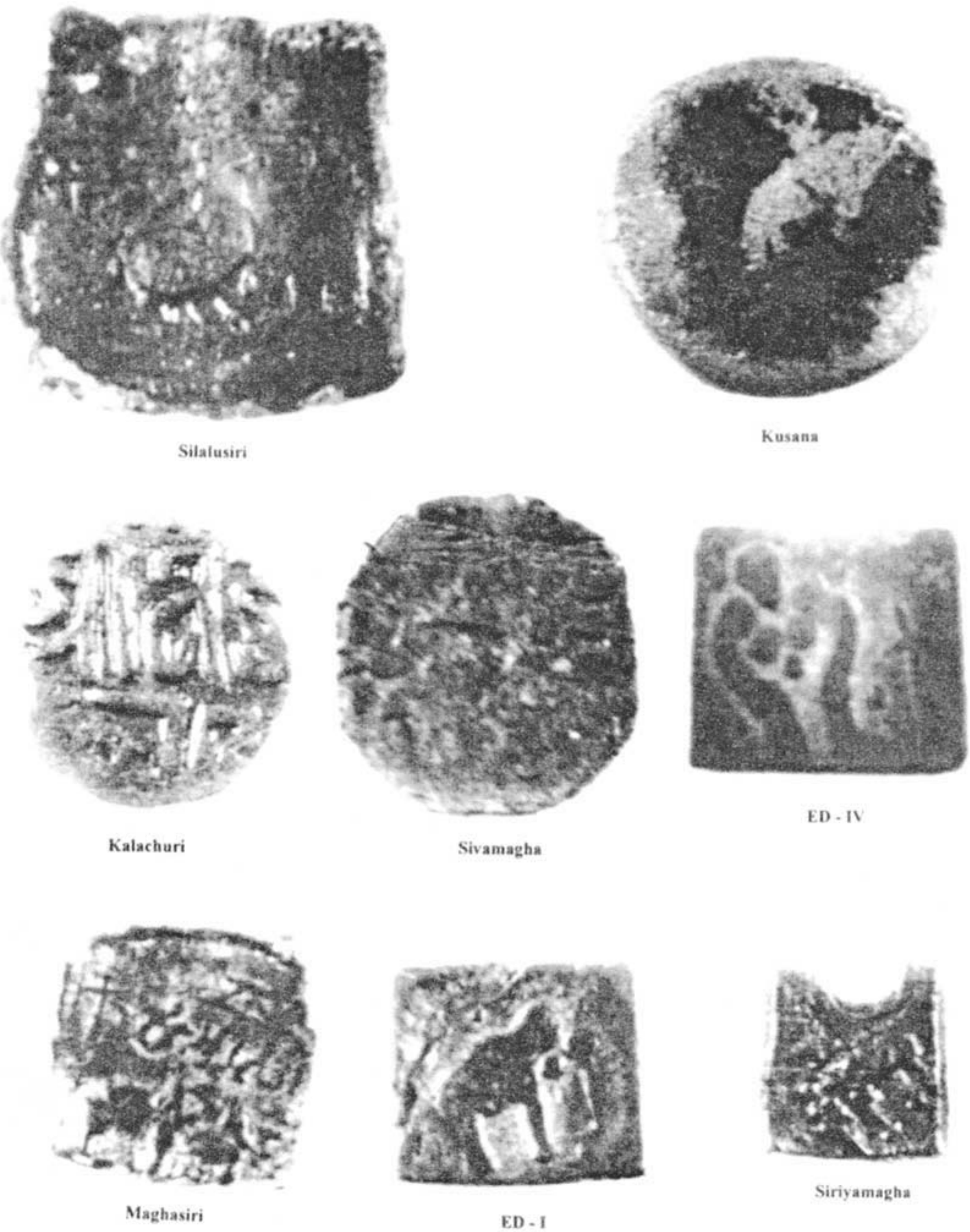

Fig. 2: Photographs of some of the coins analysed here.

and coin no.8 (Table 2) respectively. Precise energy calibration of the system were made using some pure foils such as Fe, Ni, Cu, Zn, Pb, Au and Pb.

