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Broad Applications of Scanning Electron Microscopy and Energy-Dispersive Spectroscopy in Art Conservation

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The University Circle district in Cleveland, OH is home to a top-tier research institution, Case Western Reserve University (CWRU), and a world-class art museum, the Cleveland Museum of Art (CMA), located within 1 km of each other. This proximity enables fruitful collaborations on the use of scanning electron microscopes (SEMs) and associated microanalytical techniques that are critical to art conservation. The CMA Conservation Department is home to its own analytical laboratories and staff with expertise in the conservation of a wide range of art forms. Collaboration with CWRU core facilities enables access to complementary analytical tools and technical expertise. Collaboration between CMA conservators and CWRU scientists stretches back at least 40 years, such as a petrographic study carried out in 1979 on the CMA's *Krishna Lifting Mount Govardhan* (1973.106) [1]. This collaborative effort was rejuvenated starting in 2019 with changes in leadership in both the CWRU Provost's Office, which resulted in the Think[Big] initiatives, and the Case School of Engineering's Swagelok Center for Surface Analysis of Materials, which was coincident with commissioning of a Thermo Scientific Apreo 2S SEM [2].

Here, we present an overview of specific applications of SEM/EDS in conservation of art from the CMA collection. SEM imaging of delaminated acrylic paint layers from an outdoor sculpture, *Untitled (bridge of harmony)* by Jim Hodges (2014.10), clearly showed only two paint layers instead of four layers as described in the fabricator's document. Non-destructive SEM/EDS characterization of the surface topography and alloy compositions of two gold pendants (1954.379 and 1990.162) from Central America (c. 1000-1550) led to an understanding of their surface enrichment and depletion gilding. A multi-year restoration of the 17th-century Italian painting, *Venus Discovering the Dead Adonis* (1965.19), began in 2021 and cross-sections were examined with SEM to characterize morphology, stratification, and presence of coccolith microfossils. EDS was used for determination of the elemental composition of paint and ground layers. The presence of calcium, aluminum, and potassium (Figure 1) in the faded yellow paint layer are indicative of substrates used to bind organic yellow lake colorants. SEM/EDS was also utilized on cross-section samples from the background landscape of the late 15th-century Italian painting, *Virgin and Child*, by Pintoricchio (1944.89) and helped confirm the use of two different green pigments, natural malachite and a copper-sulfate. Finally, SEM/EDS (Figure 2) was performed on a metal thread from the 17th-century French Gobelins tapestry *Spring* from the set *The Four Seasons* (1952.544) to better understand its condition, morphology, and manufacturing method in preparation for its CMA exhibition in February 2022.

We will discuss different avenues of science education: 1) Providing a "pre-training" protocol consisting of online modules covering the theoretical background of SEM imaging and EDS analysis to the art conservators fostered clear communication during the hands-on SEM/EDS training and analyses; 2)

These collaborations provide a uniquely exciting outreach opportunity. For example, the *Cycles of Life: The Four Seasons Tapestries* exhibition includes SEM/EDS technical analysis intended to educate the public about forensics necessary in textile conservation; 3) Finally, several CWRU Art History and Materials Science and Engineering students have participated in an ongoing CWRU/Cleveland Public Library program called "Mean Green STEAM Machine" which uses microscopy images in STEM outreach to elementary and junior high students, thus introducing the next generation to foundational concepts of microscopy and art history.

