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Elemental Analysis of Late Kushan Copper Coins from the Islamabad Museum, Pakistan, Using X-Ray Fluorescence (XRF) Spectroscopy

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Keywords: Non-destructive, Longevity, X-Ray Fluorescence, Spectroscopy, Inclusion, Poling, Striations

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Title

Elemental Analysis of Late Kushan Copper Coins from the Islamabad Museum, Pakistan, Using X-Ray Fluorescence (XRF) Spectroscopy

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Contents

Abstract

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Keywords:

Non-destructive, Longevity, X-Ray Fluorescence, Spectroscopy, Inclusion, Poling, Striations

Introduction

Archaeometallurgy is the study of metalworking structures, tools, waste products, and finished metal artifacts, from the Bronze Age to the recent past. There are various scientific techniques used in the elemental analysis of archaeological artifacts. Some of the techniques are destructive, while others are non-destructive and safe for valuable objects like coins. These techniques help us to understand the elemental composition of the objects reported from the archaeological context of these objects for a longer period (Rehren, 1994).

The use of analytical methods for archaeometric analysis poses a main problem when dealing with objects of high value such as coins. Due to the distinctive character and infrequency of some coins, any kind of investigation should be enhanced non-destructive, which means that neither unique sample material can be taken nor any kind of modification is permitted (Volpi, et. al, 2023).

Newly, with the development of numerous spectroscopic and microscopic methods, the research of archaeologically important copper coins developed very attractive for getting many chemical compositions at the microscopic measure. Evaluating the chemical composition of ancient coins offers appreciated understanding to archaeologists and numismatists, enlightening information about manufacturing procedures, age, monetary status, minting locations, and validity. These coins, made from many metal alloys through different eras in Indian history, reveal the development of metallurgy. They also deal with pieces of evidence about ore origins and manufacturing approaches (Upadhyay, et. al, 2024).

Elemental analysis of the Late Kushan copper coins at the Islamabad Museum has been carried out through material science, numismatic literature, and archaeometallurgical observations. The elemental analysis of the metal artifacts is an important mechanism with the help of which we can understand the elemental composition of metal and the technological advancement of the past. Elemental studies of coins result in valuable information about metal combinations used in the manufacture of coins (Manfred, 1858). Laboratory techniques such as XRF provide additional information about the metal contents, and ores, and the way to identify the various mints, when more than one, from the composition of metals. The relative proportion of the contents of the main elements provides valuable information about, the inflation of, money, economic growth or deprecation, and political conditions of that period. The connection between microstructure and mechanical properties enables the materials scientist to surmise the use of processes such as hammering, heating, and quenching used in ancient times.

The decision to use pure copper instead of common alloys like bronze or brass underscores economic considerations and resource management strategies within the Kushan Empire. The research concludes that the distinctive characteristics of these coins, including their composition and fabrication, reflect the regional diversity in ancient coinage practices and the Kushan Empire's adaptive responses to economic challenges.

Methodology

The study approach adopted in this research played an essential part in confirming its whole achievement, with specific importance on the particular performance of fieldwork and the following scientific analysis. The fieldwork stage was important, placing the basis for a systematic and disciplined analysis of the collected documents.

Ensuing the field examination, a complete scientific analysis was passed out using a variety of progressive procedures and methods. This stage was noticeable through a high level of accuracy, strict devotion to scientific procedures, and the usage of cutting-edge tools and skills. The addition of vigorous fieldwork with particular scientific investigation allowed the research to attain a nuanced and in-depth consideration of the inquiry subject, thus contribution appreciated helps to the larger field of data.

Essential to the research was the study of the elemental composition of Late Kushan copper coins. Through exploring their metallurgical possessions, the investigation aimed to expose an understanding of the materials and manufacturing methods used throughout the Late Kushan era. This investigation not only improves our understanding of Kushan numismatics but also sheds light on the scientific abilities and metallurgical performance of the period. Eventually, the study procedure helped as the keystone of the learning, emphasizing its integrity, intellectual accuracy, and historical significance.

Elemental Composition by X-ray Fluorescence (XRF) Spectroscopy

Learning the elemental composition of coins is an essential feature in archaeology. It offers a valuable understanding of mining and metallurgy applications, minting methods, and the monetary and political situations of a specific region at a particular time. Old-style physicochemical investigation, yet, frequently contains destructive techniques. To report this, nondestructive approaches of atomic spectroscopy have been employed, allowing the resolution of elemental composition without affecting harm to the sample. So, they can be used on archaeological objects (Trela et. al, 2025).

This study's objective is to examine and assess the most operative methods for examining the elemental composition of ancient copper coins from the Late Kushan period, presently housed at the Islamabad Museum. Essential to this research is the application of X-ray Fluorescence (XRF) a non-destructive radiation-based method accomplished as long as surface composition data with a diffusion penetration usually extending from a small number of micrometers to a few tens of micrometers (Marussi, et. al, 2024).

However, the study recognizes convinced limits intrinsic to XRF, mainly the probable for surface changes such as vigorous erosion enhancement to alter the outcomes. These changes might reason for differences between the slow surface composition and the true loose composition of the coins (Mamaniaa and Singhb, 2019).

XRF works by pointing an X-ray beam on top of a sample, which at that time emits distinguishing fluorescent X-rays. These productions are taken and examined by means of either an energy-dispersive or wavelength-dispersive detector. The qualitative investigation is based on the identification of precise wavelengths released by the elements extant, even though the quantitative examination is determined through the strength of these emissions. While chiefly a surface inquiry tool, XRF can suggest bulk study up to a depth of 1 cm, depending on both the model composition and the energy of the emitted X-rays. Its capability to notice elements extending from sodium to uranium makes it an extremely multipurpose technique, extensively useful in corrections such as cultural heritage preservation, environmental science, and materials investigation (Ibid).