Analysis of Data

For the elemental analysis of the coins, we used our computer program that we had developed in our laboratory earlier[5]. A detailed description of the analytical method can be found in that article. Only a short description is given here. Following the Fundamental Principle Method, intensities of all the K_α and L_α lines of the elements present in the sample (as seen in the spectrum) are theoretically calculated using arbitrary values of the incident X-ray flux and the geometry and taking the values of other physical parameters such as the photoelectric cross sections, fluorescence yields, Coster Kronig transitions rates, radiative widths, total mass absorption coefficients etc. from standard literature. The detector efficiency was theoretically generated from the detector parameters given by the manufacturer. The secondary fluorescence due to cross elemental effect for K_α,K_β,L_α,and L_β were incorporated in the program. For the initial calculations, an arbitrary set of values of concentrations of all the visible elements are used. Supposing that sum of the concentration of all the elements would add up to 100%, an iteration is done through a computer till the theoretical intensity is approximately equal to the measured ones. As inputs, one needs to provide the values of the physical parameters, incident and emergent angles and the intensities of K_α and L_α lines.

Spectra were analysed with our standard peak fitting program. The intensities of the K_α and L_α peaks obtained therefrom were then used in our program to get the final concentrations of the elements present in a sample. The error in each concentration values is ~ 10%. Elemental concentration below 1% are not quoted here. For comparison, it may be mentioned here that using the Wavelength Dispersive X-ray Spectrometry (WDX), the overall errors in the elemental concentrations may, in favourable cases, be brought down to ~ 1%.

Results

The quantitative results of the present investigation e.g. the elemental composition of the coins are given in Tables 1 and 2. The masses of the coins, as well as their period of minting are also shown. From the point of view of elemental composition, these coins can be broadly classified into two groups as detailed below.

Table 1 Metal composition of Mālhar coins

Serial no	Weight (gms)	Rules/type	Period	Elemental Composition (%) Fe	Cu	Zn	As	Pb
1	1.8387	Silalusiri	1st cent BC	-	-	1.4	-	98.6
2	3.8439	Do	Do	-	-	-	-	100
3	12.4273	Do	Do	-	-	-	-	100
4	2.3849	Achadasiri	1st cent AD	14.7	81.5	1.6	-	2.2
5	4.1167	Do	Do	-	3.3	-	-	96.7
6	4.7149	Do	Do	-	-	-	-	100
7	2.4786	Maghasiri	2nd cent AD	-	-	-	-	100
8	1.5169	Siriyamagha	2nd cent AD	2.1	90.1	-	-	7.8
9	1.3702	Sivamagha	2nd/3rd cent AD	-	-	-	-	100
10	3.2525	Do	Do	2.4	92.9	-	-	4.7
11	3.7264	Do	Do	-	-	-	-	100
12	8.0903	Do	Do	-	-	-	-	100
13	3.591	Paramagha	2nd/3rd cent AD	-	-	-	-	100
14	8.093	Do	Do	-	-	-	-	100
15	0.6857	Bhaliga	3rd cent AD	-	98.7	-	-	1.3
16	0.8129	E:D/I	4th cent onward	3.3	70.9	10.7	-	15.1
17	1.0369	Do	Do	2.0	81.4	2.8	-	13.8
18	1.0515	Do	Do	3.8	50.9	1.4	-	43.9
19	1.2254	Do	Do	3	78.7	2	-	16.3
20	1.2901	Do	Do	0.8	94.3	3.1	-	1.8
21	1.3999	Do	Do	-	95.6		-	4.4
22	3.375	E:D/III	Do	1.9	97.4		-	0.7

