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Composition Analysis of Writing Materials in Geniza Fragments

Abstract: Our current projects focus on the material analysis of the writing materials kept in the Taylor-Schechter Collection at Cambridge University Library, which houses the largest collection of Cairo Geniza fragments, about 190,000. Although Geniza manuscripts have attracted a great deal of scholarly attention, the material aspects of these documents seem to have been largely neglected. The current study aims to obtain information on the composition of the writing supports and the inks that were used, the production of the original manuscripts and the history of their degradation. The collected data should supplement the description based on Hebrew palaeography and codicology. Moreover, a characterisation of the writing materials would provide insights on trade, local production techniques and social structures. The tabulated results have the potential to be used as geo-chronological markers if sufficient data is collected.

For our study, we chose Hebrew legal documents and letters from three communities that co-existed in Fustat (today Cairo) in the 11th century: the Jerusalemite (or 'Palestinian') community, the Babylonian community and the Karaites, three different communities with different scribal traditions. In addition to this, we studied non-biblical scrolls attributed to the Palestinian and Babylonian communities. The question we addressed was whether we can correlate the use of a specific type of ink to an objective criterion.

For our analysis at Cambridge University Library, we used a number of protocols developed at BAM (Bundesanstalt für Materialforschung und -prüfung) in Berlin and at the Centre for Study of Manuscript Cultures, University of Hamburg (CSMC). These include reflectographic examination followed by non-destructive X-ray fluorescence (XRF) analysis using transportable instruments so that the analysis can be carried out *in situ*.

We have illustrated our approach here by providing two examples. The first one describes our investigation of the leather fragment containing a portion of the Babylonian Talmud on its hair side (TS Misc.26.53.17). The second example illustrates our ability to compare iron-gall inks using the XRF method. In this case, we explored the question of the codicological attribution of three fragments (TS F17.4, TS 12.755 and TS 12.756) to the same Talmud manuscript.

DOI 10.1515/9783110546422-013,

1 Background

According to the Jewish tradition, a Geniza (גניזה, plural: *genizot*) is a storage place (often a room in or near a synagogue) for manuscripts that have gone out of use. As an institution, it is based on the ban against destroying writings liable to contain the divine name (mainly *sifre Tora*, *tefillin*, *mezuzot*). This formal prohibition was informally extended to include all written documents. They are systematically stored in a Geniza, waiting to be ritually buried.[1]

Such a Geniza was attached to the Ben Ezra Synagogue in Fustat, today situated in Old Cairo, Egypt, south of the centre of the modern city. Known today by the name Cairo Geniza, it came to the attention of scholars by the end of the 19th century. The Cairo Geniza contains manuscripts with a fairly broad chronological range from the late 9th to the 19th century and originating mainly in Egypt, Tunisia, Sicily, and Palestine. They are written in many languages, including Hebrew, Judaeo-Arabic, Arabic, Aramaic, and Yiddish and mainly on parchment and paper, but also on papyrus and cloth. Furthermore, the fragments present texts on a variety of subjects – legal, social, medical, economic, cultural, literary, and religious. The Cairo Geniza's exceptional wealth of social, cultural, and historical data makes it a stimulating object of study. Unfortunately, manuscripts and fragments from the Cairo Geniza are now scattered in different libraries throughout the world, but primarily in England (Cambridge University Library; Bodleian Library, University of Oxford; John Rylands Library Manchester; British Library, London), in Russia (Firkovitch and Antonin Collections, St. Petersburg), in France (Alliance Israélite Universelle; Mosseri Collection), and in the United States (Jewish Theological Seminary, New York; Katz Center for Judaic Studies, University of Pennsylvania).[2]

The current project focuses on the material analysis of the writing materials kept today in the Taylor-Schechter Collection at the Cambridge University Library, which houses the largest collection, with about 190,000 fragments.[3] Though Geniza manuscripts have attracted a great deal of scholarly attention, the material aspects of these documents seem to have been largely neglected. The current study aims to obtain information on the composition of the writing supports and inks, their production, and the history of their degradation. The collected data should supplement the description based on Hebrew palaeography and codico-

