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ANALYSIS OF GOLD HOARD FROM LATE ROMAN/EARLY BYZANTINE PERIOD FOUND IN JORDAN

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ABSTRACT

Thirty-four gold solidi coins and two pairs of gold/jewel earrings were discovered at an archaeological site in Jordan, Tell Nimrin. The coins have stamped images of six late Roman/early Byzantine emperors who reigned from 346 AD to 518 AD. These objects were analyzed by X-ray radiography, SEMEDS and density measurements to find the gold content for comparison with other coins of that period to support their authenticity and to see whether debasement of coinage had occurred. The average surface gold content was found by EDS to be 98.1 wt %--typical of the period--but the bulk content calculated from density values was 1 to 3 wt % lower. The reason offered is that when a molten gold-copper or gold-silver alloy solidifies, the region in contact with the blank coin mold freezes first and is gold-enriched. Small “silvery” specks were observed on the obverse (“heads”) side of several coins and found by EDS to be Os-Ir-Ru alloys, which come from placer mining and indicate that the gold also came from placer mining.

INTRODUCTION

At an archaeological site in Jordan, Tell Nimrin, JWF uncovered in 1993 a trefoil-mouth terra cotta juglet containing a remarkable collection of ancient gold objects--34 gold coins (solid) and two pairs of gold/jewel earrings. Since there were archaeological interests in studying these objects by analytical methods as well as having them examined by numismatists, the Jordanian government allowed them to be brought to the U. S.--but not for public display and only for study with nondestructive techniques--and then returned to Jordan.

For nondestructive analysis the following methods were chosen: scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEMEDS), density measurements, X-ray radiography and scanning acoustic microscopy.

The questions to be addressed were: 1) What is the gold content of these objects? 2) Is there any sign of debasement of the coinage? 3) Is there any indication that the coins and earrings are not authentic? 4) What are the “silvery” specks in some of the coins? These studies were conducted in Cleveland, Ohio, at Case Western Reserve University and the XRI Testing Division of X-ray Industries, Inc.

The site of the discovery of the gold hoard, Tell Nimrin, is located just north of the Dead Sea near the Jordan River and has been occupied almost continuously since about 2000 B.C. Figure 1 shows a map of the region, a view of the area from the top of the Tell, an external view of some of the ancient walls, and the archaeological dig.

The 34 gold coins are stamped with images of six different emperors from the late Roman/Early Byzantine era and also information on the dates and the mints. Figure 2 shows photos of the obverse and reverse sides of the oldest, the latest and the rarest coins [1]. Table I lists the information about the coins and the emperors [2].

A description of the experiment, its results, a discussion and the conclusions follow.
Figure 1. Region in Jordan where gold hoard was found (Tell Nimrin). (a) map of region: Tell Nimrin lies just north of Dead Sea and near Jordan River. (b) View of local region from top of Tell Nimrin. (c) Archaeological site. (d) ancient walls.
Fig. 2. Photos of three gold coins from the hoard of 34 found at Tell Nimrin in Jordan. The emperors shown and the range of the coin dates are: (a) Valentinian, 364-367 A.D.; (b) Basiliscus, 475-476 A.D.; and (c) Anastasius I, 491-518 A.D. Top row: obverse (heads) side of the coins; bottom row: reverse (tails side).

TABLE 1. List of Roman and Byzantine emperors whose images are stamped on the gold coins found at Tell Nimrin. Also listed are the range of coin dates, the cities where the coins were minted and the number of each.

<table>
<thead>
<tr>
<th>EMPEROR</th>
<th>DATES</th>
<th>MINT</th>
<th>NO. OF COINS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valens</td>
<td>364-367 AD</td>
<td>Antioch</td>
<td>8</td>
</tr>
<tr>
<td>Valentinian</td>
<td>364-367 AD</td>
<td>Antioch</td>
<td>11</td>
</tr>
<tr>
<td>Leo I</td>
<td>457-473 AD</td>
<td>Constantinople</td>
<td>3</td>
</tr>
<tr>
<td>Basiliscus and Marcus</td>
<td>475-476 AD</td>
<td>Constantinople</td>
<td>1</td>
</tr>
<tr>
<td>Zeno</td>
<td>476-491 AD</td>
<td>Constantinople</td>
<td>7</td>
</tr>
<tr>
<td>Anastasius I</td>
<td>491-518 AD</td>
<td>Constantinople</td>
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</table>
EXPERIMENT

Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM/EDS)

The most useful analytical technique employed was SEM/EDS, which could quickly evaluate the gold content and minor elements in the near-surface regions of the coins and earrings. With 34 wins to analyze and with limited time, it was important to use a high-speed method. Furthermore, no surface preparation was required—or allowed—for these analyses. Although the gold objects had been buried for approximately 1500 years, their surfaces are still electrically conductive, since gold is relatively unreactive chemically.