Serial no	Weight (gms)	Rules/type	Period	Elemental Composition (%)				
				Fe	Cu	Zn	As	Pb
23	3.6164	E:D/III	4th cent onward	1.1	98.1	-	-	0.8
24	2.2428	E:D/IV	Do	1.4	98.6	-	-	-
25	2.6884	Do	Do	1.7	98.3	-	-	-
26	2.7828	Do	Do	1.2	89.7	6.9	-	2.2
27	2.8961	Do	Do	0.9	83.8	12.8	-	2.5
28	3.1095	Do	Do	-	94.9	-	-	5.1
29	3.1616	Do	Do	1.4	93.8	0.4	-	4.4
30	3.2918	Do	Do	1.4	96.7	-	-	1.9
31	3.3446	Do	Do	2.0	89.7	-	-	8.3
32	3.3497	Do	Do	1.0	89.8	5.9	-	3.3
33	3.3684	Do	Do	0.9	80.1	-	-	19
34	3.4143	Do	Do	0.8	89.1	7.0	-	3.1
35	3.4323	Do	Do	1.5	82.9	12.0	-	3.6
36	1.2498	Do	Do	3.3	78.7	-	-	18.0
37	2.6461	E:D/ V	Do	1.1	81.6	-	-	17.3
38	2.8476	Do	Do	1.4	90.3	2.2	-	6.1
39	3.2175	Do	Do	2.3	96.5	-	-	1.2
40	3.7488	Do	Do	1.1	88.7	7.8	-	2.4
41	4.3299	Do	Do	2.4	72.0	1.1	-	24.5
42	0.2179	E:D/I/16	Do	-	91.8	-	-	8.2
43	0.2534	Do	Do	-	66.7	-	-	33.3
44	0.3512	Do	Do	-	92.3	-	-	7.7
45	0.649	E:D/I/8	Do	3.4	86.3	-	-	10.3

Table 2 Metal compositons of Imperial/Local coins of provenance near Mālhar

Serial No	Weight (gms)	Rules/Types	Period	Elemental Composition (%) Fe	Cu	Zn	As	Pb
1	1.6696	Punch marked Coin(PMC)	5th BC to 3rd AD	-	96.4	-	-	3.6
2	2.594	Do	Do	1.3	92.6	-	-	6.1
3	1.1062	Do	Do	1.2	89.7	-	-	9.1
4	1.0508	Do	Do	1.4	88.9	1.9	-	7.8
5	1.1163	Do	Do	1.9	81.6	11.9	-	4.6
6	1.2498	Do	Do	1.4	94.9	-	-	3.7
7	1.0346	Do	Do	2.1	94.6	-	-	3.3
8	0.5372	Do	Do	-	100		-	-
9	0.9088	Do	Do	2.5	83.8	1.7	-	12.0
10	0.8074	Do	Do	-	70.5	1.8	-	27.7
11	1.1107	Do	Do	-	71.0	-	-	29.0
12	0.6545	Do	Do	-	93.7	-	-	6.3
13	2.3509	Do	Do	-	100	-	-	-
14	0.937	Thathārī	1st AD	-	92.6	1.4	-	6.0
15	0.7843	Do	Do	-	93.2	1.2	-	5.6
16	3.666	Tripurī	2nd to3rd AD	2.4	93.5	-	4.1	-
17	5.0111	Do	Do	4.0	93.3	-	2.7	-
18	5.6984	Do	Do	1.1	96.6	-	2.3	-
19	3.5785	Do	Do	1.3	94.3	-	3.0	1.4
20	13.388	Kuṣāna	1st cent AD	1.1	98.9	-	-	-
21	14.118	Do	Do	1.0	99.0	-	-	-
22	1.2094	Śātavāhana	1st/2nd AD	-	70.5	-	-	29.5
23	1.8186	Kalācuri	9th to11th AD	0.6	99.4	-	-	-
24	2.5788	Do	Do	-	99.1	-	0.9	-
25	6.2726	Do	Do	0.9	98.2	-	-	0.9

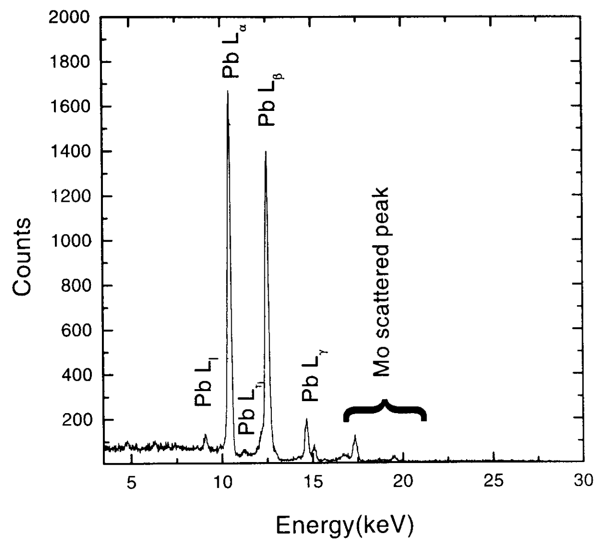

Fig.3: Spectrum from coin no.2 (Table 1) excited with Mo K x-rays obtained from a Mo secondary target. The X-ray tube was run at 35 KV with a current of 0.35 mA.