In this research, a portable XRF device was used to examine 22 copper coins from the Late Kushan period. The study took place at the Experimental Archaeology Lab, Department of Archaeology, Hazara University, Mansehra. The procedure of a portable XRF system permitted for non-invasive, on-site examination, conserving the physical reliability of these culturally important objects though yielding dangerous compositional facts. This applied use highlights the importance of portable XRF devices in archaeological study, and contributes a stability between analytical accuracy and conservation (Paulo et al., 2009).

Specified the incomplete documentation existing on the metallurgical composition of Late Kushan copper coinage, this research fills a significant gap in the works. XRF was useful to both the obverse and reverse sides of the coins to attain a further complete study. This dual-sided method improves the consistency and understanding of the data, causal to a deeper appreciation of the alloying performance and metallurgical methods working throughout the Late Kushan era.

Experimental Results of X-ray Fluorescence (XRF) Spectroscopy

The Energy Dispersive X-ray Fluorescence (EDXRF) has been performed on 22 Late Kushan copper coins described above. Analysis by WD-XRF. The copper coin under study is the major elements identified in these coins are Cu and Si, whereas P, S, Co, Ni, Ag, and Pb are present in trace quantities in Late Kushan copper coins. The chemical composition of the coins derived from sensitive WD-XRF is shown in Table 3.11. As the coins are not much corroded, the WD-XRF was targeted on non corroded surfaces on a larger surface area. The copper percentage on the obverse side varied between 77.339 to 98.629% (Table 3.11). On the reverse side, the percentage of copper varied between 75.916 to 91.769%, showing copper as the main constituent of the Late Kushan copper coins. Except for coin No. 313, none of the copper coins showed the presence of any Cobalt (Co) on the exterior surfaces. Coin No. 313 shows variations of sulfur from 0.169% on the obverse to 0.145% on the reverse side. None of the coins showed any traces of iron on the external surfaces wherein iron was noticed through RBS analysis before conservation of coin No. 340 from traces to as high as 2.64%. All the copper coins are free from the presence of any chloride, K, Na, and iron on the external surfaces. The elements Co (No. 313), Pb (No. 5), and Ag (No. 5) are present in traces on the surface. Ni is present in traces (0.12%) on the obverse and reverse side of the majority of coins which may be impurity/contaminated during smelting. The obverse/ reverse composition of all the coins shows the presence of silica in major quantities from 0.821 to 17.305%. Probably, silica could not be removed during the metallurgical process, which points towards poor workmanship for this hoard. Phosphorus in traces (0.021 to 0.025%) is present in all the studied coins.

Results:

Obverse and Reverse view of the Late Kushan copper coins for XRF analysis

Figure 1

coin 1

Figure 2

coin 5

Figure 3

coin 7

Figure 4

coin 26

Figure 5

coin 27

Figure 6

coin 36

Figure 7

coin 40

Figure 8

coin 56

Figure 9

coin 81

Figure 10
coin 98

Figure 11
coin 109

Figure 12
coin 12

Figure 13
coin 134

Figure 14
coin 184

Figure 15

coin 237

Figure 16

coin 245

Figure 17

coin 253

Figure 18

coin 259

Figure 19

coin 265

Figure 20

coin 302

Figure 21

coin 313

Figure 22

coin 335

X-Ray Fluorescence Spectroscopy Results of Late Kushan Copper Coins

Table 1

Elemental Analysis (mas. %) by WD-XRF of Late Kushan Copper Coins from Obverse and Reverse View

No	Element		Cu	Si	P	S	Ni	Pb	Ag	Co
1	Coin 1	Obverse	98.692	0.821	0.025	0.058	_	_	_	_
		Reverse	90.632	8.88	0.023	0.095	_	_	_	_
2	Coin 5	Obverse	77.339	15.591	0.021	0.101	0.022	0.135	4.768	_
		Reverse	75.916	15.668	0.021	0.105	0.037	0.273	5.014	_
3	Coin 7	Obverse	95.404	3.813	0.024	0.023	_	_	_	_
		Reverse	87.298	11.648	0.022	0.072	0.001	_	_	_
4	Coin 26	Obverse	98.568	0.873	0.025	0.06	_	_	_	_
		Reverse	79.713	18.0	0.02	0.089	_	_	_	_
5	Coin 27	Obverse	98.386	0.924	0.025	0.036	_	_	_	_
		Reverse	86.509	12.587	0.022	0.069	0.004	_	_	_
6	Coin 36	Obverse	98.594	0.893	0.025	0.035	_	_	_	_
		Reverse	89.277	10.032	0.022	0.166	_	_	_	_
7	Coin 40	Obverse	90.228	9.255	0.023	0.177	0.002	_	_	_

