

CASE STUDY

Materials Insights for Ancient Roman Coins (Julian II)

Introduction

Ancient coins are tiny time capsules—and they're also a magnet for modern counterfeits. The tricky part is that the most convincing fakes can look "right" at arm's length. A collector provided two samples thought to be mint-state ancient Roman coins and needed high-confidence, non-destructive evidence to assess authenticity and manufacturing method—without risking sample damage. So instead of arguing style or documented ownership history, we did what we always do in materials characterization: we measured what we could measure—and we did it without damaging the coins.

About the Samples

In this context, "mint state" means the coins showed no wear from circulation. In collector/grading language, it is a coin that is essentially in the condition it left the Roman manufacturing site where the coin was fabricated (the mint). In ancient Rome, coins were made by stamping the design into metal using engraved dies. Nowadays, coins are made by casting, a process in which molten metal is poured into mold. That distinction matters, because one of the main questions was whether the coins showed features consistent with ancient struck manufacture rather than signs of modern casting.



Figure 1: Sides A and B of solidus from Julian II, as Augustus.

The markings on the A-side of the coin read **FL CL IVLIANVS P F AVG**, which stands for Flavius Claudius Julianus, Pius Felix, Augustus. This indicates that it was made during the short reign of Julian II as Augustus, a title which means he was the senior Roman emperor. This dates the coin from 361 to 363 CE¹.

At the base of the B side of the coin, we can clearly see ANT followed by Θ (theta). This indicates the coin was fabricated at Antioch (Ant), one of the most important cities in the eastern Roman Empire in the ninth workshop (indicated by the Θ)



Figure 2: Sides A and B from Julian II, as Caesar.

The markings on the silver coin (called a siliqua) indicate that the coin was issued for Julian II as Caesar, before he became senior Roman emperor. This would date the coin between 360–361 CE². The letters LVG at the base of the coin's B-side indicate that it was struck at Lugdunum (modern Lyon)³, one of the western Roman Empire's most important minting centers⁴.

As-Received Condition and Forensic Workflow

While the coins may show small handling marks, bag marks, manufacturing imperfections or natural color change due to the metal reacting with its environment, we noted no obvious wear on the high points, sharp details in the design and surface features that were preserved rather than rubbed down by use. This is a good indicator that the coins were uncirculated. This is ideal because it allows us to narrow in on the tell-tale signs of manufacturing rather than wear.

The goal was to look for internal defects or telltale casting features, and to verify whether microstructure and chemistry were consistent with ancient struck coinage. We used optical microscopy, micro-computed tomography (micro-CT), pattern-light optical profilometry and scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) to build a forensic fingerprint of each coin.

First Up: Optical Microscopy

To view the high-resolution images of the coins, visit go.covalent.com/coins

This link will allow viewers to zoom in to view close-ups of fine features on the coin surface.

High-magnification imaging of the lettering shows distinct directional flow lines and

smeared metal adjacent to the letter boundaries. These features indicate localized deformation during die striking, where metal was forced to flow into and around the engraved letter forms. The morphology is consistent with struck manufacture and not with a cast surface.

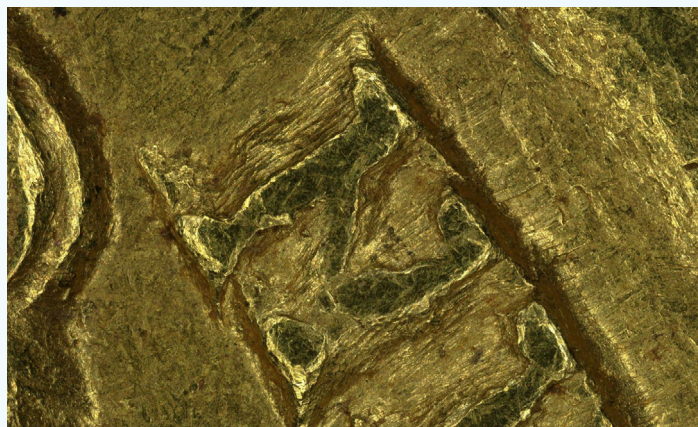


Figure 3: Close up on solidus with flow lines and smeared metal visible.



Figure 4: Close up on siliqua with flow lines visible.