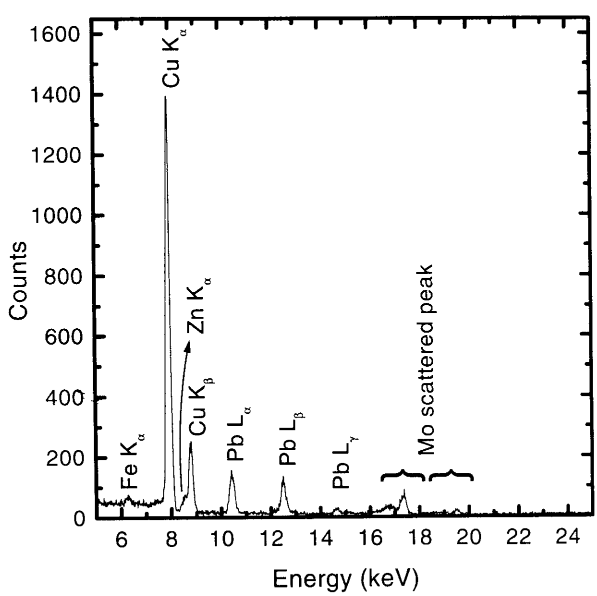

Fig. 4: Spectrum from coin no. 19 (Table 1). Other conditions are same as in Fig. 3.

Group A: This group comprises of eleven lead coins (serial nos. 1-3, 5-7, 9, 11-14 in Table 1) with weights varying between 1.4 to 12.4 gms. Nine of these coins are of pure lead. Chronologically they belong to the earlier era. The other two coins of this group have a slight (2-3%) admixture of zinc in one case, and copper in the other. The presence of these impurities might be due to using lead from different sources (mines).

Group B: The second group consists of coins where the major element is copper. Other elements e.g. iron, zinc, lead etc. are present in various proportions. The variation of the relative proportion of the different elements seems to have been done intentionally. It is pertinent to note here that compared to the coins of group A, most of these coins were minted at a later period. It is quite plausible that keeping the goals of durability and hardness of the coins in mind, the people involved had experimented with the relative proportions of copper, iron, zinc, and lead while making these coins. As can be seen in Table 1, the percentage variations of the four elements

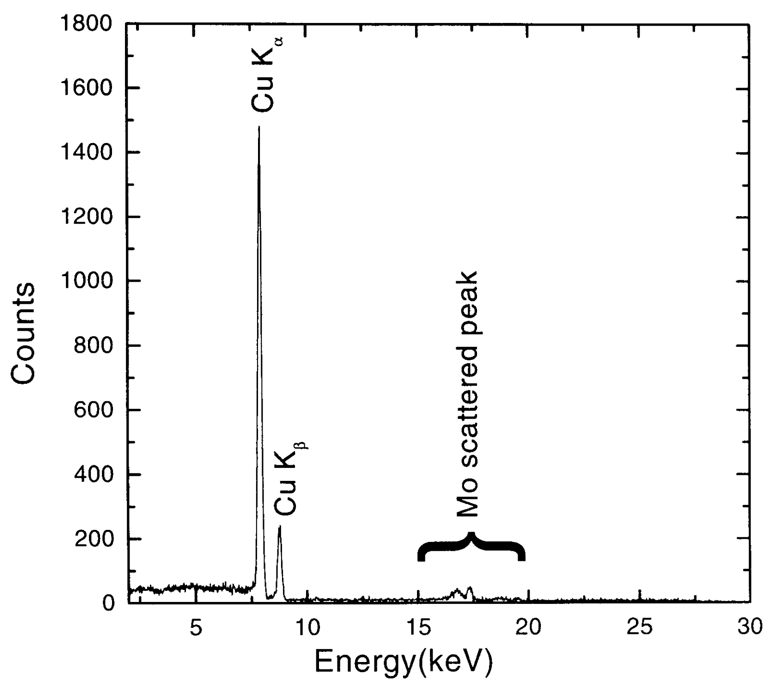

Fig. 5: Spectrum from coin no. 8 (Table 2). Other conditions are same as in Fig. 3.

