doi:10.1017/S143192761801499X
Microsc. Microanal. 24 (Suppl 2), 2018

Will Synchrotron Studies Unlock the Mystery of the Invention of Coinage?

Lisa L. Van Loon[1,2,3], Andrew J. Nelson,[3,4] and Neil R. Banerjee[1,2*]

[1.] Numismatic Institute of North America Inc., London, Canada.
[2.] Department of Earth Sciences, Western University, London, Canada.
[3.] Department of Anthropology, Western University, London, Canada.
[4.] Department of Chemistry, Western University, London, Canada.
* Corresponding author, neil.banerjee@uwo.ca

The invention of coins changed the world forever by permanently changing the way society operates. Coinage has profoundly affected the lives of individuals and economies of states in immeasurable ways, and yet has remained remarkably unchanged for millennia. But unlike other momentous events that shaped world history such as the invention of agriculture and writing, for which there is a large body of scholarly inquiry, surprisingly little research exists on the invention of coins. The first coins were minted in the mid-7th century BCE in Western Asia Minor, by the Kings of the Lydian Empire. These coins were made of electrum, an alloy of gold and silver. They are small and irregularly shaped with powerful visual images, executed in exquisite artistic detail. The coins have specific metallic content, weight, and value. While there is consensus about when and where these coins were made, it is much less clear why electrum was used. Popular theory suggests that alluvial nuggets were used, but it is more likely that the earliest coins were minted from a man-made alloy created by mixing alluvial gold with mined silver.

In the past few years, a small group of scholars, including numismatists, archaeologists, scientists, and monetary historians have begun to re-examine the evidence for the invention of coins [1,2]. We take the position that instead of answering, in isolation, why these coins were first produced, we must first address how they were made. There are many theories in the literature regarding why these early coins were produced, but they lack a sound theory of both the process of and rationale for early coin production. We are applying state-of-the-art synchrotron radiation and associated analytical techniques to large numbers of electrum coins to better understand trace element variations, the origin and provenance of the metals used, as well as metallurgical techniques utilized during minting.

Experimental: Lydian electrum coins, modern 99.999% gold coins, and gold reference materials were analyzed for their trace element composition at the F3 (CHESS), 20-ID (APS), VESPERS, and IDEAS (CLS) beamlines. High-energy synchrotron radiation micro X-ray fluorescence (SR-μXRF) and synchrotron radiation X-ray diffraction (SR-XRD) data was collected at 11-ID (APS). High-energy SR-μXRF and μCT data was collected at 1-ID (APS). Synchrotron radiation X-ray photoelectron spectroscopy (SR-XPS) data was collected at the VLS-PGM and SXRMB beamlines (CLS).

The trace element composition of coins was examined using an excitation energy of 11.6 keV to minimize detector saturation by the gold fluorescence. At IDEAS, the entire coins and reference materials were mapped with a 500 μm x 500 μm beam spot size. At VESPERS and 20-ID, sections of the coins were mapped using a spot size of 5-7 μm x 5-7 μm and a dwell time of 1 second. All data was analyzed using Peakaboo, software [3]. At F3, SR-μXRF mapping of the entire coins was done using a Maia detector at 20 μm resolution and 5 msec dwell time. The data was analyzed using GeoPIXE [4]. The composition information of the heavier elements such as Ag, Pt, W, and Bi was obtained at 11-ID and 1-ID. At 11-ID SR-μXRD and SR-μXRF data were collected using an excitation energy of 105.6

keV and a 100 µm x 100 µm spot. SR-µXRD data was collected to overlay the XRF data. At 1-ID SR-µXRF and SR-µCT data was collected on the outer rims of the coins. The SR-µXRF data was collected 80 keV, just below the gold K-edge, but at sufficient energy to excite Pt. µCT data was collected at 80 keV and 103 keV with an exposure time of 30 msec. SR-XPS data was collected at 160 eV, 3000 eV and 7000 eV and a beam spot size of 600 µm. At least 10 data points were collected on each coin.

Results: SR-µXRF mapping reveals trace element variation within and between coins, Figure 1. The electrum components gold and silver are found together, but Cu is distributed in a unique honeycomb pattern, suggesting that Cu is segregated to grain boundaries. SR-XPS reveals differences in the electrum and trace elements distribution at the surface of the coins to a depth of 20 nm. Au and Ag are observed at the surface but Cu is not, suggesting that Cu is likely oxidized and has dissolved off the surface, enriching the Au-Ag. The combination of SR-µXRF, SR-µXRD and SR-µCT provides information about the relationship between structural components such as inclusions, electrum, and trace elements shedding new light on the question "How were the first coins made?" [5].

References:

[1] *White Gold*, Jerusalem, Israel Museum (2012).
[2] *The Beginning of Coinage: New Discoveries and Research on Early Electrum Coinage.* American Numismatic Society (2013).
[3] N. Sherry *et al*, Science Studio: a Computer Network and Software for the Collection and Management of Scientific Data from Remote Sites Project Summary (2012) p.1.
[4] Maia GeoPIXE Software: Wizard Programming Interface, CSIRO Report EP155331
[5] Research described in this paper was performed at the Canadian Light Source (CLS), the Advanced Photon Source (APS), and the Cornell High Energy Synchrotron Source (CHESS). The CLS is supported by CFI, NSERC, the University of Saskatchewan, the Government of Saskatchewan, Western Economic Diversification Canada, the NRC, and CIHR. The APS is an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science by Argonne National Laboratory, and is supported by the U.S. DOE under Contract No. DE-AC02-06CH11357. CHESS is supported by the National Science Foundation under award DMR-1332208. The authors thank Renfei Feng, Peter Blanchard, Ronny Sutarto, and Xiaoyu Cui (CLS), Zou Finfrock, Robert Gordon, Andrew Chuang, Sarvjit Shastri, Yang Ren, Uta Ruett (APS), and Arthur Woll, Rong Huang, and Louisa Smieska (CHESS) for their support in conducting the experiments. Coins analysed in this study were graciously provided by the American Numismatic Society, Jonathan Kagan, and Ute Wartenberg Kagan. Gold reference materials were graciously loaned by the Royal Canadian Mint.

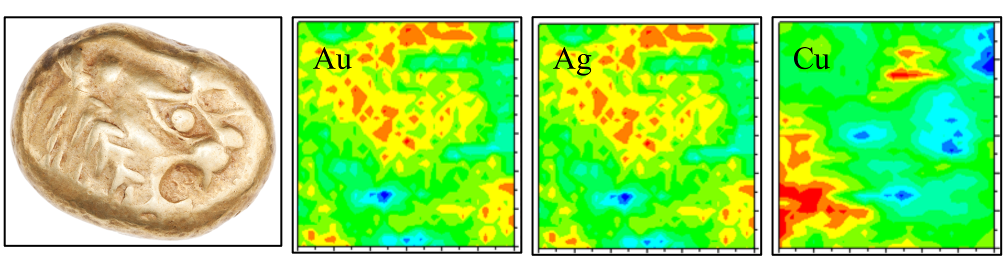

Figure. 1. Lydian lion electrum coin with SR-µXRF maps of the electrum components Au, Ag, and Cu inside and below the lion's mouth, collected with a 7 µm x 7 µm beam spot size at VESPERS. Each map is 300 µm x 300 µm. The distribution of gold and silver correlate, while copper does not.

https://doi.org/10.1017/S143192761801499X Published online by Cambridge University Press