The instrument used was a JEOL 840 Scanning Microanalyzer, located in the Department of Macromolecular Science at Case Western Reserve University (CWRU), Cleveland, Ohio. The sensitivity of the EDS system for elemental analysis by characteristic X-ray emission is about 0.1 wt% for elements heavier than sodium, and the precision is approximately ± 0.05 wt%.

A reference standard—a modern British gold sovereign—was studied by SEM/EDS before the ancient coins were examined to become familiar with the X-ray spectra of gold and copper.

Density Measurements

As part of the win analysis, the densities of several coins from the hoard were measured. From the density measurements—and the EDS information on the minor element content—the bulk gold content could be calculated to compare with the near-surface content from EDS data.

The method for evaluating the density of these ancient coins was the ancient Archimedes approach based on his principle that the loss of weight of a submerged object equals the weight of the liquid displaced. The liquid used was distilled water with Kodak Photo-Flo added as a wetting agent to reduce surface tension around the wire supporting the coin; the instrument used was a Mettler analytical balance and a Mettler 33340 Density Determination Kit. The density measurements were conducted in the Department of Materials Science and Engineering, CWRU.

The handbook values of the densities of the elements expected in the coins are: Au, 19.3 g/cc; Ag, 10.5 g/cc; Cu, 8.96 g/cc; and Fe, 7.87 g/cc. These are needed to calculate the gold content from the bulk density and information on the other elements present.

X-ray Radiography and Scanning Acoustic Microscopy

X-ray radiography was used as a nondestructive method to search for interior features of the gold coins, such as porosity from casting or a base of entirely different composition. These features could affect density measurements and hence lead to incorrectly calculated gold content.

The gold/jewel earrings were also examined by X-ray radiography to see whether the gold stem that appeared between the jewels actually went through them continuously.

The X-ray instruments were located at the X.RI. Testing Division of X-ray Industries, Inc., in Cleveland, Ohio. The voltage setting varied 60 m 15 to 80 kV, and the exposure time ranged from 20 to 30 seconds.

Additional information about the interior structure of the coins was attempted to be generated by scanning acoustic (ultrasonic) microscopy. The system used was located in the Department of Macromolecular Science, CWRU.
RESULTS

SEM/EDS

The SEM images of the ancient gold coins showed surface cracks, pits and scratches, unlike the modern British gold sovereign, which showed a relatively smooth surface between the Queen’s image and the inscriptions (see Fig. 3). These surface features on the coins from the hoard support the belief that they are indeed ancient. Several of the coins have long, deep, straight scratches on the obverse surface. Perhaps they were deliberately made to check that the interior was also gold and not bronze. Our analyses support this position.

From the EDS spectrum and data reduction, the near-surface gold content of the modern British sovereign from the black box is 91.9 wt % and the balance is 8.1 wt % copper (Fig. 4a) By contrast, the gold coins from the hoard were found to contain a higher near-surface gold content, ranging from 96.2 wt % to 98.7 wt % and at most only 0.5 wt % copper. Several of the oldest coins contain between 1 and 3 wt % silver (Fig. 4b and Table II)

Figure 3. Surface texture of modern British gold coin (a) and late Roman gold coin (b)

Figure 4. EDS spectra from modern British gold sovereign (a) with 8.1 wt % Cu, and Roman gold coin from hoard (b) with 2.8 wt % silver.
TABLE II. Elemental composition (in weight percent) of near-surface region of 29 gold coins from the hoard found at Tell Nimrin, Jordan, as determined by energy-dispersive X-ray spectroscopy (EDS).

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<th>Cu</th>
<th>Rb*</th>
<th>Au</th>
<th>Au #</th>
<th>Au##</th>
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<td>91.49</td>
<td>99.10</td>
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</tr>
</tbody>
</table>

* Rh (rubidium) X-ray energy peaks overlap several gold peaks. The EDS software identified the peaks as Rb rather than gold. Rb is soluble in Au, but since Rb is an alkali metal with a low melting point and high vapor pressure, it is unlikely to have survived the gold processing. Therefore, the wt % Rb values are added to the sohare Au values to yield column Au #. # A later seving of the SEMEDS instrument adjusted the Au values by - 1.0 wt %.
Eight of the 34 coins displayed many puzzling “silvery” specks. These specks were visible to the naked eye and were examined first by optical microscopy and then by SEM (see Fig. 5a). All of these eight coins with specks--Nos. 5, 6, 7, 8, 12, 13, 14, and 19—are in the first (older) group. The specks appear only on the obverse side of each win except for No. 19, which is covered with specks on the reverse side. With EDS, the specks were found to be composed of osmium, iridium and ruthenium--platinum-group metals--but in different proportions (Fig. 5b,c,d).

