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

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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:
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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.