1 See Reif 2000, 12f.
2 See Reif 2000, 15ff.
3 See the website of the Taylor-Schechter Genizah Research Unit, Cambridge University Library: http://www.lib.cam.ac.uk/collections/departments/taylor-schechter-genizah-research-unit/taylor-schechter-genizah-priceless (last accessed 12 April 2017).

logy. Moreover, a characterisation of the writing materials would provide insights on trade, local technologies, and social structures. If sufficient data is collected, the tabulated results have the potential for use as a geo-chronological marker.

2 Objectives

The first objective of this research is a technical one: to conduct a systematic study of the composition of inks from Geniza fragments and to characterise the interaction between the writing materials and the writing medium. Identification of the types of the inks and their main ingredients and a tentative reconstruction of their recipes provide valuable information on the still unwritten history of writing inks. In addition to their intrinsic value, the results might provide information useful for the efficient preservation of manuscripts.

The second objective is sociological and historical. The ink composition established by scientific methods can be used as an indirect geo-chronological marker, in particular in the case of iron-gall ink. The composition of the vitriol used for the iron-gall ink preparation depends on the place of extraction. While attributing the vitriol used to a specific source of extraction is seldom possible, a number of origins can be excluded thanks to such analysis. Though ink composition alone cannot be used as a direct geo-chronological marker, superposition of chemical, palaeographical, codicological, and textual data would help to date and localize and serve as an additional argument for a typology and dating of other Hebrew scripts. Furthermore, to include the aspect of social interaction, we focus on the inks used by the scribes from different local Jewish communities as compared with the rest of Fustat (Muslim scribes, for example) and with inks used by those who did not reside in Egypt.

3 The corpus

The Cairo Geniza contains a significant number of fragments written by scribes from different schools and origins. Judaism accords great importance to tradition, which differs depending on the region the believer (or his family) comes from. Migrations (travels, trade, expulsion…) already led to the mixing of the population and the installation, in Cairo, of a number of Jewish communities with different rites. Our question is: can we correlate the use of the ink type to an objective criterion? Does the ink type depend on the manuscript type (legal, private, religious)? On the support type? On the geographic origin of the document? On the community the scribe belongs to?

For our study, we chose Hebrew legal documents and letters from three communities that coexisted in Fustat in the 11th century: the so-called Jerusalemite (or Palestinian) community, the Babylonian community, and the Karaites, three different communities with different scribal traditions.[4] During the first half of the 11th century, the borders between these communities were well defined, so that attribution was possible. Moreover, the number of fragments building our corpus is sufficiently large for reasonable statistical analysis.

Tab. 1: The documents and the scribes chosen for the study.[5]

Palestinian / Jerusalemite congregation	Documents	Babylonian / Iraqi congregation	Documents	Karaite congregation	Documents
Efrayim ben Shemarya. Spiritual leader of the Jerusalemite congregation in Fustat (1007–1055)	4 documents 1 *halakha* 11 legal documents 9 letters 1 list 1 petition 1 poetry 1 responsum **29 items**	**Elḥanan ben Shemarya.** Leader of the Babylonian congregation (until his death in 1026) in Fustat and responsible for contacts with the yeshiva in Babylonia (today Iraq)	4 letters 1 note 1 legal document **6 items**	**Unknown scribes**	2 manuscripts 2 wedding contracts (*ketubot*) **4 items**
Yefet ben David Assistant of Efrayim ben Shemarya	2 accounts 1 legal document 4 *ketubot* 4 letters 1 fragment **12 items**	**Avraham ben Saḥlān.** Head of the Iraqi congregation in Fustat, *alluf* and *ḥaver* (1016–*c.* 1032)	4 legal documents **4 items**		
		Saḥlān ben Avraham *Payṭan* and like his father head of the Iraqi congregation in Fustat, *alluf* and *ḥaver* (1034–1049/1050)	6 letters 1 legal document 1 *piyyuṭ* 1 note 1 calendar **10 items**		

