Article

Ink study of Herculaneum Papyri

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In recent years, various studies have applied advanced techniques to explore the texts on rolled Herculaneum papyri.[1] Non-destructive technology such as X-ray Phase Contrast Tomography (XPCT) and 3D visualization software are applied to the extremely fragile carbonized Herculaneum papyrus scrolls to visualize the letters written in carbon-based ink. The radiation used by XPCT can penetrate through several windings and may reveal some letters in the dense structure of the charred papyrus without unwrapping and damaging the rolls. The results of these studies show that it is possible to visualize the internal structure of the carbonized Herculaneum papyrus, including the texture, shapes, damaged area, density and some contaminations of the fibres of papyrus sheets. In some cases, however, it is difficult to completely decipher the letters. Therefore, it is important to understand the contrast between the carbonized papyrus surface and the carbon-based ink, the composition of the ink used by the scribes and the concentration of the ink in each letter of the text.

One of the most valuable heritages in Naples, Italy is a collection of hundreds of papyrus scrolls, buried during the eruption of Mount Vesuvius in 79 CE and belonging to the only library passed on from Antiquity. This library was discovered between 1752 and 1754 in Herculaneum.[2] This inestimable treasure, which was discovered in a small room in a huge villa, comprises texts mainly concerning Epicurean philosophy. The scrolls were stored on shelves covering the walls of that room and are presently stored in the Officina dei Papiri section of the National Library of Naples.[3]

Over the years, curiosity and the inestimable value of the texts hidden in the carbonized scrolls have driven researchers to try to open the scrolls by various mechanical methods, which imposed physical stress on the structure of the fragile papyrus.[4] Among these methods, it is worthwhile to mention the Oslo method applied in the 1980s to two scrolls.[5] However, these mechanical techniques have been abandoned due to their low efficiency and in order to maintain and preserve the physical integrity of this important cultural heritage.[6] In recent years, with the progress of technology, some texts on unrolled fragments of the Herculaneum papyrus scrolls have been read using microscopes, digital photography (with multispectral filters) and multispectral techniques.[7] However, when applied to the rolled papyrus, the same techniques have failed because of the radiation's low capacity to penetrate several layers. Additionally, the level of carbonization makes it very difficult to distinguish the ink from the papyrus' supporting texture when using conventional X-ray source and techniques.[8]

Since Antiquity, the alphabetic writing process and the evolution of the chemical composition of the inks used were historical steps.[9] Pliny the Elder reports the use of carbon-based ink in his lifetime and described how it was obtained from residues of smoke from wood burnt in furnaces, without adding any metals.[10] Further, according to the literature, ancient Greek and Latin papyri may have been written using carbon-based ink until the fourth to fifth centuries CE.[11]

[1] Mocella et al. 2015, Seales and Delattre 2013.

[2] See the letter from Camillo Paderni to Dr Mead concerning the Antiquities dug up from the ancient Herculaneum, dated Naples, 18 November 1752;Paderni 1753. Also see Mocella et al. 2015; Tack et al. 2016; Mattus 2005.

[3] Mocella et al. 2015, Gigante 1979.

[4] Angeli 1994.

[5] Mocella et al. 2015, Delattre 2009.

[6] Mocella et al. 2015.

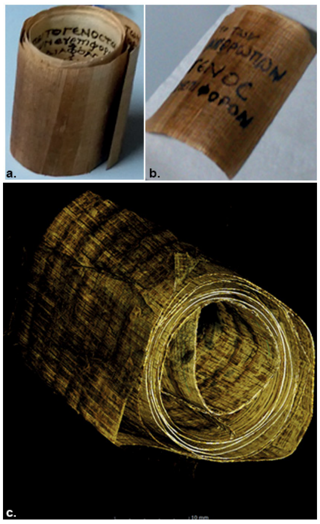
[7] Chabries et al. 2003.

[8] Mocella et al. 2015.

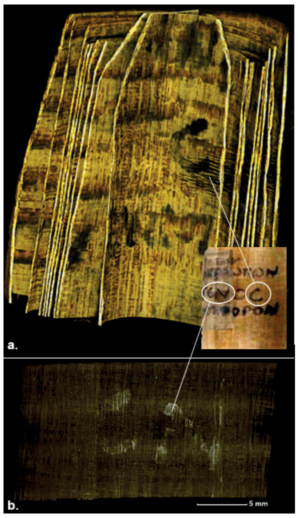
[9] Brun et al. 2016.

[10] *Natural History*, ed. Eichholz et al. 1938.

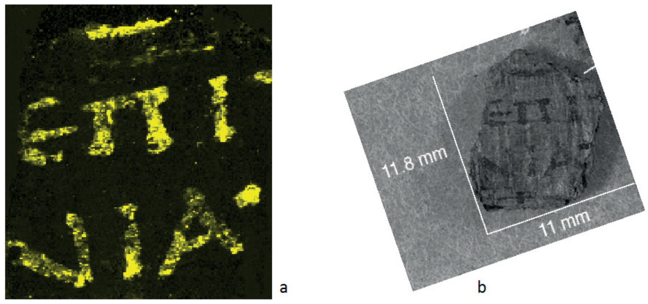
[11] Brun et al. 2016, Thompson 2007.