Micro-CT (look inside without cutting)

Micro-computed tomography (micro-CT) is a non-destructive X-ray imaging technique that reveals the internal structure of an object in three dimensions without cutting it open. During analysis, the sample is rotated while a series of X-ray images are collected from many angles. Software then reconstructs those projections into a 3D volume, allowing analysts to virtually “slice” through the object and examine internal features such as voids, cracks, inclusions, density variations, and manufacturing defects.

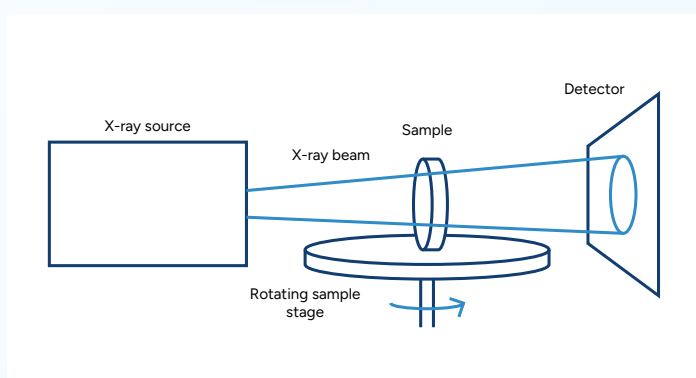


Figure 5: Diagram of micro-CT

For ancient coins, micro-CT is especially useful because it can help distinguish solid struck material from internal porosity or other features that may be associated with casting or later alteration.

We used micro-CT to examine the internal structure—looking for things like voids, cracks, inclusions, and density variations. These internal features act like a manufacturing fingerprint, helping distinguish dense struck metal from the hidden porosity or structural irregularities often associated with casting or later modification.

Inclusions are small particles of material different from the bulk metal that become trapped during metal production. In ancient

coinage, they can reflect the original ore source and the limitations of historical refining and melting—microscopic mineral grains or oxides can survive processing and remain embedded in the metal even when the final coin is die-struck. Because micro-CT reveals whether these features are truly internal (rather than surface residues or corrosion), inclusions can serve as a useful indicator of the metal's history. In this study, the presence and distribution of inclusions—without accompanying bulk voiding or cracking—provided additional context for evaluating whether the coins were consistent with ancient manufacturing pathways.

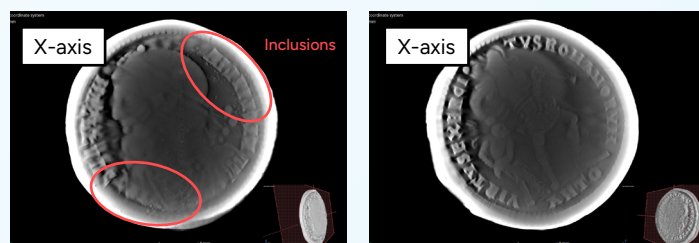


Figure 6: Micro-CT scans of gold coin in X-axis with inclusions annotated.

Pictured above are multiple micro-CT cross-section planes along the X-axis. Inclusions are concentrated closer to the head side of the coin, appearing as lighter (higher-density) spots in the scans. No cracking or voiding was observed in the bulk material.

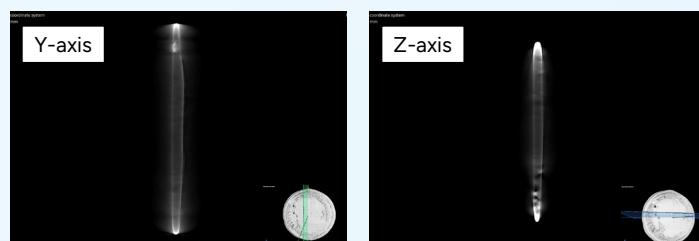


Figure 7: Micro-CT scans of gold coin in Y and Z axes.

Pictured above are mid-point micro-CT cross-section planes through the coin in the Y-axis and Z-axis. No cracking or voiding was observed in the bulk of the material. Areas that appear as very dark or very bright spots are attributable to beam-hardening artifacts, which occur when higher-density regions—such as the raised surface lettering—affect X-ray attenuation and create localized contrast distortions in the reconstructed images.

