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X-ray fluorescence imaging analysis of inscription provenance

J. Powers [a], D.-M. Smilgies [b], E.C. Geil [a], K. Clinton [c], N. Dimitrova [c], M. Peachin [d], R.E. Thorne [a,*]

[a] *Department of Physics, Cornell University, Ithaca, NY 14853, USA*
[b] *Cornell High-Energy Synchrotron Source, Ithaca, NY 14853, USA*
[c] *Department of Classics, Cornell University, Ithaca, NY 14853, USA*
[d] *Department of Classics, New York University, NY 10012, USA*

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ABSTRACT

A stone tablet from New York University considered to be a copy of an inscription from Teanum Sidicinum is examined with X-ray fluorescence (XRF) and XRF imaging. Fluorescence spectra show many of the same elements seen in ancient Roman inscriptions, but the fluorescence intensity from calcium is much weaker and that from many other elements is much stronger. The weak calcium fluorescence cannot be due to X-ray absorption by other elements present, and so the tablet is unlikely to be of marble. This conclusion is supported by X-ray diffraction and electron microprobe measurements. Unlike for other examined inscriptions, XRF imaging indicates little or no correlation between the variation of trace element concentrations across the tablet surface and the presence of characters. These results confirm that the inscription is a copy and demonstrate how XRF imaging can assist in evaluating inscription provenance.

1. Introduction

A number of tools have been used to study ancient Greek and Roman inscriptions, including rubbings, squeezes, raking light imaging, and laser transmission (Chambers, 1992). We have shown that by using the ultra-intense X-ray beams produced by synchrotron X-ray sources, trace element concentrations in an inscription's surface layers at the glyph scale can easily be measured in seconds (Powers et al., 2005). By raster scanning the inscription relative to the X-ray beam, chemical analysis can be performed at an array of points across the inscribed surface. This data can be combined to create images showing the concentration variations of single elements. Some elements, including iron and lead, are present in larger concentrations in inscribed glyphs, and likely arose from tool wear during inscription and from subsequent painting. Lead can be detected in layers well below the original inscribed surface of the glyphs, opening the possibility of using XRF imaging to recover ancient text from worn and abraded inscriptions.

Here we describe an application of synchrotron-based XRF to examine an inscription of uncertain provenance. We perform XRF chemical analysis at single points and XRF imaging to correlate composition and the presence of inscribed letters, and show how this combination can provide useful insight into the possible origins of an inscription.

According to published records, NY.NY.NYU.L20 (U.S. Epigraphy no.) "appears to be an exact copy of the fragmentary consular *fasti* from Teanum Sidicinum in central Italy, of which the original is preserved at the American Academy in Rome" (Bodel and Tracy, 1997). The original tablet (General Meeting of the Archaeological Institute of America, 1905) is now on loan to the town of Teano in Italy (John Bodel, personal communication, July 29, 2006). No analysis beyond comparison of photographs has been performed on these tablets prior to our investigations.

The surface of the NYU tablet is slightly warped along the direction of the lines of text, such that its lettered side is on the outside of an arc. There is no obvious visual difference between the uninscribed surface of the tablet and the inscribed letters. There is no evidence of paint, pigment, dirt or debris within the inscribed letters. The only information we have about the Teano inscription is a photograph (Fig. 1a), which can be compared with a photograph of the NYU inscription (Fig. 1b). The tablets have the same shape, and both have a crack running from the bottom edge of the lower-right quadrant and slanting upward and to the left into the lower-left quadrant. The lettering on the two tablets appears identical, and any differences between the two photographs can be attributed to differences in lighting and perspective. However, the surfaces of the two tablets are noticeably different. The surface of the NYU tablet has many small, round raised formations (visible at the original resolution of the photograph, and one of which is visible inside the "D" in Fig. 3). It has a chip along its top edge, and is darkened in a large area in the lower right. The surface of the Teano tablet shows none of these features. It appears to be much smoother overall, and exhibits pitting on its right

* Corresponding author. Tel.: +1 607 255 6487; fax: +1 607 697 0400.
E-mail address: ret6@cornell.edu (R.E. Thorne).

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Fig. 1. (a) Inscription from Teanum Sidicinum and (b) examined tablet from NYU. The similarity in shape of these fragmentary tablets and the imperfect rendering in (b) of the crack in the lower right of the Teanum Sidicinum inscription in (a) suggest that the NYU tablet is a modern copy.