No	Element		Cu	Si	P	S	Ni	Pb	Ag	Co
		Reverse	90.518	8.684	0.023	0.169	0.005	–	–	–
8	Coin 56	Obverse	81.671	14.578	0.021	0.121	0.043	–	–	–
		Reverse	77.721	17.305	0.021	0.094	0.044	–	–	–
9	Coin 81	Obverse	98.69	0.852	0.025	0.02	–	–	–	–
		Reverse	88.638	10.691	0.022	0.041	–	–	–	–
10	Coin 98	Obverse	94.934	4.088	0.024	0.045	–	–	–	–
		Reverse	84.648	14.431	0.021	0.02	–	–	–	–
11	Coin 109	Obverse	84.868	14.051	0.021	0.123	–	–	–	–
		Reverse	87.399	11.815	0.022	0.159	–	–	–	–
12	Coin 129	Obverse	97.18	2.067	0.024	0.054	–	–	–	–
		Reverse	90.358	8.404	0.062	0.068	–	–	–	–
13	Coin 134	Obverse	95.113	3.749	0.024	0.052	0.001	–	–	–
		Reverse	88.464	10.42	0.022	0.105	–	–	–	–
14	Coin 184	Obverse	97.956	0.967	0.025	0.02	–	–	–	–
		Reverse	87.661	11.345	0.022	0.087	–	–	–	–
15	Coin 237	Obverse	95.033	4.277	0.024	0.033	0.001	–	–	–
		Reverse	85.799	13.584	0.022	0.048	–	–	–	–
16	Coin 245	Obverse	97.548	1.691	0.025	0.039	–	–	–	–
		Reverse	86.28	12.955	0.022	0.051	–	–	–	–
17	Coin 253	Obverse	90.898	8.747	0.023	0.048	0.004	–	–	–
		Reverse	91.769	7.806	0.023	0.018	0.001	–	–	–
18	Coin 259	Obverse	96.284	3.008	0.024	0.058	0.006	–	–	–
		Reverse	90.321	8.689	0.023	0.106	0.004	–	–	–
19	Coin 265	Obverse	89.849	8.978	0.023	0.124	–	–	–	–
		Reverse	91.419	7.389	0.023	0.14	–	–	–	–
20	Coin 302	Obverse	96.608	2.862	0.024	0.031	–	–	–	–
		Reverse	89.47	9.963	0.022	0.092	0.002	–	–	–
21	Coin 313	Obverse	95.806	3.223	0.024	0.05	0.05	–	–	0.169
		Reverse	90.628	8.486	0.023	0.094	0.043	–	–	0.145
22	Coin 335	Obverse	86.62	12.95	0.022	0.06	–	–	–	–
		Reverse	92.35	7.046	0.023	0.102	–	–	–	–