4 For a more detailed review, see Olszowy-Schlanger in the present volume.
5 Bareket 1999.

4 Analysis methods

The choice of the analytical protocol is usually based on the scientific question, the material to be analysed, and, not least, on the available instrumentation. Several methods of analysis are available today and have been used so far in the study of black inks.[6] The BAM (Bundesanstalt für Materialforschung und -prüfung) in Berlin and the CSMC/UHH (Centre for the Study of Manuscript Cultures, University of Hamburg) are working toward setting up a standard procedure for the study of writing materials and, more specifically, of inks. The procedure is based on reflectographic examination followed by non-destructive X-ray fluorescence (XRF) analysis using portable or transportable instruments so that the analysis can be carried out *in situ*. The first of these methods, infrared reflectography, has a practical application in the determination of the type of ink used: the color of soot ink/carbon ink is independent of the wavelength between 300–1700 nm; iron-gall ink loses opacity toward long wavelengths (i.e., 750–1000 nm) and becomes transparent at 1200 nm, while plant ink is transparent already at ~700 nm.[7] The second technique, XRF, is a non-invasive method for characterizing inorganic materials and is commonly used to analyse the elemental composition of various objects in the field of cultural heritage, including manuscripts. The development and use of a fingerprint model based on the qualitative and quantitative detection of the inorganic components of iron-gall inks allows their reliable classification.[8] In short, X-ray incident radiation causes ink components such as iron, copper, zinc, etc. to emit characteristic X-rays that are recorded as spectra by the XRF spectrometer. Evaluation of the spectra results in a fingerprint of the ink under investigation.

For our analysis in the Cambridge University Library in 2015, we used the following protocol:

1. Macroscopic observations concerning the type of the support and the state of preservation.
2. Ink typology: we used a portable microscope (Dino-Lite) with illumination in ultraviolet (UV, 390 nm), visible (VIS), and near infrared (NIR, 940 nm) regions of the electromagnetic spectrum and magnifications of x50 to x200. In addition, we used the micrographs to study the ductus of the script.

6 Aceto et al. 2008; Easton et al. 2010; Gambaro et al. 2009; Hahn et al. 2004; Lee et al. 2006; Mocella et al. 2015; Nastova et al. 2013; Rabin et al. 2014; Tack et al. 2016; Tanevska et al. 2014.

7 Mrusek et al. 1992; Rabin et al. 2014; Rabin and Binetti 2014.

8 Hahn et al. 2004.

3. Ink composition by micro X-ray fluorescence (micro XRF): we used a commercial micro-XRF spectrometer specially designed for the *in-situ* study of cultural heritage objects (ARTAX, Bruker GmbH). It consists of an air-cooled, low-power X-ray tube, polycapillary X-ray optics (measuring spot size 70 μm in diameter), an electro-thermally cooled Xflash detector, and a CCD camera for sample positioning. Furthermore, open helium purging in the excitation and detection paths allows the detection of light elements (Z ≥ 11). In addition to the ARTAX, we used an imaging XRF spectrometer, the Jet Stream M6 (Bruker GmbH), during our visit in Cambridge in 2015. This device is specially designed to obtain detailed, spatially resolved elemental maps of large areas, so that we planned to use it to reveal damaged text in conjunction with multispectral imaging. Its major improvements include a variable measurement spot of 50 to 850 μm and the use of a high-speed probe that moves with a predefined speed over XY frame of 60 × 80 cm with the mounted sample. The absence of helium (He) purging is the major drawback of this setup since the elements Z < 19 cannot be securely quantified. It is, however, well suited for the identification of the metallic components of iron-gall inks.