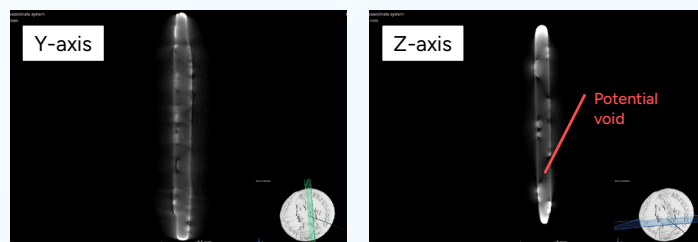


Figure 9: Micro-CT scans of silver coin in Y and Z axes with potential void annotated.

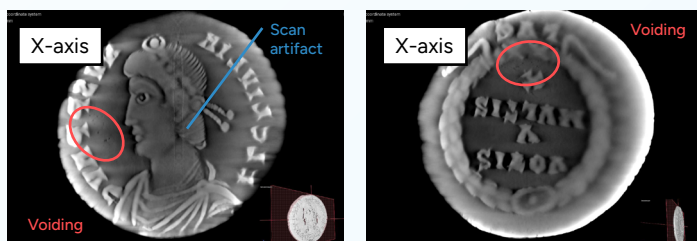


Figure 8: Micro-CT scans of silver coin in X-axis with voiding and scan artifacts annotated.

Micro-CT reconstruction of the silver coin shows multiple cross-section planes along the X-axis. Slight voiding is visible as small dark spots near both faces of the coin, while no cracking was observed in the bulk material. Limited near-surface voiding can occur for several reasons, including localized porosity introduced during metal preparation or casting of the initial stock (even if the final coin was die-struck), minor corrosion-related loss near the surfaces over time, or small planar gaps associated with surface features and relief that can accentuate contrast in CT reconstructions. In this case, the voiding was minor and confined near the surfaces, with the interior remaining structurally sound.

Pictured above are mid-point micro-CT cross-section planes through the coin in the Y-axis and Z-axis. A small potential void was observed in the Z-axis view. However, interpretation near the raised surface lettering was complicated by beam-hardening artifacts: higher-density regions at the surface can distort X-ray attenuation and create areas that appear unusually dark or very bright in the reconstruction. As a result, it was difficult to confidently identify voiding in that specific region because the artifacts can mask or mimic true subsurface features.

Next up: 3D surface metrology

We then mapped surface topography using patterned-light optical profilometry. Patterned-light optical profilometry is a non-contact surface topography method that measures 3D shape by projecting a known light pattern (typically stripes/fringes) onto the sample and viewing it with a camera. Because the surface isn't perfectly flat, the projected pattern appears warped in the camera image; that distortion encodes the surface height. The instrument then reconstructs the surface as a quantitative 2D height map / 3D height map (like the ones shown below) without physically touching the sample.

In practice, the instrument shines a series of evenly spaced light stripes onto the surface and takes images of how those stripes bend over bumps, grooves, and edges. The software compares those stripe distortions from point to point and uses that information to calculate surface height, building a detailed 3D map without touching the object. This makes patterned-light profilometry especially useful for delicate samples, because it can quickly reveal fine surface details—such as flow lines, pits, and wear—over relatively large areas without risking damage.

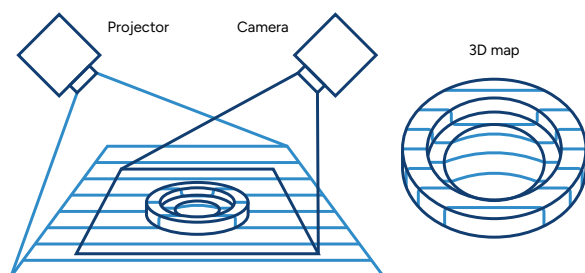


Figure 10: Diagram showing patterned-light optical profilometry set up (left) and an example of how a pattern of horizontal lines would be distorted by surface features on the coin (right)

Surface profilometry is important for our study because struck coins can preserve surface flow lines and deformation features associated with die impact—features you don't expect to see the same way in a cast surface.