![Figure 5: “Silvery” specks on gold coin.](image)

Similar findings have been analyzed by Ogden and by Meeks and Tite. According to their studies, the presence of such inclusions indicates that the gold was recovered by placer mining since these Os, Ir, Ru alloy particles can be washed downstream with particles of gold. Since these elements are virtually insoluble in gold, they survive the melting and refining process and reappear in the final product—a stamped gold coin. Because the alloy particles are denser than gold, they would settle to the bottom of a piece being cast. This description would explain why the “silvery specks” are on the obverse side of the coins—except for one—if the down side of the blank coin is the one that is struck to be the obverse.
SEM and EDS were also used to examine one of the earrings (Fig. 6). The near-surface gold content was found to be 97.9 wt%, which is very similar to the coin values. A pearl-shaped jewel in the earring was examined by EDS and found to consist of only calcium. Since a pearl is made of calcium carbonate but this EDS system cannot detect the low energy X-ray photons emitted by carbon and oxygen, the finding of only Ca is consistent with the pearl identification. A "jewel" in the earring had been guessed to be paste or glass instead of a mineral. This guess was probably supported by the EDS results, which identified the following major elements--Mg, Si, Al, K, Ca, Fe, Cu--and the following minor elements--Ti and Mn. A major peak for CI appeared, but it might have been associated with small salt crystals on the surface. Such a crystal was found on a gold coin by SEM and analyzed with EDS to confirm its composition.

Figure 6. Earring study: (a) photo of the two pairs of earrings found in the hoard. (b) SEM micrograph of a section of one of the earrings-by EDS, 97.9 wt% Au. (c)SEM micrograph of a "jewel." (d) EDS spectrum of "jewel" suggesting glass.
Density

The density values obtained for the two single crystals used to test the Mettler density kit are as follows: 2.714 g/cc for calcite and 2.320 g/cc for silicon. Compared with published densities of 2.710 g/cc for calcite and 2.328 g/cc for silicon, the experimental densities were within -0.15% and +0.34%, respectively.

The gold sovereign’s density was calculated from the weight difference in air and water and using the chemical information supplied by EDS about its alloying material, copper. The calculated density is 8.96 g/cc, and the average bulk gold content calculated from this value is 91.79 wt %, which is within 0.12 wt % of the surface EDS value of 91.90 wt %.

The Tell Nimrin coins were weighed using the Mettler balance. The values are given in Table III.

Due to the ancient coins’ limited accessibility and project time constraints, only coins 1-12 were available for final density determination. Of those 12 coins several appeared to have unusual surface artifacts which might have been damaged by the planned ultrasonic cleaning in acetone and rinsing in methanol and water. In order to preserve the features those coins were not studied; only six coins underwent density analysis. Each of the values of bulk gold content calculated from the density measurements was between 1 and 3 wt % lower than found by EDS for the near-surface composition, for an average of 96.0 wt % Au. A preliminary density analysis of many of the coins also found the calculated gold value to be several percent less than the EDS surface value; the second set confirmed the sign of the difference but reduced its value.

Since the difference between surface and bulk gold content in these coins is small, it cannot be attributed to surface gilding. Such treatment would be necessary for bronze coins to be turned into fake “gold” coins, but not for almost solid gold ones. A likely interpretation is that when the molten gold containing a small amount of silver and/or copper is poured into coin molds, the material that strikes the surface first will solidify with a gold content higher than material which solidifies later. This point is clear from the binary alloy phase diagrams of Au-Ag and Au-Cu: the addition of a small amount of copper or silver to gold lowers its melting point, and there is a separation between the liquidus and solidus curves.

Another possible interpretation is that over the centuries, salty water might have removed some of the copper or silver from the gold surface and thus enriched it. The detection of minute salt crystals on coin Surfaces by SEM/EDS is consistent with that idea, which has been found to apply to gold objects recovered from shipwrecks studied by A. Gordus and P. Gordus [3].
X-ray Radiography and Scanning Acoustic Microscopy

Lighter regions in the radiographs indicated increased X-ray scattering and absorption in the images of the emperors and the other stamped details. The explanation is that plastic deformation during the stamping plastically deforms the surface, increasing the thickness of these regions and reducing the thickness of the flat regions. However, no large pores or other flaws that would seriously affect density were detected, and there was no evidence of a coating over a different material. Similar results were obtained from scanning acoustic microscopy. Although pores can be left in early castings, the act of stamping coins from the cast blanks eliminates them, as pointed out by Hughes and Oddy [4].