Until now, two analytic campaigns for the study of the manuscripts from the Cairo Geniza collection housed in the University Library of Cambridge have been conducted.

In 2015, a team composed of scholars (Judith Olszowy-Schlanger, Judith Kogel, and Daniel Stökl Ben Ezra from the École Pratique des Hautes Études, Paris – EPHE), multispectral imaging specialists (Roger Easton, Michael Phelps, Gregory Heyworth, and Damian Kasotakis from the Early Manuscripts Electronic Library – EMEL), and a group of scientists from the BAM/UHH (Ira Rabin, Oliver Hahn, and Zina Cohen) studied a number of manuscripts from the Cairo Geniza collection in the Cambridge University Library. The group performing material analysis inspected 36 manuscripts using three different instruments: ARTAX and Jet Stream for XRF analysis and a three-colour USB-microscope Dino-Lite for reflectography. Manuscripts subjected to the studies were dated from the 9th to the 11th century and were written mostly for a religious purpose (Bible, Talmud, *ketubot* [wedding contracts]).

In 2016, a team composed of Ira Rabin, Olivier Bonnerot, and Zina Cohen analysed 17 documents written during the first half of the 11th century. The primary screening with the Dino-Lite microscope made it possible to sort the documents by ink type. To test as many variables as possible, we chose manuscripts with different writing substrates (paper, leather and parchment) and subjects, different ink types, and different signatures of the congregation leaders (Palestinian:

Efrayim ben Shemarya and Yefet ben David; Babylonian: Elḥanan ben Shemarya, Avraham ben Saḥlān, Saḥlān ben Avraham).

5 Example results

We plan to publish all the results at the end of the project. Here we would like to present two examples that elucidate our work and its impact on the history of manuscripts.

The first example is a leather fragment inscribed on both sides, Cambridge University Library, TS Misc.26.53.17. A portion of the Babylonian Talmud appears on the grain side (recto), whereas the flesh side displays a typical re-use of the writing support: another text appears that is turned 90 degrees from the orientation of the text on the recto side.[9] The manuscript can be dated palaeographically to the period between the 9th and the 10th century. It contains notes added in darker ink beside the main text.

5.1 TS Misc.26.53.17, recto

Figure 1 shows an example from the series of images of the text portions on the recto side, which were photographed under visible illumination (left) and near-infrared illumination (NIR) (right). The larger letters that correspond to the main text are darker under the NIR illumination, testifying to the carbonaceous nature of the ink. In contrast, the smaller letters in the notes become hardly visible as the illumination changes from visible to NIR light, indicating that this ink belongs to the iron-gall type.

Results of the XRF analysis of the inks from the main text and the notes are shown in Figure 2. We conducted a series of point measurements along a line, which is called a line scan, that starts in the note (top-left image), passes over uninscribed leather (top-middle image) and ends in the main text (top-right image). The graph below the images presents the evolution of the signals from elements calcium (Ca), iron (Fe), and potassium (K) during the progress of the scan. The element intensities of the middle part, i.e. the uninscribed leather, describe the metal content of the writing support or background signal. On the left, i.e. the ink

9 This manuscript is included as number XVI in the paper by Olszowy-Schlanger, see in the present volume.

of the notes, the higher intensity of iron and potassium indicates that here we are dealing with iron-gall ink, confirming the result obtained by reflectography (Fig. 1). The right portion of the graph depicts the intensities of the ink of the main text. Here, the signal from iron and potassium do not rise above the background level of the leather, again confirming the result obtained by reflectography. Curiously, the intensity of the element Ca is highly heterogeneous in this fragment. This could be due to the leather processing or to water damage that occurred at a later time.