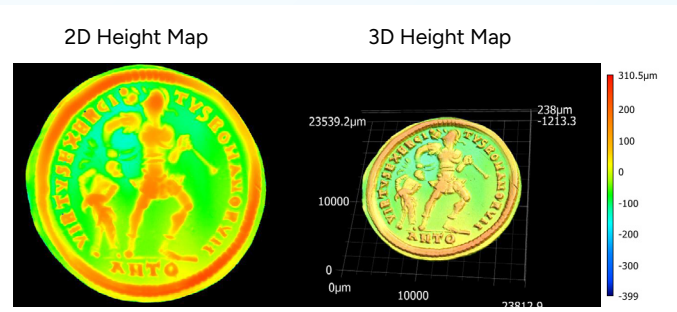
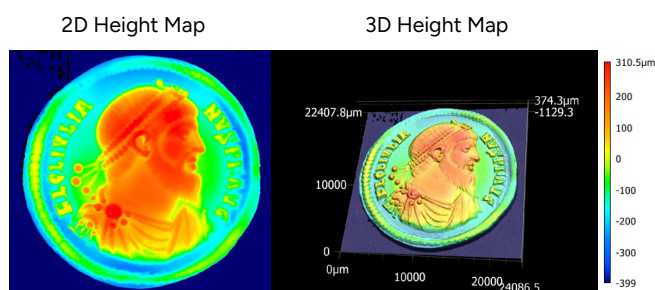


Figure 11: Patterned light optical profilometry height maps of both sides of gold coin.

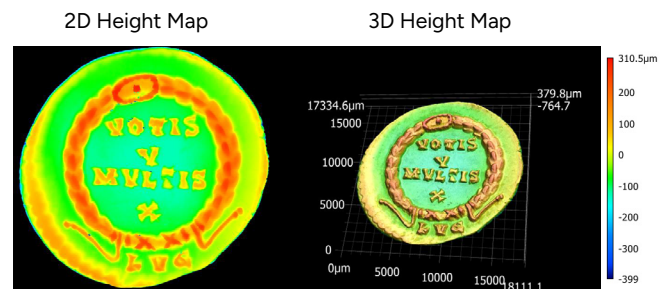
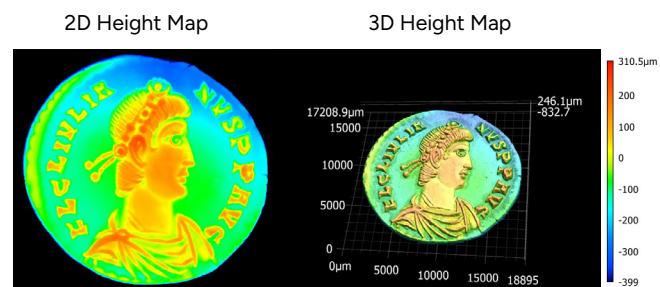


Figure 12: Patterned light optical profilometry height maps of both sides of silver coin.

Profilometry gave us a crisp, quantitative look at the coins' surface relief—without touching them. The 2D and 3D height maps clearly resolve the portrait, wreath, and legends standing proud above the fields, with overall height contrast on the order of a few hundred microns. That kind of clean relief measurement is ideal for documenting preservation and manufacturing detail, because it captures true topography (rim

and lettering height, device definition) rather than relying on lighting or photography alone.

Just as importantly, the maps do not show an obvious “casting seam line” signature. A mold parting seam typically appears as a long, continuous ridge or valley that tracks across both fields and devices; in the false-color maps and 3D renders here, there isn’t a single uninterrupted linear feature that reads like a seam. We did observe that the silver coin presents more surface irregularity than the gold—especially along the rim and in localized texture variation—but that’s not automatically diagnostic of casting. Differences like these can also reflect normal planchet variability, handling/stacking marks, minor surface degradation, or past cleaning, all of which can alter surface texture without indicating a cast origin.

Finally: SEM + EDS (microscale features + elemental fingerprinting)

To close the loop, we used scanning electron microscopy (SEM) to resolve fine surface texture and energy dispersive X-ray spectroscopy (EDS) to check elemental signatures at microscopic regions of interest.