X-ray radiographs of the gold earrings showed continuity of the gold stem on which the jewels are supported: it passes through holes in the jewels.

DISCUSSION

The hoarding of Byzantine gold in the 6th century A.D., as illustrated by the Tell Nimrin find, is explained by Hawkes, Merrick and Metcalf: ‘Numerous finds buried in hoards and graves testify to the vast quantities of the precious metal that were available for conversion into personal ornaments and into currency (in the 5th, 6th and 7th centuries)....the bulk of the gold in Germanic hands came not from natural sources directly, but from the Roman and Byzantine world, mainly in the form of coinage passing out of it through plunder, tribute, subsidies and diplomatic gifts”[5].

The Tell Nimrin coins are solidi, the new coinage established by the Emperor Constantine in 309 A.D. at 1/72th of a Roman pound (4.55 g) to replace the debased Diocletianic ameus--1/60th of a pound, or 5.56 g [6]. From the weight measurements conducted in this project (Table III), the coins are close to the solidi 4.55 g standard but presumably through wear they are somewhat lower. The lowest is 4.04 g and the highest is 4.51 g; none is above the standard weight, 4.55 g.

The value of the gold content in the coins and earrings—approximately 98 wt % in the near-surface region—is typical of coins and jewelry of the late Roman/early Byzantine period, as noted by Drayman-Weiser and Herbert in a study of a Byzantine gold medallion: “Although such high purity gold (98.6 % gold, 1.4 % silver) could be the result of surface enrichment, it is also consistent with that reported for ancient [7], early medieval and middle Byzantine periods” [8]. This composition represents natural gold, not a deliberate alloy, and might be able to locate the gold origin from Tylecote’s table [9]. However, the only sources listed with 1-2 wt% silver in the gold are Finland, England and West Africa. More information may now be available.

The presence of “silvery” specks in several of the gold coins suggests the possibility of locating the origin of the gold, since it involves placer mining in specific areas. Detailed studies of platinum-group inclusions were conducted by Ogden [10] and by Meeks and Tite [11], who analyzed numerous objects and identified sources for Os-Ir-Ru alloys of different compositions. However, remelting and faking raise questions about sourcing of gold objects.

The question of possible debasement of the coinage during the period represented by the coins—346 A.D. to 518 A.D.—was answered: no, the gold percentage remained in the neighborhood of 98 wt % at the near-surface region. This result agrees with a statement by Oddy: “Various studies have shown that up to the end of the ninth century the gold coinage of Constantinople (where many of the Tell Nimrin coins were minted) was not debased and consisted of almost pure gold [12].

More details about the archaeological site where the coins were found—its history, archaeology, climate, ecology, anthropology—can be found in a report by Flanagan, McCreery, and Yassine, with McNutt, Dempsey, Ross and Warnock [13].
CONCLUSIONS

1. The hoard of 34 late Roman/early Byzantine gold coins from an archaeological site in Jordan (Tell Nimrin) was analyzed by SEM/EDS and found to have near-surface gold content averaging 98.1 wt %, typical of the period.

2. Density measurements found the bulk content to be 1 to 3 wt % lower. Two possible explanations: faster solidification of the molten metal in contact with the coin mold, hence enrichment; or salt water corrosion leading to removal of some surface copper and/or silver.

3. X-ray radiography found no major casting flaws of different internal material that would have affected the density measurements.

4. The earrings had gold content similar to the coins. One of them had a glass jewel.

5. Several coins had silver specks (inclusions) on the obverse surface consisting of Os-Ir-Ru alloys, indicating that the gold in these coins came from placer mining.

ACKNOWLEDGMENTS

The authors thank two individuals who, as undergraduate students, performed the density measurements and wrote helpful reports—Michael R Opincar (CWRU), and Kristi Dahm (Cornell). We are also grateful to James Byrd, the SEM/EDS operator at CWRU who collected the elemental surface data for the gold coins and earrings, and to the X-ray machine operators at Cleveland's XRI Testing Division for their radiographs. The project received financial support from The National Endowment for the Humanities Archaeological Program Grant No. RK-20043-93 - Tell Nimrin Project.

REFERENCES

2. Photos of coins and earrings taken in laboratory in Jordan.