in this group of coins are, indeed, quite large, e.g. 0.8 to 14.7 for iron; 41.6 to 98.7 for copper; 0.4 to 12.8 for zinc; and 0.7 to 44.2 for lead. It is unlikely that such a large variation could be unintentional.

It may be relevant to point out here that the techniques of metal alloying were known in India since the Harappan times. They also know that addition of small amounts of lead to copper increases the fusibility of the metal[6].

It is possible that another goal of their experimentation was to reduce the proportion of lead in their coins. A careful scrutiny of Table 1 reveals that out of a total of thirty five coins classified under group B, there are only eleven coins with lead contents of 10% or higher, two coins do not contain any lead, whereas the average lead content of the rest twenty two coins is only 3.9%.

We also notice in the Table that sixteen of the forty five coins contain zinc in varying percentages between 0.4 to 12.8 with an average of 4.9%. It is known that introduction of zinc to a copper coin would make it harder. Thus this observation can also be taken as an illustration of the 'experimentation' that we mentioned earlier. The idea of 'experimentation', however, is not the only conclusion. These coins were in actual use and hence alloying with different metals; as also with the same metal with different concentrations; were actually being practiced to achieve a specific property. We may even say that the people concerned were aware of 'alloying' and of the fact that alloying changes physical properties of materials.

Twenty nine coins of this group have iron as one of its components, with an average iron content of 2.7%. Two coins, however, show iron contents of 14.3% and 14.7% respectively. The number being too small, it would not be proper to draw any conclusions, even if tentative, from this.

The results for the imperial/local coins of nearby provenances that we have included in our study for comparison are shown in Table 2. The results of the analysis of these twenty five coins are very similar to the group B *Mālhar* coins. These are all copper coins with slight admixture of iron, zinc and lead. An interesting exception is the group of four *Tripūrī* coins, all of whom contain small (1-4%) amounts of arsenic.

Discussion

The results of the EDXRF analysis has helped us to corroborate the chronological arrangement of the Mālhar coins, done previously on the basis of paleography of the coin legends. The early rulers like *Śilaluśirī, Āchādaśirī* and others up to *Paramagha* (2nd /3rd century AD) have issued coins mostly in lead or with high lead percentage mixed with some other metals like iron, copper and zinc. The early rulers also issued some coins with high copper content mixed with metals like iron, lead and zinc but these were very few in number when compared to their lead issues. The possible reasons could be that the metal was easily available in this regions; that lead has a low melting point and hardens fast on cooling. These factors made it an intelligent metal for minting purpose.

It should, however, be pointed out that along with lead coins, the early rulers e.g. *Āchādaśirī, Śirīyamagha, Śivamagha,* and *Bhaliga* had also issued coins in copper (c.f. serial nos. 4,8,10,15 in Table 1). Lead being easily available and hence cheaper than copper, coins minted in this metal were of lesser valuation. The minimal occurrence of copper iron and zinc in the lead coins was possibly not due to any kind of alloying as these metals have not been mixed in any particular proportion. These were present in the ore in the form of natural contamination and the process of purification of the ore was either not known to the people of that area or they hardly paid any attention to the purity factor as these coins were for transaction only within the area of Mālhar. With widening of transaction the people needed coins in a more durable metal and they started experimenting with harder metals like copper mixed with iron, lead or zinc. This experimentation in the alloying process continued till they reached an approximate standard of 80-90 percent copper with small admixture of the other metals mentioned above.