Scanning electron microscopy (SEM) is a powerful imaging technique that uses a focused beam of electrons—rather than light—to scan across a sample surface and generate high-resolution images of its microstructure and topography. Because electrons interact strongly with matter, SEM can reveal fine details such as surface texture, wear, corrosion products, and small particles that are difficult or impossible to see with optical microscopy. For a deeper, visual walk-through of how SEM works and what it can do, [check out our eBook](#).

Energy-dispersive X-ray spectroscopy (EDS) is a chemical microanalysis technique most often performed inside an SEM to identify what elements are present in a specific spot or across a mapped area. When the SEM’s electron beam hits the sample, it can knock inner-shell electrons out of atoms; as higher-energy electrons drop down to fill those vacancies, the atom emits X-rays with energies that are characteristic of each element. By measuring the energies and intensities of those X-rays, EDS produces spectra and color-coded elemental maps that show which elements are present and where they’re concentrated—useful for distinguishing alloy constituents from corrosion products, residues, and transferred contamination. EDS maps typically indicate which characteristic X-ray line series was used for each element (K, L, or M), corresponding to the electron shell transition that produced the signal.

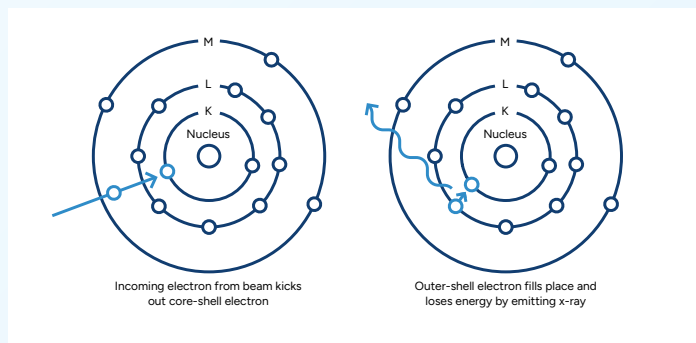


Figure 13: Diagram demonstrating mechanism for EDS.

SEM and EDS allow us to catch subtle “tells,” like unexpected surface compositions, unusual inclusions or residues or micro-features that don’t match an authentic manufacturing pathway.

For the gold coin, we scanned the regions indicated in the image below.



Figure 14: Optical image indicating regions scanned with SEM and EDS on gold coin.

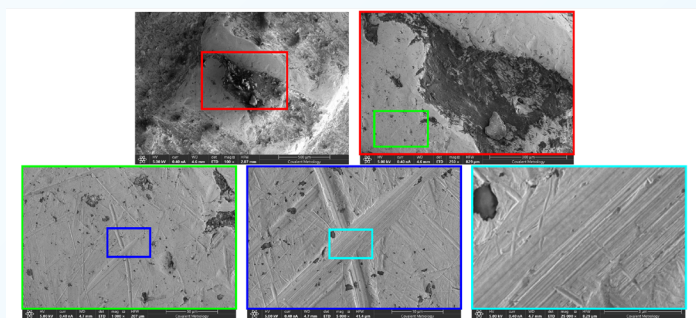


Figure 15: SEM images of A region, zooming in on scratch marks.

In the SEM images, we observed some scratch marks that clearly cut across the surface and overprint everything else, so they're from handling, cleaning, wiping, or contact with other objects after the coin was made. The density of fine, intersecting scratches (especially the more uniform, directionally biased ones in the higher-mag images) looks a lot like abrasive wiping or polishing, not random circulation wear alone.

Coins that have been "improved" by cleaning often show exactly this kind of cross-hatched micro-scratch field.