Figure 23

obverse spectrum of coin 1

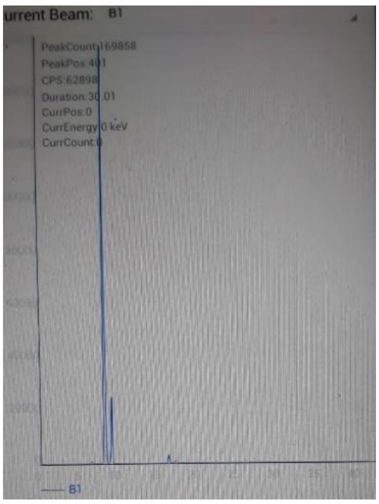


Figure 24

reverse spectrum of coin 1

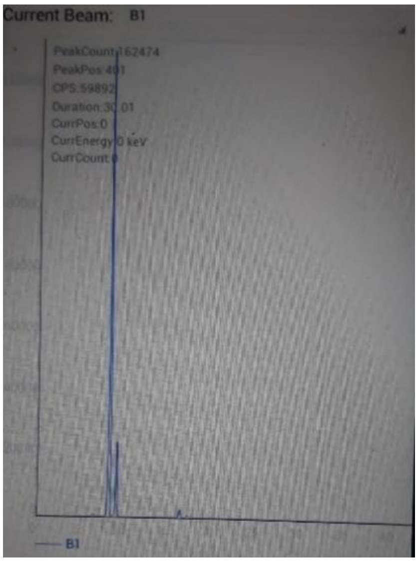


Figure 25

obverse spectrum of coin 5

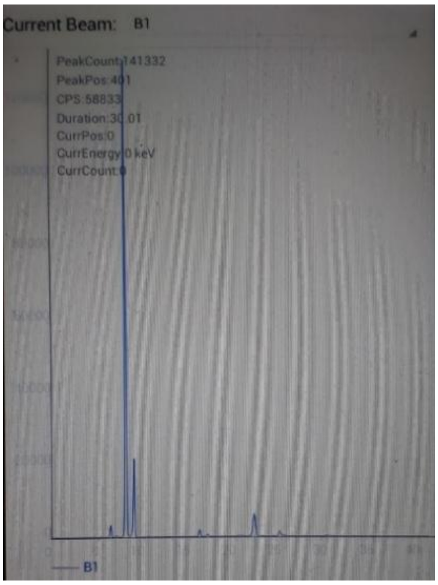


Figure 26

reverse spectrum of coin 5

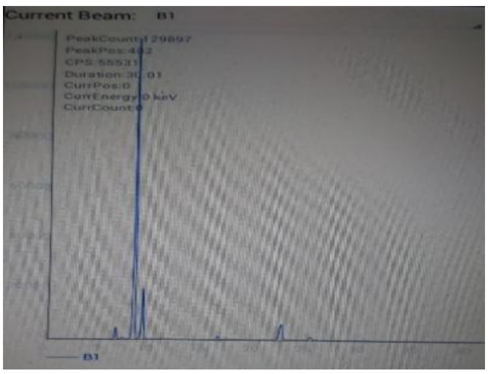


Figure 27

obverse spectrum of coin 7

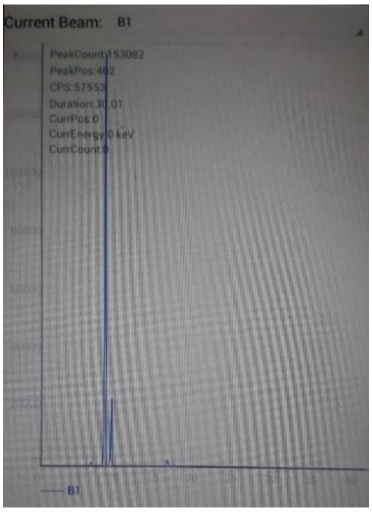


Figure 28

the reverse spectrum of coin 7

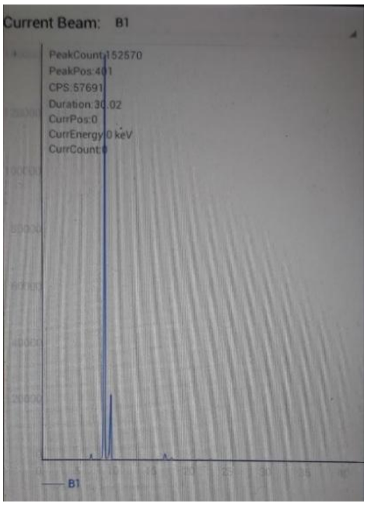


Figure 29

the obverse spectrum of coin 26

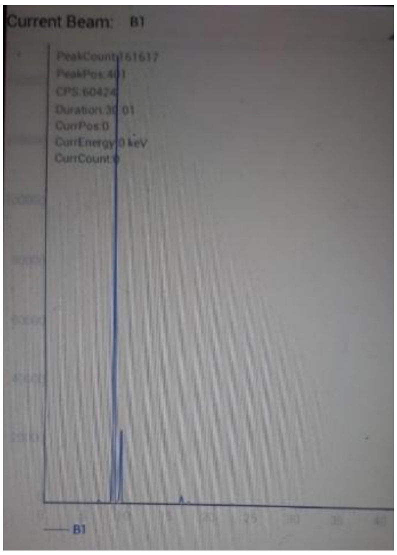


Figure 30

reverse spectrum of coin 26

Figure 31

obverse spectrum of coin 27

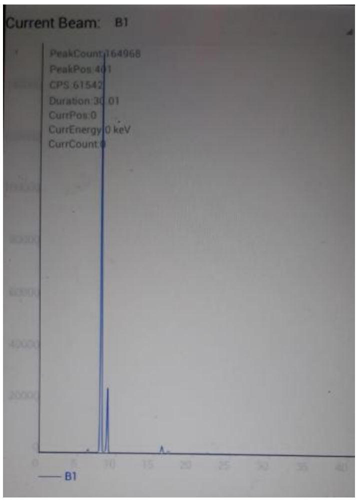


Figure 32

the reverse spectrum of coin 27

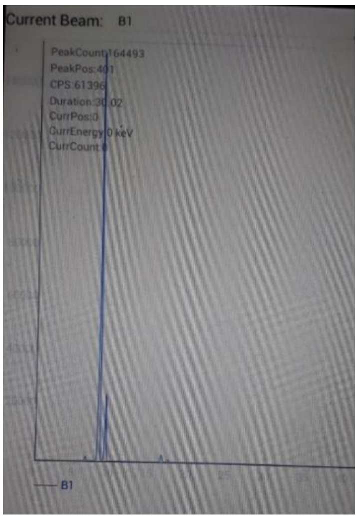


Figure 33

the obverse spectrum of coin 36

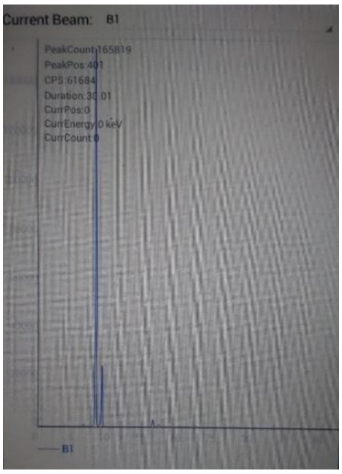


Figure 34

reverse spectrum of coin 36

