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Chemical characterization of black and red inks inscribed on ancient Egyptian papyri: The Tebtunis temple library

Thomas Christiansen[a], David Buti[b,*], Kim Nicole Dalby[c], Poul Erik Lindelof[d], Kim Ryholt[a], Anna Vila[b]

[a] Section of Egyptology, Department of Cross Cultural and Regional Studies (ToRS), University of Copenhagen, 10 Karen Blixens Plads 8, 2300 Copenhagen S, Denmark
[b] Centre for Art Technological Studies and Conservation, Statens Museum for Kunst (CATS-SMK), Sølvgade 48-50, 1307 Copenhagen K, Denmark
[c] NanoGeoScience, Nano-Science Center, Department of Chemistry, University of Copenhagen, C110 Universitetsparken 5, 2100 Copenhagen Ø, Denmark
[d] X-ray and Neutron Science, Niels Bohr Institute (NBI), University of Copenhagen, D316 Universitetsparken 5, 2100 Copenhagen Ø, Denmark

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A B S T R A C T

This article presents the results of a study on the chemistry of the black and red inks used on papyri from the only institutional library to survive from ancient Egypt – the Tebtunis temple library. The aim of the study is to identify, through the chemistry of the inks, if certain papyrus fragments from the library are related. The papyri are examined using non-invasive analytical methods, including optical microscopy, X-ray fluorescence (XRF) spectroscopy, scanning electron microscopy-energy dispersive spectroscopy (SEM-EDXS), Raman spectroscopy and fiber optics reflectance spectroscopy (FORS). Via these techniques, inks undocumented in the analytical record are detected. Moreover, the analytical results are compared to other assemblages of ancient manuscripts from the Hellenistic and Roman periods (c. 200 BCE–400 CE) and provide new information on the history of the production of ink in the ancient Mediterranean cultures.

1. Introduction

1.1. The Tebtunis temple library

The “Tebtunis temple library” constitutes the largest homogenous collection of cultic, literary and scientific texts that have survived from Ancient Egypt and arguably ranks among the most important assemblages of papyri ever discovered in Egypt (Ryholt, 2005; Von Lieven, 2005; Quack, 2006). They include some 300–400 papyrus manuscripts which span the first through the early third-century CE, with the bulk dating from the late first and second century CE. It was discovered within two small cellars inside the main temple precinct at Tebtunis, modern Umm el-Breigât, which is located in the south of the Fayum depression some 100 km south-west of Cairo. The dry and brittle manuscripts are all poorly preserved and broken into several thousand smaller fragments. Whole columns or pages are rarely preserved, and the difficult and time-consuming process of sorting and identifying fragments of specific manuscripts is still ongoing. Published texts indicate that on average < 10% of a manuscript is likely to have been preserved.

In order to map manuscripts geographically and chronologically it is useful to study the chemical composition of ancient Egyptian inks through non-invasive analysis. Here we report on the first analysis of inks used to inscribe ancient Egyptian papyrus from the Tebtunis temple library, from samples belonging to the Papyrus Carlsberg Collection. It is an interdisciplinary effort carried out in collaboration between the University of Copenhagen and several partners including the Centre for Art Technological Studies and Conservation (CATS) at the National Gallery of Art (SMK), Copenhagen. The teams include chemists, physicists, conservation scientists, and Egyptologists, bringing a unique perspective. The aim was to explore the extent to which different inks might have been used within a small and well-defined social context, i.e. the discrete circumstances afforded by the priestly community at the temple of Soknebtunis at Tebtunis in the first-second centuries CE, and possible implications of the results. The analytical results are compared to three other ancient assemblages (Pathyris in Egypt, Qumran in Palestine, and Herculanum in Italy), which are deliberately selected to reflect non-related cultural contexts, time periods, or geographical regions.

1.2. Sources of contamination

The bulk of the manuscripts from the cellars pertain directly to the temple and the cult of the main local deity, Soknebtunis, and many of

* Corresponding author.
E-mail address: david.buti@smk.dk (D. Buti).

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the manuscripts appear to be written by the same scribes. However, their exact nature remains uncertain. The manuscripts might have been kept there when the temple was still in use, have been deposited there when it was abandoned, or have been collected for re-use. For the purposes of the present paper, the exact nature of the archaeological context has limited relevance. More relevant here is the fact that the papyri were found in rock-cut cellars and were found covered in sand, since this relates to the potential for contamination of the samples and needs to be taken into consideration in the interpretation of the analytical data.

When examining papyri chemically, we differentiate between at least two types of materials: intrinsic and extrinsic. Here, intrinsic is defined as the original, uncontaminated composition of the papyri and its ink. In comparison, the extrinsic constituents represent later contamination, which can also provide information about the archaeological context or environment in which the material objects were found. Much analysis has been carried out on Books of the Dead which are visually impressive and frequently well preserved (Section 1.4). Virtually all these papyri were found within tombs, often in coffins or even inside mummy wrappings, minimizing extrinsic contamination. By contrast, papyri deriving from settlement contexts have usually been covered with earth and thus brought into direct and long-term contact with sand or soil which will, to a smaller or greater degree, have embedded particles into the fiber structure of the papyrus. Therefore, care was taken to distinguish between the potential chemical markers unique to the papyri and ink and those coming from extrinsic sources.