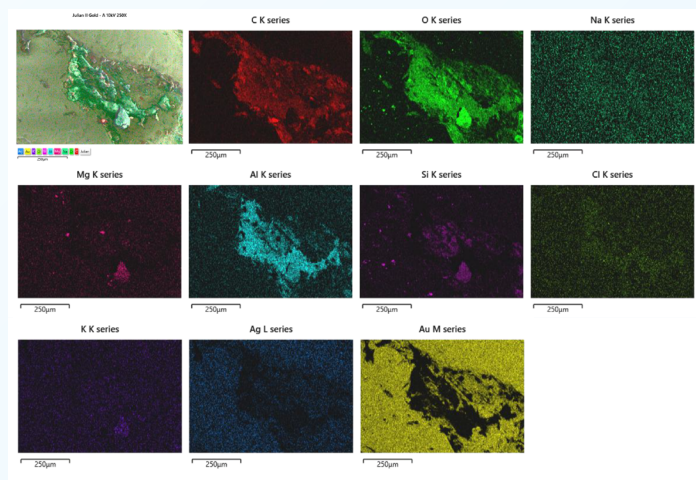


Figure 16: EDS maps of A region

EDS results were consistent with the expected coin materials and typical surface aging/handling effects. The gold coin showed a dominant gold signal, with some silver as well. The silver may appear because ancient gold coins are rarely 100% Au. Au and Ag are natural companions⁵. Natural gold often contains some Ag (electrum-range impurities), and historical refining/minting commonly left trace-to-percent-level Ag behind. So, an Au-dominant EDS spectrum with a smaller Ag signal can simply reflect real metallurgy.

Trace C and O are consistent with common surface contaminants such as skin oil, while Na, Mg, Al, Si, and K are most consistent with small specs of dust/mineral particles on the coin surface.

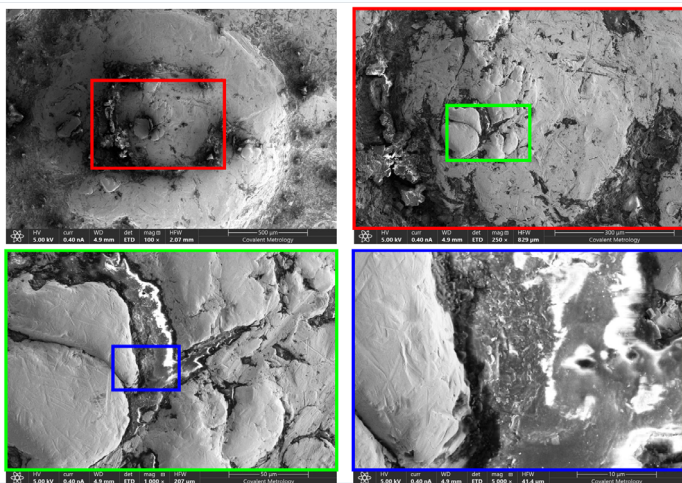


Figure 17: SEM images of the collar region.

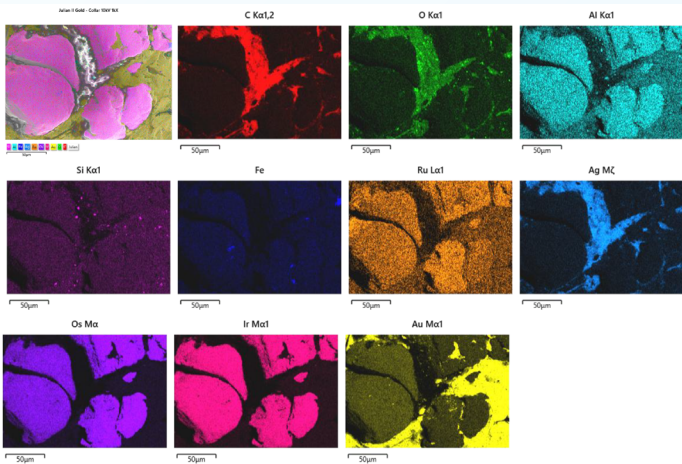


Figure 18: EDS maps of collar region.

EDS also picked up tiny traces of osmium (Os), iridium (Ir), and ruthenium (Ru)—rare metals in the platinum-group that can naturally ride along with gold in certain ores and river-deposit gold. These elements didn't appear evenly across the coin; they showed up in a few small hot spots, which is what you'd expect if the microscope beam happened to land on microscopic mineral inclusions trapped in the gold. Because these platinum-group minerals are extremely tough and resistant, ancient refining methods often

couldn't remove every last trace. Seeing them in this spotty, inclusion-like way is consistent with gold produced from natural deposits using historical processing, rather than modern ultra-refined gold that tends to be much more chemically uniform.

On the silver coin, we scanned the regions indicated in the image below.



Figure 19: Optical image indicating where we scanned on the silver coin.