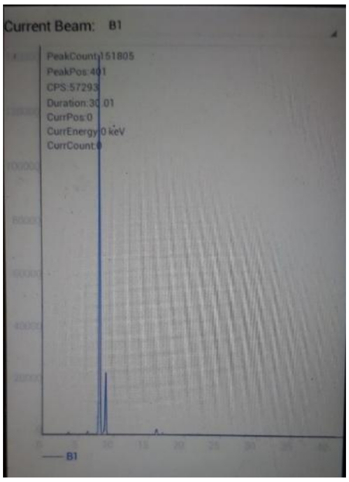


Figure 35

the obverse spectrum of coin 40

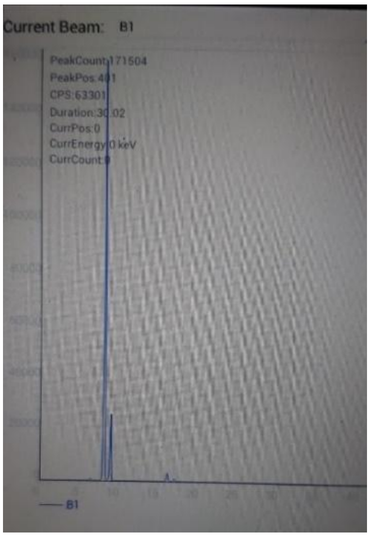


Figure 36

reverse spectrum of coin 40

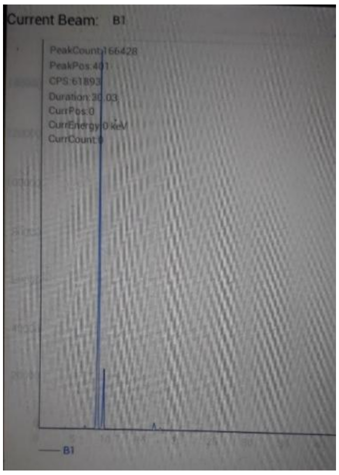


Figure 37

the obverse spectrum of coin 56

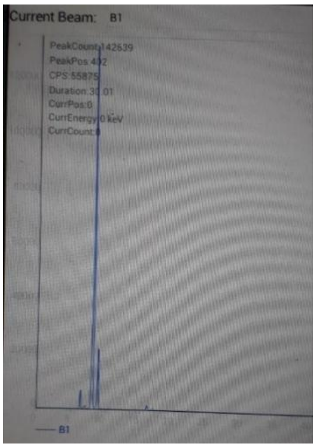


Figure 38

the reverse spectrum of coin 56

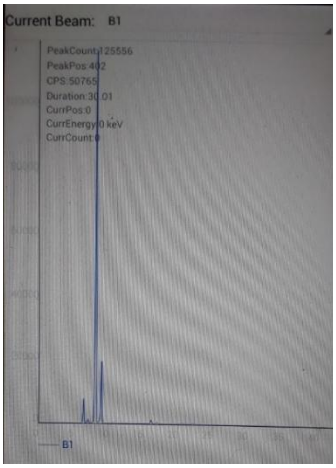


Figure 39

the obverse spectrum of coin 81

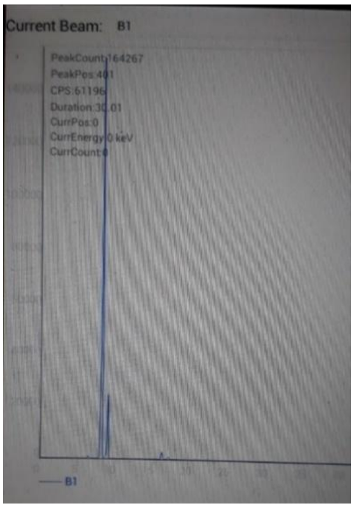


Figure 40

reverse spectrum of coin 81

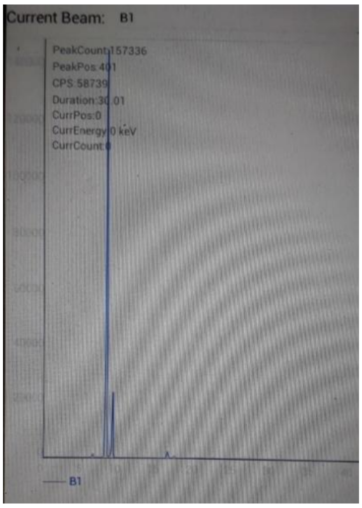


Figure 41

the obverse spectrum of coin 98

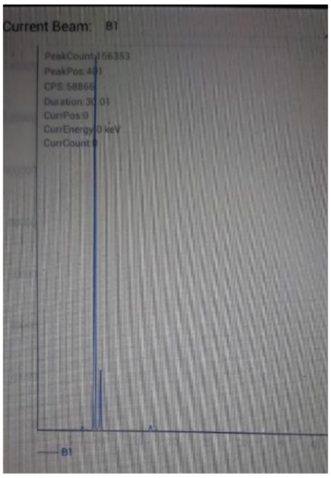


Figure 42

the reverse spectrum of coin 98

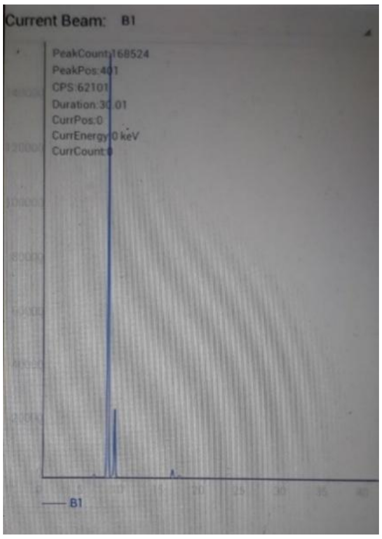


Figure 43

the obverse spectrum of coin 109

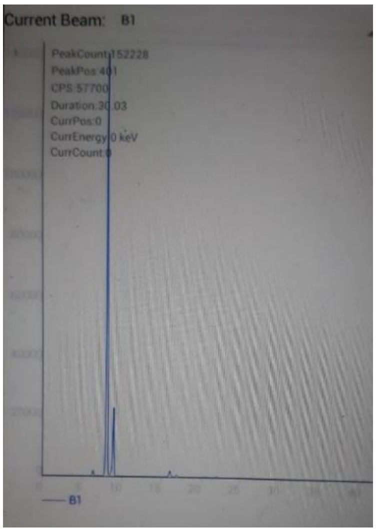


Figure 44

the reverse spectrum of coin 109

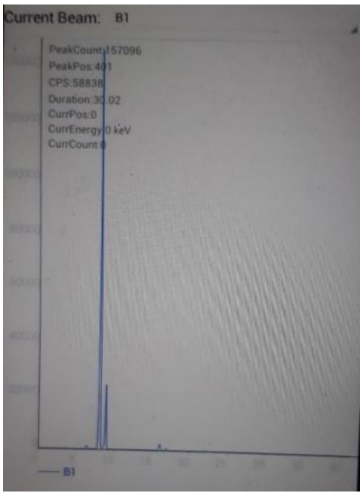


