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Bubbles in the Bullion: Micro-CT Imaging of the Internal Structure of Ancient Coins

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The earliest coins known to mankind were made of electrum, an alloy of gold and silver, in Western Turkey in the middle of the 7th century BCE, within the geographical and political context of the Lydian Empire. The invention of coinage created new economic patterns and behaviours in the ancient world, which remain fundamentally in place today. Such Lydian and other coins are irregularly shaped but approximately circular. Interestingly, they adhere strictly to a set of weight standards and have weights ranging from ~17 g (stater) to ~0.05g (1/192th stater) [1]. Many of the coins have designs on the obverse and more simple punches on the reverse. The coin discussed in this paper (ANS 1977.158.75) (Fig. 1b) is part the most famous series, the so-called "Phanes" coinage, which shows a grazing stag on the obverse; on this small 1/48th stater, weighing 0.3g, only the head of the stag is shown [2].

This research is part of a larger interdisciplinary project that seeks to place the origin of coinage within its cultural, economic and geological context to better understand this momentous event in our history. We have used synchrotron micro-X-ray fluorescence (SR-μXRF) to determine the trace element variations and origin and provenance of the metals [3]. In addition, we are conducting micro-computed tomography (μCT) analysis to shed light on the internal structure of these coins to gain insight into how these coins were made. To our knowledge, this is the first μCT examination of early electrum coins.

Coins were analysed at Sustainable Archaeology at Western University in London, ON. Data was collected with an industrial high-power Nikon Metris XTH-225ST micro-computed tomography (μCT) system with a microfocus X-ray source and a rotating tungsten target. The samples were mounted on the holder vertically, Figure 1a, and 3140 projection images were gathered as the sample rotated through 360^{o}. The coins examined ranged in weight from less than a gram to a full stater.

The acquisition parameters were a tube potential of 225 kVp and a tube current of 400 μA. A 500 msec exposure was used to collect each frame and 2 frames were collected per projection to increase the signal to noise ratio. The volume resolution was 10^3 μm voxels. Each analysis took >2 hours. An 8 mm thick Cu filter on the head and 1 mm thick Cu filtration sheet on the detector were used to minimize scatter and beam hardening. A Pb collimator was placed between the object and the detector.

Data acquisition was done using the Inspect-X v.4.3 software (Nikon). Reconstruction of the images was performed with CT-Pro 3D v.4.3 (Nikon). Visualization was done with VG Studio Max v.2.2 (Volume Graphics, Heidelberg) or ORS Visual SI v.1.8.0.1913 (Object Research Systems, Montreal, QC).

The romantic narrative found in many modern accounts suggests that the minting of Lydian electrum coins was very primitive; naturally occurring electrum nuggets were collected from the Hermos and Pactolus Rivers (called the Gediz River in modern Turkey) and these were hammered into staters. However, an alternative view is that the electrum was purposefully created by mixing alluvial placer gold with mined silver. Coins produced from these two methods would be expected to have different internal structures. We undertook µCT analysis to address this question by examining the metal matrix of the coin.

The analysis of coins made from a gold-silver alloy using µCT presents a tremendous challenge. First, only an industrial high-power µCT system has sufficient tube potential to penetrate the dense metal matrix. Second, even with high power, beam hardening and image artefacts occur, complicating the analysis. Despite these difficulties, we have obtained µCT scans of several Lydian coins. A photograph of one coin and its corresponding µCT surface image are shown in Figure 1 b and c. Beam hardening and image artifacts are minimal in the smallest coins and most affect the larger coins.

Several structural features are revealed by the µCT imaging. Cracks, varying thickness, dense material inclusions, and bubbles are revealed in the µCT images. First, the images indicate that the gold and silver are homogeneously mixed. Small, dense inclusions are heavier elements that did not melt and homogenize into the gold-silver alloy. Considering of what we know about metal refining from the ancient capital Sardis [4], it is not surprising that the temperature was not sufficient to melt PGE's. The punches on the reverse sides (not shown) create regions of minimum thickness. Cracks radiate from the edges but disappear towards the centers of the coins. The coins also show a distinctive pattern of void spaces reminiscent of small bubbles in the alloy matrix. Together, these observations on the internal structure of Lydian coins suggest that the refining and minting of these electrum coins was much more complex than previously thought [5].

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Figure 1. (a) Photograph of a Phanes electrum coin mounted for µCT analysis; (b) Photograph of the obverse side of the Phanes electrum coin with a stag head to right; (c) µCT image of the surface of the coin in (b) showing the surface profile as well as cracks near the antler at the coin edge.

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