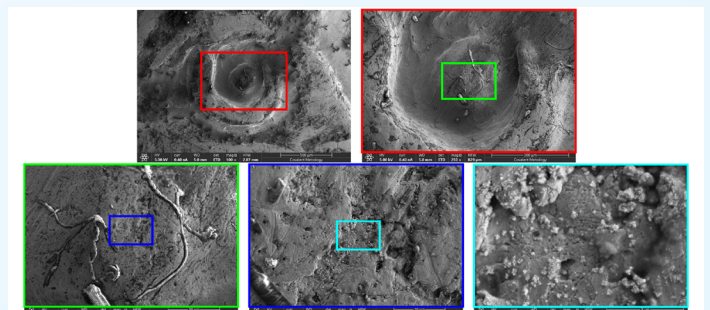


Figure 20: SEM images of eye region.

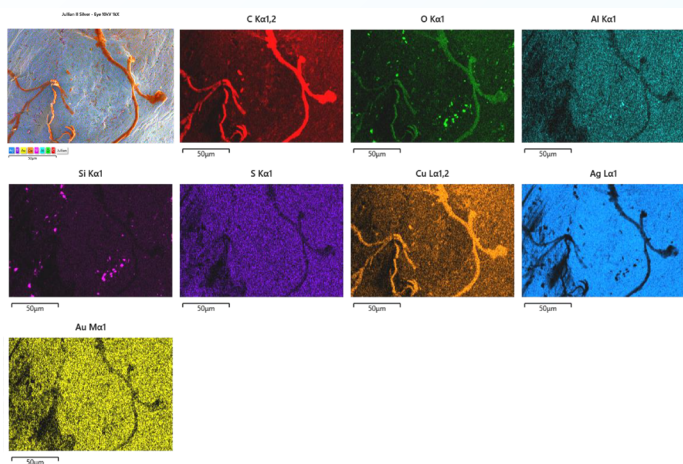


Figure 21: EDS maps of eye region.

As expected, the silver coin showed predominantly Ag signal with some Au from alloying. We also detected sulfur—consistent with tarnish chemistry (silver sulfide—type surface films) that develops over time.

The Cu-rich, hair-like fibers observed by SEM/EDS are consistent with debris shed from a copper- or brass-bristled brush. During brushing, tiny bristle fragments can break off and snag on the coin's raised relief, leaving filamentary particles that map strongly as Cu. Because these features sit on the surface rather than appearing as a uniform alloy signal, they support the interpretation of post-mint cleaning or polishing rather than original coin composition.

The observation of Cu-rich, hair-like fibers concentrated along the edges of raised details—such as the ornament—supports the interpretation that these features are debris transferred during cleaning, consistent with bristle fragments shed from a copper- or brass-polishing brush.

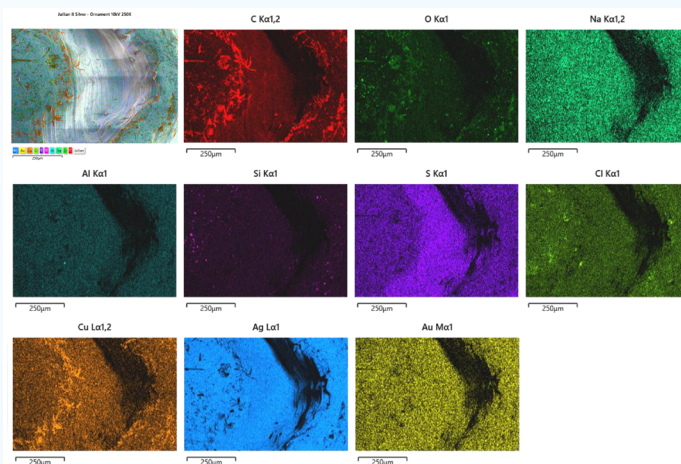


Figure 22: EDS maps of ornament.

The features in the SEM images below are very interesting looking and almost appear biological in nature.

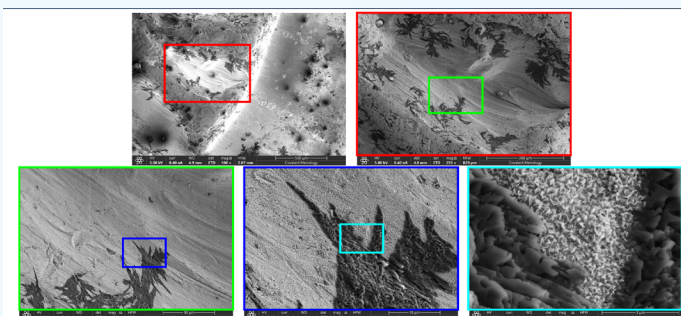


Figure 23: SEM images of 'V' region.