Figure 45

the obverse spectrum of Coin 129

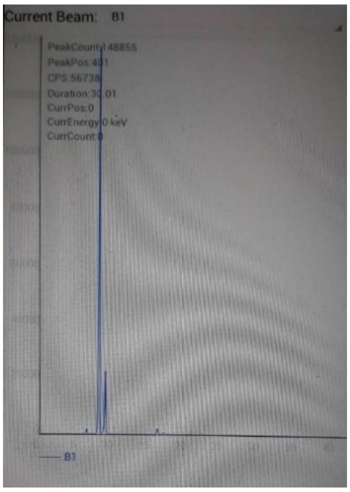


Figure 46

the reverse spectrum of coin 129

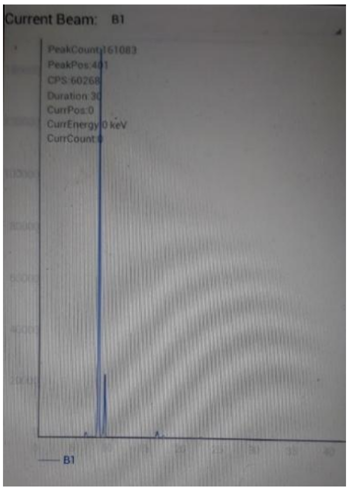


Figure 47

the obverse spectrum of coin 134

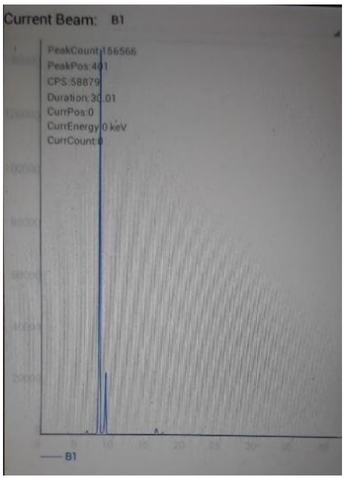


Figure 48

the reverse spectrum of coin 134

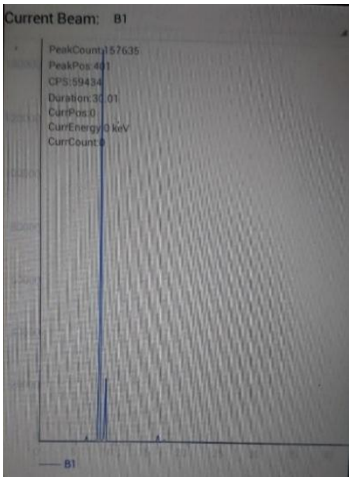


Figure 49

the obverse spectrum of coin 184

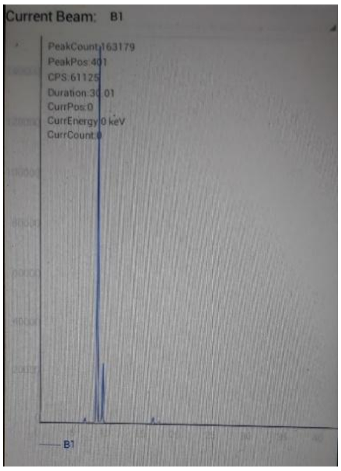


Figure 50

reverse spectrum of coin 184

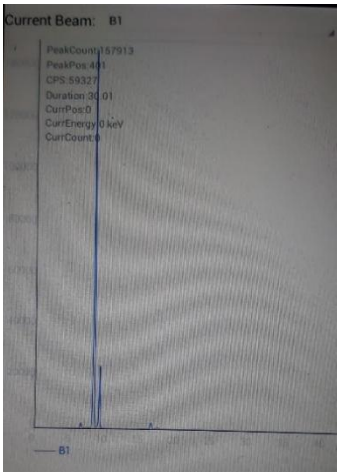


Figure 51

the obverse spectrum of coin 237

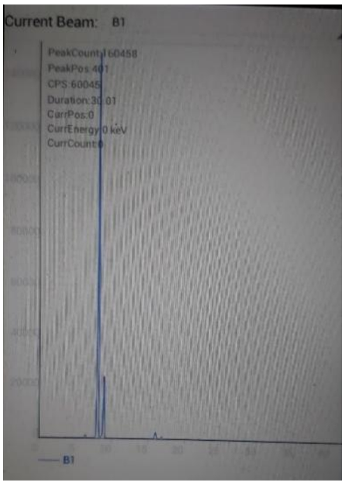


Figure 52

reverse spectrum of coin 237

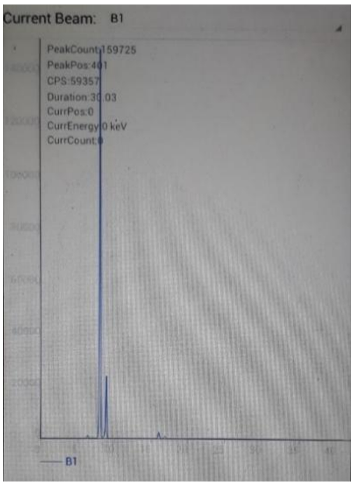


Figure 53

the obverse spectrum of coin 245

Figure 54

reverse spectrum of coin 245

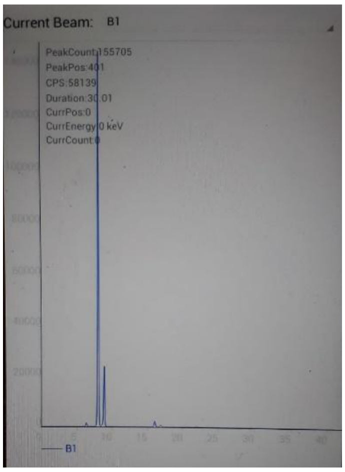


Figure 55

the obverse spectrum of coin 253

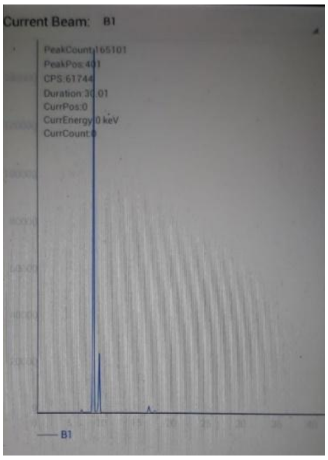