While contamination can make interpretation of the results more complex, it may at the same time be useful in determining the origin of specific papyrus samples. If affected by contamination, it must be expected that a group of papyri found in the same archaeological context will likely share the same specific contamination signatures. Contamination by salt is characteristic of many Egyptian objects (Moussa et al., 2009). On papyrus the presence of this kind of contamination manifests itself as small crystal encrustations embedded in the material, where it can be seen with the naked eye or through a microscope. When salt particles effloresce, due to the absorption of moisture from the air, it is very detrimental to papyrus, since the particles form within the physical structure of the material, thus destroying the surrounding tissue (Nielsen, 1985; Leach and Tait, 2000; Neate et al., 2011). Investigations into the soil and water of the Fayum Province were undertaken for agricultural purposes, as early as 1902, demonstrated that the soil in the area is especially high in salt (Lucas, 1902; Monson, 2013). It was found that the soil contained sodium chloride and sodium sulfate at concentrations of up to 5.3%. The analysis concluded that the irrigation water in the Fayum was not the source of salt in the soil, but rather the desert sand, and the underlying limestone and clays.

1.3. Description of the samples

A multi-analytical approach, using different imaging and spectroscopic techniques, was applied to 22 fragments from 13 manuscripts stemming from the Tebtunis temple library (see Table 1). All the samples belong to the Papyrus Carlsberg Collection and are inscribed with either black ink or a combination of black and red ink. This was standard practice in ancient Egypt, where black was used for the main body of the text, while red was used to mark headings or important phrases (rubrication). The black inks fasten to the papyri in different ways; some are entirely stable, while others display cracking. Most are stable in water, but others are soluble (Lau-Lamb, 2010). It is to be expected that these differences are due to variations in their composition, i.e. in the way in which they were prepared.

The fragments chosen for analysis all derive from manuscripts that are representative of the different genres typically stemming from the library: divinatory literature (ten fragments from four manuscripts: **7**, **11**, **18–21**, **22**), medical literature (five fragments from one manuscript: **12–16**), narrative literature (four fragments from two or more different manuscripts: **1**, **2**, **3**, **17**) and ritual literature (three fragments from three manuscripts: **4**, **5**, **6**). Some of the texts were written on the blank backside of Greek administrative papyrus rolls, which did not originally concern the temple library but had been acquired as “scrap paper” for later re-use (8 fragments from six manuscripts: **1**, **2**, **3**, **6**, **11**, **18–21**). The ink used to write these Greek texts has also been analyzed, but will not be discussed in any detail in the present context, where the focus is the temple library itself. Black ink is used on all the 22 papyri fragments, while red ink is found on 11 out of the 22 fragments, which represent seven manuscripts (**4**, **6**, **7**, **8–9**, **11**, **12–15**, **22**). Since the papyri from the library are generally very fragmentary, groups of fragments, which have been assigned to specific manuscripts on the basis of content, paleography, and other criteria, were analyzed in order to determine whether the individual fragments would display similar traits or differ significantly from each other. We have selected three such examples; five fragments from a medical treatise (**12–16**), four from a divinatory text concerning dream interpretation (**18–21**), and three from another divinatory text concerning astrology (**8–10**).

The majority of the papyrus samples display clearly distinct types of hand-writing, but three fragments (**1**, **2**, **3**) are written in a characteristic hand that is assumed to represent a single prolific scribe who wrote about two dozen of the literary texts found in the library (Ryholt, 2017; Quack, 2017). There are literally hundreds of smaller and larger fragments from the library in this hand, as a result of the manner in which it was excavated (Section 1.1), and the sorting of this material poses immense difficulties. The three fragments sampled here have not yet been assigned to any specific original manuscript and are therefore designated P. Carlsberg SN 1-3 (sn = *sine numero*, without number).

1.4. History of the studies

Previous analysis of ink used on Egyptian papyri show that the black pigments are almost invariably based on amorphous carbon in the form of soot (“lamp black”), charcoal, or bone black (Lucas and Harris, 1962; Lee and Quirke, 2000; Di Stefano and Fuchs, 2011; Goler et al., 2016). Water was added twice in the manufacturing of carbon inks. First, in the production of the dry ink, soot was mixed with a binder dissolved in small amounts of water. Then the mixture was dried and pressed into pellets which could be stored or carried by the scribe. When the scribe was ready to write a text, he would prepare a fluid ink by mixing the ink pellet with a second quantity of water. The binding agent seems almost invariably to have been gum Arabic from the *Acacia nilotica* (L.), but the occasional use of different types of glair cannot be ruled out, since they were applied regularly in ancient Egyptian paints (Afifi, 2011).

Different types of black inks often described as “metallic” seem to have been applied as a writing fluid in ancient Egypt and by extension in the ancient Mediterranean at an early date (Bülow-Jacobsen, 2009). A type of iron/metal-gall ink (*encre métallogallique*) was detected during chemical analyses undertaken at the Louvre in the late 1980s (Delange et al., 1990). The black inks of papyri written in both Demotic and Greek, dating to c. 250–100 BCE, were analyzed using proton induced X-ray emission (PIXE). The results showed that all the Demotic texts were written with carbon ink and that all the Greek texts, besides one, were written with a type of metallic ink. The iron-gall inks from 5th century CE until the pre-modern era are made from a mixture of tannic acid, typically extracted from oak trees, and iron sulfates (II).

The black inks of three papyrus fragments from Qumran, discovered in Cave 4, were analyzed in the mid-1990′s using X-ray fluorescence (XRF). Both Cu and Pb were detected in relatively low amounts in black inks of an otherwise carbonaceous nature. The same elements were found in an unspecified number of parchment fragments from Qumran and especially in the Genesis Apocryphon (1QapGen), where the ink seems to have reacted with the support (i.e. the physical manuscript) and caused severe patterns of degradation. The study concluded that Cu and Pb likely had their origin in the bronze inkwells employed by the