The EDS maps from this region reveals a strong presence of Cu in the area of these dendritic growth-looking features.

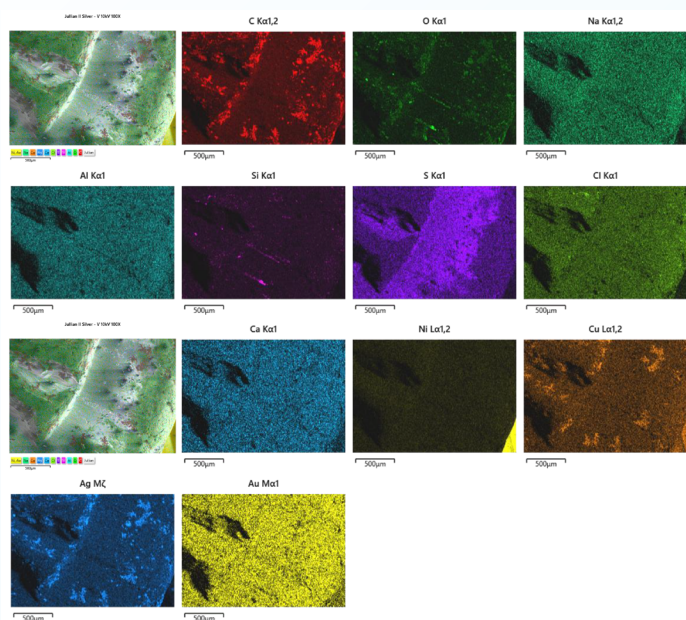


Figure 24: EDS maps of V region.

The Cu-rich dendritic features could reflect transferred copper debris from cleaning; however, it doesn't look similar to the fiber Cu features seen in other regions of the coin. Another plausible explanation could be a chemical plating-like deposition if the silver was exposed to copper ions in a conductive moisture film (e.g., if this coin was stored near Cu coins in a humid environment). This could produce localized copper-rich dendritic crystal deposits on more noble silver surfaces.

Overall, the EDS findings support authentic metal composition with surface chemistry influenced by normal aging, storage, and handling rather than indicating any singular modern coating or manufacturing anomaly.

Conclusion

By combining micro-CT, patterned-light optical profilometry, and SEM/EDS, we built a non-destructive forensic fingerprint of both coins—looking inside for hidden porosity and structural clues, quantifying surface relief in 3D, and confirming microscale features and chemistry. Across the workflow, the results were most consistent with ancient struck manufacture rather than modern casting: the coins showed dense internal structure without widespread voiding or cracking, crisp preserved relief, and no continuous seam-like topographic feature that would suggest a mold parting line.

At the microscale, SEM/EDS reinforced that story. The gold coin's chemistry was dominated by Au with expected minor signals (including Ag), and it also showed localized Os/Ir/Ru "hot spots" consistent with trace platinum-group inclusions that can persist from natural-source gold and historical refining constraints. On the silver coin, Ag dominated as expected, with sulfur consistent with normal tarnish chemistry. Importantly, we also observed Cu-rich filamentary features concentrated on raised details—strong evidence of post-mint cleaning or handling (e.g., brush debris or Cu transfer), not a manufacturing anomaly. Taken together, the internal structure, surface metrology, and elemental signatures support an interpretation of authentic ancient materials and processing, with surface changes primarily attributable to normal aging, storage, and cleaning history.

Citations

1. Institute for the Study of the Ancient World. (n.d.). Solidus issued by Julian [Object description]. New York University. <https://isaw.nyu.edu/exhibitions/berthouville/objects/coin-fg-1843>
2. Classical Numismatic Group. (n.d.). Julian II. As Caesar, AD 355–360. AR Siliqua ... Quinquennalia issue. Lugdunum (Lyon) mint. Struck AD 360–361 [Auction listing]
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