Figure 56

reverse spectrum of coin 253

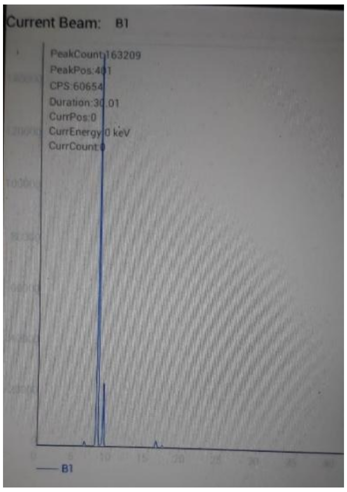


Figure 57

the obverse spectrum of Coin 259

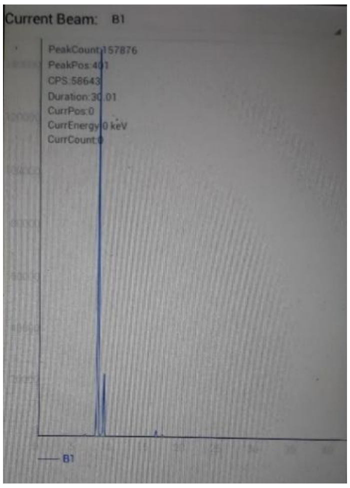


Figure 58

reverse spectrum of coin 259

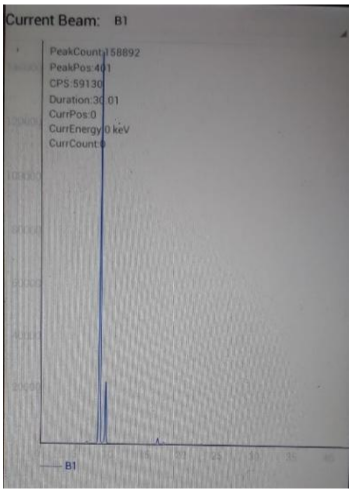


Figure 59

the obverse spectrum of coin 26

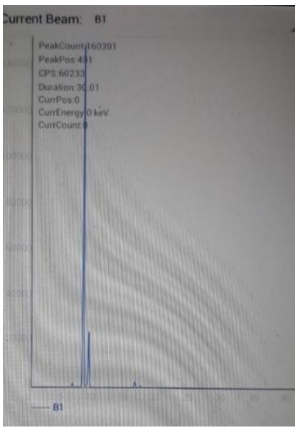


Figure 60

reverse spectrum of coin 265

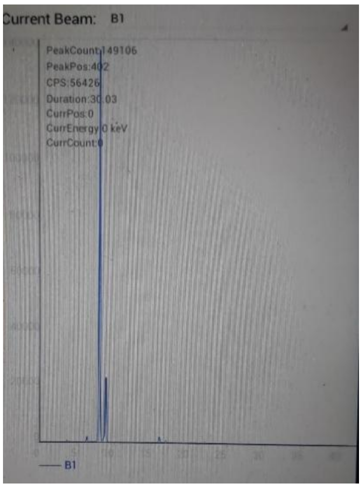


Figure 61

reverse spectrum of coin 302

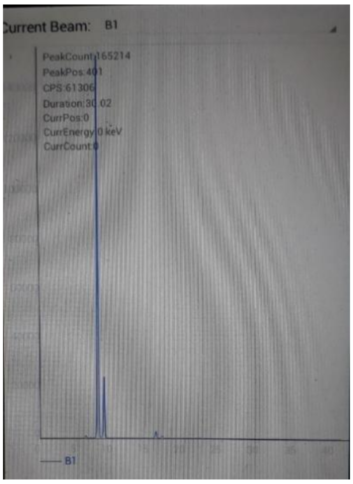


Figure 62

the obverse spectrum of coin 302

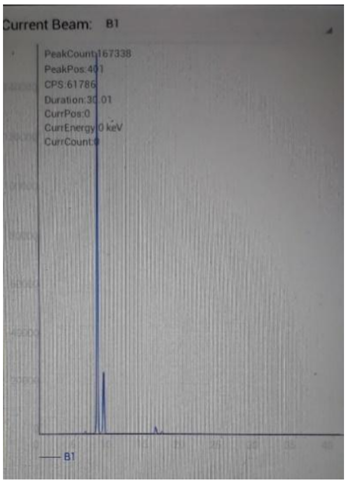


Figure 63

the obverse spectrum of coin 313

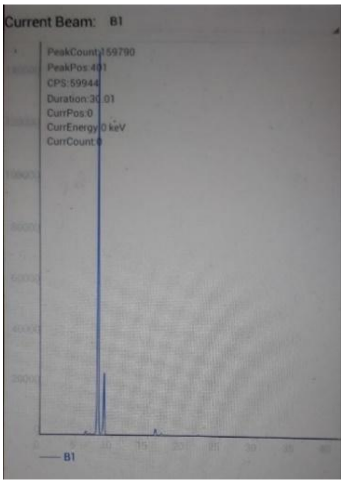


Figure 64

reverse spectrum of coin 313

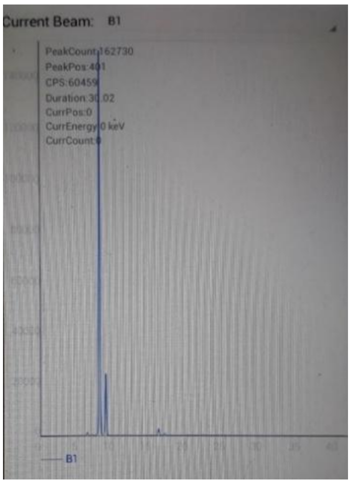


Figure 65

the obverse spectrum of coin 335

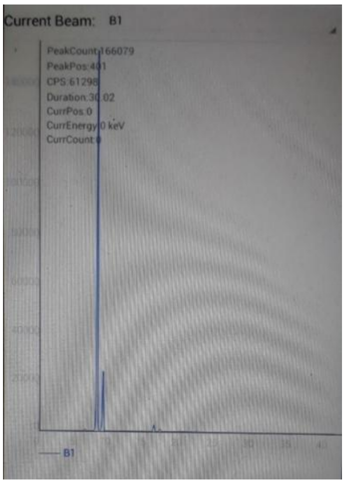
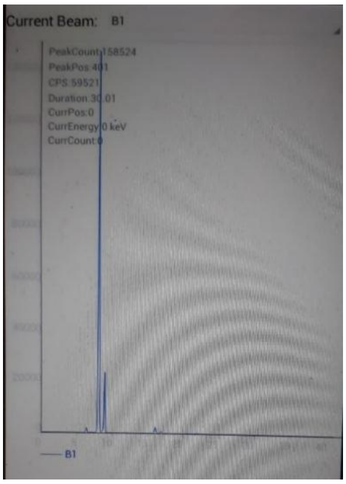