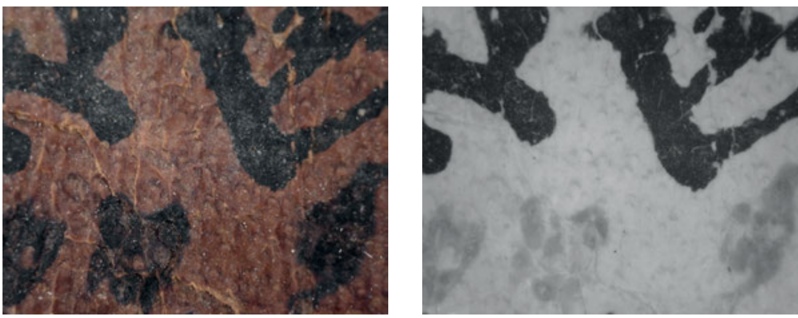

Fig. 1: Visible (left) and NIR (right) images of a text portion from the recto of the fragment T-S Misc. 26.53.17 at 50x magnification, made with the Dino-Lite AD413T-I2V USB.

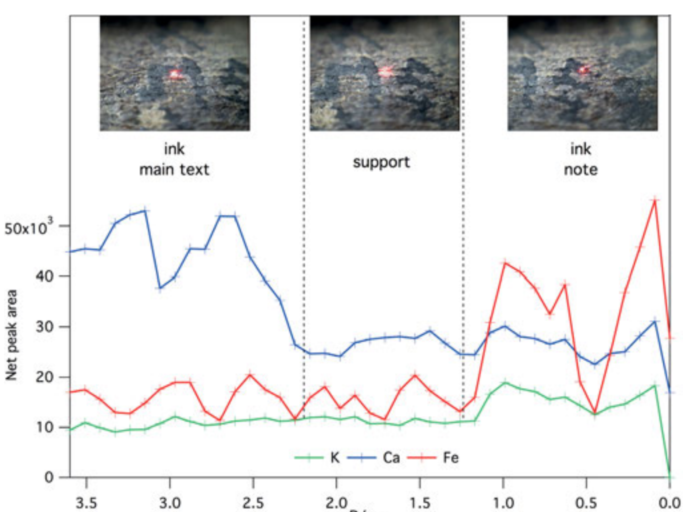

Fig. 2: µ-XRF line scan of the inks (note and main text) of the manuscript TS Misc.26.53.17; Fe – red, K – green, Ca – blue. Three micrographs indicate the area of the measurements that correspond to the respective element intensities on the graph. The scan was conducted with ARTAX (Bruker GmbH).

5.2 TS Misc.26.53.17, verso

In Figure 3, the micrographs show the letters from the inscription on the verso side of the fragment. The slight fading of the black ink on the right side (NIR light) as compared with that in the visible light (left) makes it possible to identify the ink's type as iron-gall. XRF analyses conducted in this case with both line scanning (ARTAX) and imaging (Jet Stream) XRF spectrometers also confirmed this conclusion. To illustrate the high resolving power of the Jet Stream, we included the distributions of Ca, K, and Fe in Figure 4.

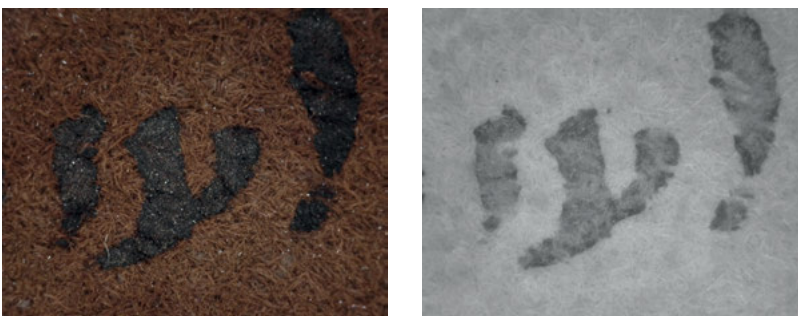

Fig. 3: Visible (left) and NIR (right) images of a text portion from the verso of the fragment TS Misc.26.53.17 at 50x magnification, made with the Dino-Lite AD413T-I2V USB.