With the introduction of the Elephant: Deity type variety we notice a complete switch over from lead to copper. Besides, the gradual disappearance of the Mālhar symbol from the coins of this variety indicates that the circulation of these coins was no longer restricted to the Mālhar region (for whose identity stood the symbol). We find the *Elephant: Deity* type coins without the Mālhar symbol from many sites of South Kośala (e.g. almost the whole of Chhattisgarh state and the adjacent districts of Kalahandi, Sambalpur and Bolangir in Orissa). Initially Mālhar was an isolated indigenous numismatic zone in South Kośala but with the *Elephant : Deity* Class III/IV/V coins we notice indigenous moneytization of the whole of South Kośala. All these factors taken together help us to conclude that by this time the use of indigenous money had come into practice in this region. This in turn proves that either the authority at Mālhar had spread its sway over the whole of South Kośala or this indigenous moneytization of the whole of South Kośala was due to the increase in inter-locality or regional transactions. Possibly due to this brisk transaction process lead was rejected (keeping the erosion factor in mind) and copper was adopted for minting coins. However, the role played by lead as a cheaper or lower denomination metal money was now met by adopting different denominations of a coin standard (possibly *karṣapaṇa;* 1/2, 1/4th 1/8th and 1/16th of *karṣapaṇa*).

A comparative study of the metal composition of the coins found in the neighbouring areas, local as well as imperial (c.f. Table 2), has revealed certain interesting facts. The imperial *Kuṣāṇa* copper coins belonging to the 1st-2nd century AD were of almost pure copper with a little amount (1-1.5%) of iron which shows that the process of extraction of pure metal from the ore was known to the minting authorities of the *Kuṣāṇa* coins and the purity of these imperial coins was an important issue. As far as the coins of *Tripūrī* are concerned it is quite interesting to find that all these local coins of the *Tripūrī* region contain 1-4 percent Arsenic in them. These coins are mostly of copper with nominal amounts of iron and arsenic. We may conclude that the copper ore used in minting these coins came from a mine which had a natural contamination of arsenic. It is well known that the copper ores from the 'Khetrī' mines of Rajasthan does, indeed, contain arsenic as an impurity.[6] The coins of *Thathārī*, are un-inscribed and hence it is difficult to ascertain a particular date to these coins. Some scholars have assigned a very early date to these coins on the ground that they are un-inscribed, but as we have already seen in case of Malhar that the incribed coins belong to an earlier date than the un-inscribed ones. *Thathārī*, in ancient times, was within the limits of South Kośala. The present EDXRF analysis shows that these coins contain high copper percentage of around 92%-94%. Such coins are not found from any other region in South Kośala. These coins have some lead and zinc contents. Zinc was added to copper as the hardening factor of zinc was possibly known by then and lead was either added or was an impurity present in the copper ore used for minting these coins. The *Kalācurī* copper coins issued from 10th Century onwards are of almost pure copper (copper content 98-100%), with small amount of lead, iron and in a single case nominal amount of arsenic.

ACKNOWLEDGEMENT

Technical help from Mr P. K. Das is thankfully acknowledged.

References

1. F. He and P. J. Van Espen, 'General approach for quantitative energy dispersive x-ray fluorescence analysis based on fundamental parameters', *Anal. Chem.* 63 (1991) 2237-2244.

2. P. L. Gupta, *'Coins'*; National Book Trust, India, 2000.

3. S. B. Majumdar, *Local Coins of ancient India-a new series: Coins of Malhar* ; IIRNs (A Division of Indian Institute of Research in Numismatic Studies) publications, Nasik, India, 2000.

4. A. C. Mandal, M. Sarkar, D. Bhattacharya and P. Sen, ' Measurement of photon-induced L shell fluorescence cross-sections of gold and lead at 21.6, 23.7 and 25.8 keV', *Nucl. Inst. & Methods* B174 (2001) 41-46.

5. A. C. Mandal, M. Sarkar and D. Bhattacharya, 'A simple EDXRF technique to analyse alloys', Eur. Phy. J. AP 17 (2002) 81-84; A.C.Mandal, S. Santra, D. Mitra, M. Sarkar and D. Bhattacharya, 'EDXRF as a routine tool for numismatic studies', *Current Science,* **85** (2003) 134-135.

6. D.P. Agrawal, *Metal Technology of the Harappan Culture*, incuded as ch. 9 of the book by D. P. Chattopadhyay, *'History of Science and Technology in Ancient India'* Firma KLM, India, 1986, Table VI, p.324.