Figure 66
reverse spectrum of coin 335



Discussion

The Late Kushan copper coins are a window into the technological capabilities and minting practices of the Kushan Empire. Archaeological evidence suggests that the primary method of coin production was striking rather than casting. The presence of consistent design features and sharply detailed imprints in Late Kushan copper coins strongly suggests that they were produced through striking rather than casting. Supporting evidence comes from archaeological findings of minting tools and die remnants, which exhibit significant wear patterns consistent with high-volume production. The accuracy and complexity of the dies reflect a high level of skill and technical development within Kushan's striking performance.

The elemental study, mainly through X-ray Fluorescence (XRF), exposes that these coins were not collected of pure copper but were as alternative compound alloys (Oud Bashi, et. al, 2023). Elements such as tin, lead, and nickel were deliberately further probable to recover automatic strength, and stability, and to decrease support on pure copper, which may have been costlier or less freely offered. This careful alloying proposes that Kushan metallurgists controlled a nuanced understanding of metal properties and operated them to enhance both the monetary efficiency and physical flexibility of the coinage.

An obvious trend in the steady decline of coin weight among Late Kushan matters seems to have resulted from numerous contributing causes. Initially, physical wear from prolonged circulation would obviously corrode material over the period. Moreover, copper's liability to erosion, mainly in funeral surroundings, is more added to material damage. Furthermore, developing minting applications probably played a part. In reaction to monetary pressures, Kushan establishments might have deliberately compacted the metal content per coin to increase economic resources, resulting in well-lit, later-issue coins.

The exposure of alloying elements and contaminations suggests the main perceptions of the metallurgical performance of the Kushan period. While metals like tin and lead were purposely combined to improve coin value, the presence of contaminations such as silica, iron, sulfur, and phosphorus recommends suboptimal smelting procedures. These impurities are to be expected made from the copper ore or from insufficient purifying procedures. The usage of sulfide ores for smelting is obvious, up till now the conservation of unstable and destructive elements like sulfur highlights technical confines or cost-driven cooperation in metallurgical processes.

XRF and WD-XRF examine specific restricted applications of sulfur and silica on coin surfaces. Though sulfur naturally causes faster erosion, its instability and propensity to isolate into inaccessible regions may have summary whole corrosion but added to spot-specific degradation. The occurrence of phosphorus and silica, mainly in raw forms, points to ineffective purifying procedures maybe due to insufficient pushing or deficiency of progressive metallurgical facts.

Relative investigation with additional Indian Kushan coins makes known important differences in composition and manufacturing methods. Different from many Kushan coins that work additional advanced alloying procedures, the considered hoard includes coins made mostly of copper with varying impurity outlines. These differences may reveal local differences in resource accessibility, technical abilities, or monetary circumstances within the broader Kushan Empire. Such changes highlight the significance of restricted observations in taking the difficulty and variety of ancient minting behaviors.

Inclusive, the metallurgical and technological features of Late Kushan copper coins reveal a lively interaction between financial requirements, source availability, and developing skills. The results not merely lighten the difficulty of Kushan minting performs but equally expose the tasks and variations that molded their material values.

Conclusion

The multi-analytical study of Late Kushan copper coins deals with a complete understanding of the metallurgical performance and financial plans of the Kushan Kingdom. The outcomes point to the practice of sulfide ores and the occurrence of important contaminations such as silica, phosphorus, and sulfur. Furthermore, the thoughtful use of comparatively pure copper relative to other commonly used alloys such as bronze or brass reveals both technical confines and deliberate executive by the Kushan minting system. These selections were probably influenced by means of resource accessibility, manufacturing abilities, and usual monetary burdens.

The existence of these impurities proposes limitations in purifying technology, indicating to not as much of stylish smelting techniques. At the same time, the selection to mint coins with pure copper may symbolize a practical method, matching the requirement for a constant currency with the monetary realism of raw material obtaining and treating. The experimental differences between this coin hoard and further Kushan coinages underscoring local differences in metallurgical applies, highlighting the flexibility of the Kushan Empire to native resources and situations.

Although the learning offers appreciated information on minting methods and their wider monetary inferences, it would benefit from an additional relative outline. Investigating coins from numerous areas or chronological stages within the territory could contextualize these results and support recognizing larger numismatic styles. Furthermore, discovering socio-political issues such as moves in trade systems, governmental developments, or times of political uncertainty could improve our acceptance of the monetary deflation evident in the Late Kushan era.

The investigation pays meaningfully to our consideration of the Kushan Empire's technological abilities and monetary preparation. Data proposes that refined minting procedures were employed, formed by both technological development and applied financial considerations. The conservation approach suggested in this research goal is to confirm the long-term preservation of these historically appreciated coins, emphasizing the significance of participating in scientific study with culture conservation.

Moreover, the usage of sulfide ores and the existence of contaminations such as iron, sulfur, and silica suggest that smelting procedures were less sophisticated. These features suggest that the metallurgical processes probably happened at comparatively low temperatures, and insufficient purifying methods such as unsuitable poling might have delayed the effective elimination of undesirable elements.

Generally, this study develops our information on ancient coinage manufacture, reflecting the connection of skill, monetary, and resource administration in the Kushan period. It correspondingly highlights the wider role of archaeometallurgy in conserving and understanding cultural heritage over interdisciplinary methods.

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