Figs 1a, b and c



Figs 2a and b



Figs 3a and b

Fig. 1: Pictures of phantom 1 (a) and phantom 2 (b) used for the study of the ink. Phantom 2 was placed within phantom 2, but only the ink with lead added was decipherable using XPCT + 3D visualization.

Fig. 2: Two portions of letters visualized by using VGStudio MAX 2.2 software. The large amount of ink with Pb is visible on the fibres of phantom 2 scroll. Letters with a greater concentration of Pb in the ink reflect more radiation.

Fig. 3: X-Ray Fluorescence map of Pb (a) perfectly matches the ink distribution of the visible photograph (b)

However, Brun et al.[12] recently showed that the ink of two Herculaneum fragments, Fig. 3, exhibits a high concentration of lead, which is deemed strong evidence that the lead was intentionally used in the ink on the Herculaneum papyri.

On the other hand, accordingly to Tack et al.,[13] lead could have been introduced unknowingly in different ways, for instance by the contamination of the water used as a solvent for the ink, or from the bronze container in which the ink was stored. It might also gave been introduced to the ink with the lead-based pigments galena (PbS), lead white (cerusite, $PbCO_3$, hydrocerusite ($2PbCO_3 \cdot Pb(OH)_2$) and/or minium ($Pb^{2+}{}_2Pb^{4+}O_4$). Furthermore, the lead could originate from a binding medium in the ink utilised as an agent to speed the process of drying, in the same way as for paintings. We can also surmise that lipid-based ink was used to draft the writing on papyri.[14] Knowing the chemical composition of the ink makes it possible to make a targeted choice of the imaging technique to be used or to optimize the selection of X-ray wavelengths used.[15] An additional difficulty is that the individual scribes made their own inks and variations in the materials can be expected.[16] A considerable amount of work has been done to enable the virtual unrolling and visualization of the ancient texts,[17] including X-ray computed tomography (XCT), which also finds many applications in medicine,[18] material science, palaeontology and archaeology.[19] However, XCT has some limitations when applied to the Herculaneum scrolls. Recently, Mocella et al.[20] discovered some letters inside a charred roll by applying XPCT to two of the six Herculaneum scrolls (one unrolled and the other still rolled), which were a 'gift' to Premier Consul Napoléon Bonaparte in 1802 and currently belong to the collection of the Institute de France. Phase contrast imaging technique exploits variations in the refractive indexes of structures that absorb quite uniformly within a composite object, thus significantly enhancing image contrast.[21] Moreover, according to the literature, XPCT shows suitability for discriminating

12 Brun et al. 2016.

13 Tack et al. 2016.

14 Tack et al. 2016.

15 Brun et al. 2016.

16 Brun et al. 2016.

17 Shutthanandan et al. 2008.

18 Allegra et al. 2015.

19 Mocella et. al. 2015.

20 Mocella et. al. 2015.

21 Mocella et. al. 2015.

among different materials of similar composition within a single object, as in the case of the black charcoal ink and carbonized papyrus.[22] The results of Mocella et al. show that XPCT is the first technique that enables us to read many Greek letters and some words on the rolled Herculaneum papyri without any physical damage.[23] These discoveries are very promising, but new experiments are needed to increase the image quality using future synchrotron beamlines with better coherence and other phase contrast techniques.[24]

On the other hand, there are doubts about the composition of the ink on the rolled Herculaneum papyrus, such as the possible addition of metal, i.e. the high concentration of lead found by Brun et al., as mentioned above.[25] The results of XPCT imaging of the rolled Herculaneum papyrus to decipher the letters are also unconfirmed. We studied two facsimiles (phantom) of Herculaneum papyrus made of modern materials – a present-day papyrus support and commercial ink. The virtual unrolling of the phantom was performed with advanced imaging software (VGStudio MAX). In the larger phantom (phantom 1), a black commercial Chinese ink was used to write a portion of text in the Greek alphabet, reproducing the ancient technique, Figure 1a. In the shorter phantom (phantom 2), Figure 1b, a blue commercial Chinese ink was used, to which lead(II) acetate was added. The text written with this ink used Greek letters, too. This blue ink was made with the aim of simulating the amount of lead found in the original Herculaneum papyrus studied by Brun et al. and Tack et al.[26] Phantom 2 was placed in phantom 1, Figure 1c, so that they looked like a single scroll. When XPCT + 3D visualization software was applied, the results from the phantom showed that it is possible to decipher the letters on the contemporaneous phantom 2, which is written with commercial ink with lead added. In Figures 2a and 2b, some letters were clearly visible.

The results show that more extensive research is needed to develop a method for virtually unrolling ancient carbonized papyrus scrolls using the experimental, non-destructive technique XPCT and the 3D visualization software to elucidate the contrast between the carbonized papyrus surface and the carbon-based ink, as well as the composition and concentration of ink, i.e. the question of the presence of lead (or other metals). Additional knowledge will make it possible to adapt future XPCT experiments specifically to Herculaneum scrolls.

[22] Mocella et. al. 2015.

[23] Mocella et. al. 2015.

[24] Mocella et. al. 2015.

[25] Brun et al. 2016.

[26] Brun et al. 2016, Tack et al. 2016.

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