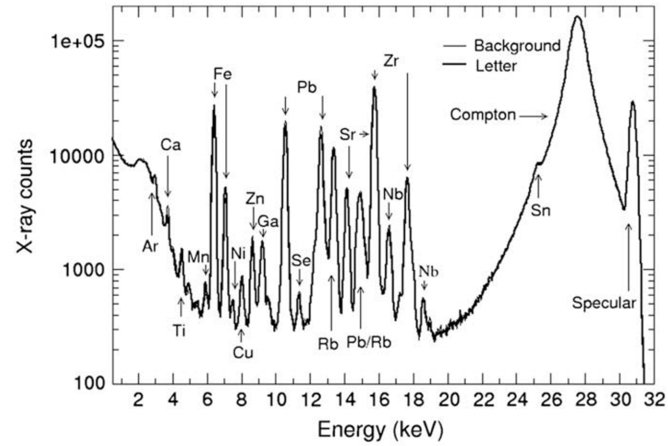

Fig. 2. X-ray fluorescence spectra acquired from two points on the NYU tablet, one on ("letter") and one beside ("background") the letter "D" in Fig. 3. Two of the observed peaks are produced by overlapping fluorescence from Pb and Rb and from Sr and Zr, respectively.

side that is not present in the NYU tablet. These differences suggest that the tablets have had different histories, are made of different materials, and/or were prepared using different methods.

In antiquity it was not unusual for more than one copy of the same document to be inscribed on stone, but it is extremely unlikely that both copies were broken up in the passage of time to yield identically shaped and cracked fragments with identical text. The crack in the Teano tablet appears to be real, tapering to a hairline, whereas the crack in the NYU tablet ends abruptly. This visual evidence suggests that the NYU tablet may be a relatively recent copy.

1.1. Method

The NYU tablet was examined at the Cornell High-Energy Synchrotron Source (CHESS). A 30 keV X-ray beam with a bandwidth of 0.5% was produced using a 15 Å W:B_4C multilayer monochromator. The beam was trimmed using mechanical slits to a 0.50 $\times$ 0.50 mm spot size at the sample. The tablet was oriented with its surface perpendicular to the X-ray beam, and translated in the plane perpendicular to the beam using a motorized *xyz* stage with a resolution of better than 2 μm. Fluorescent and scattered X-ray photons were detected by an energy-dispersive X-ray detector placed at a 150° angle from the incident beam, and then processed using a multichannel analyzer to yield spectra of photon count versus photon energy. Hardware control and data collection were automated using SPEC (Certified Scientific Software). Data analysis was performed using MCASPEC (Huang, Argonne National Lab), MATLAB, and Octave. Some inscriptions used in comparisons with the NYU tablet were examined with a 17 keV beam produced using a 30 Å Mo:B_4C multilayer having a 1.5% bandwidth.

To complement these XRF measurements, electron microprobe analysis of tablet chemical composition was performed using a JEOL JXA-9800R system with a solid-state electron dispersive spectrometer. Nearly microscopic grains were pulled off the tablet surface using carbon tape, and then placed in the microprobe chamber. The microprobe's electron beam is only micrometers in size, and can be used to examine individual mineral phases within a single grain. X-ray diffraction patterns were acquired using a general area detector diffraction system (GADDS) manufactured by Bruker AXS. Diffraction patterns were acquired using a 1.5 mm diameter X-ray beam from several points on the tablet surface, and compared with a powder diffraction database for several thousand minerals.

2. Results

2.1. X-ray fluorescence spectra

Our X-ray fluorescence spectra from ancient Roman inscriptions on marble typically show a strong Ca peak, weaker but pronounced Fe, Zn and Pb peaks, and detectable peaks of a number of other trace elements. These elements are present both within the inscribed letters and in the uninscribed regions of the stone's surface. Spatial variations in fluorescence intensity from these elements often correlate with the presence of inscribed lines that form the written text of the inscription (Powers et al., 2005).

XRF spectra from the NYU tablet such as those shown in Fig. 2 indicate the presence of Ca, Fe, Zn, Pb, Ti, Mn, Ni, Cu, Ga, Se, Rb, Sr and Nb, both within the inscribed letters and in the uninscribed background. Of these, Ca, Ti, Mn and Ni have peak heights roughly