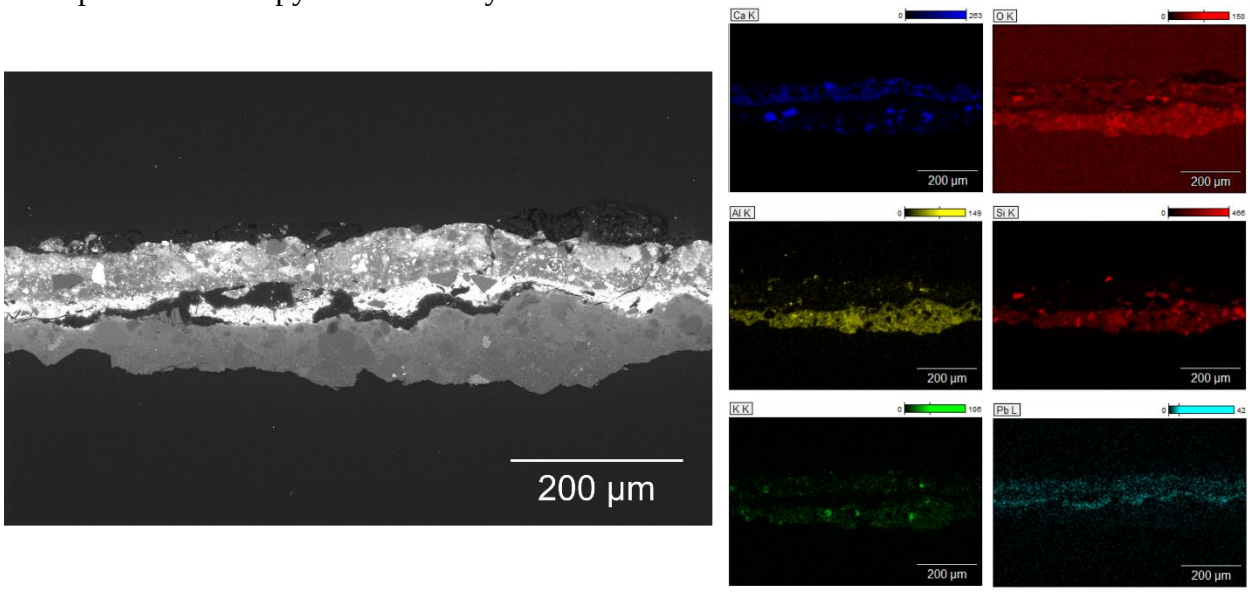

Figure 1. Backscattered-electron micrograph (left) of paint cross-section from *Venus Discovering the Dead Adonis* with elemental maps (right) from EDS. Imaging and EDS data collection of the epoxy-embedded samples were done in low-vacuum mode.

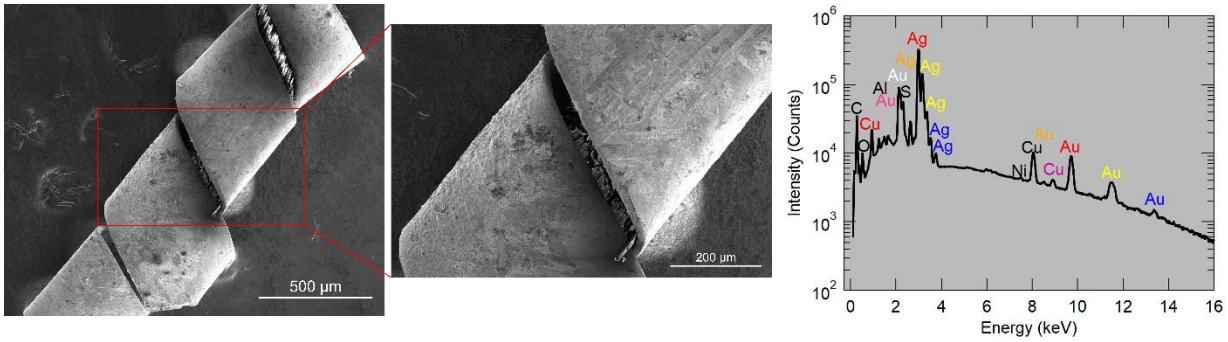

Figure 2. Secondary-electron micrographs (left and middle) of a thread sample from the tapestry, *Spring*, from *The Four Seasons* set with EDS (right) from the metal. EDS lines are color-coded as follows: K_α (black), K_β (purple), L1 (orange), L_α (red), L_β (yellow), L_γ (blue), M_ζ (pink), M_α (white).

References:

[1] Czuma, S. (1979), The case of the buried fragments, *The Bulletin of the Cleveland Museum of Art*, **66**, 288-295.

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