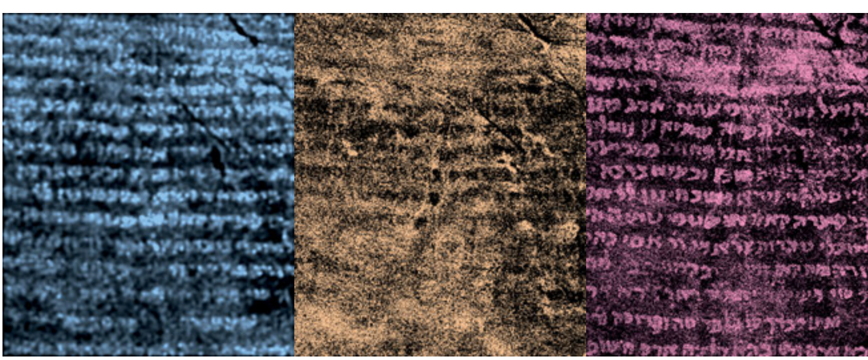

Fig. 4: Selected element maps obtained by macro-XRF scanning of a text portion from the flesh (verso) side of the manuscript TS Misc.26.53.17: blue – potassium (K), red – calcium (Ca) and purple – iron (Fe).

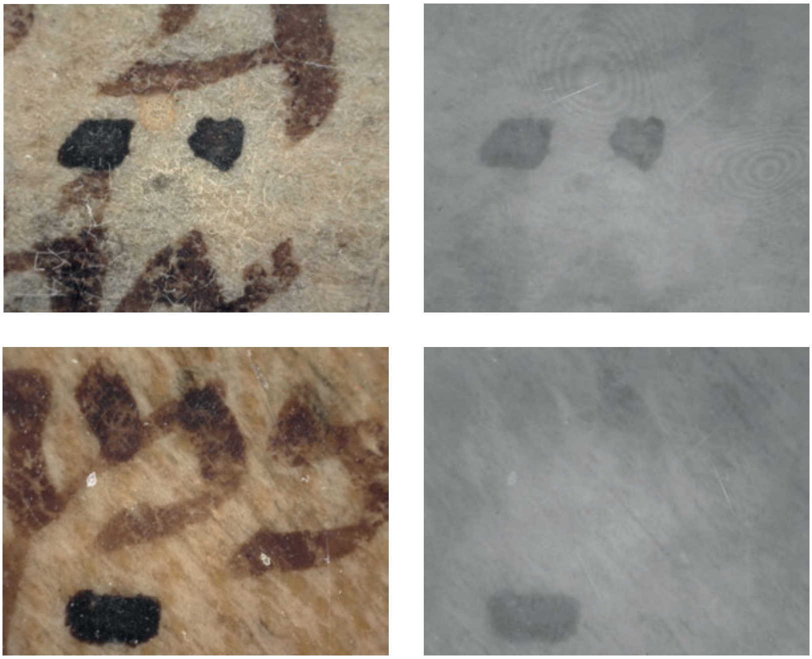

Fig. 5: Visible (left) and NIR (right) images of a text portion from the flesh (top) and grain (bottom) sides of the fragment T-S F17.4 at 50x magnification, made with the Dino-Lite AD413T-I2V USB.

The distributions of Fe and K are clearly associated with the ink, so that they produced single-element text images. Note that in the upper part of the imaged area the signal from iron loses its sharpness and is spread also over uninscribed leather, whereas the signal of potassium is not affected. Such appearance of the element maps is closely associated with the nature of the iron-gall inks that contain water-soluble ingredients and insoluble pigment – iron gallate. Water-soluble ingredients penetrate the substrate, whereas the pigment stays on the surface and is strongly affected by such external influences as mechanical abrasion or water damage. Element maps obtained by XRF document also showed displacements of the elements due to damage. The Ca map presents an extremely complicated picture here. First, the text damage presented in the iron map can be recognized in the Ca map. And second, the heterogeneity of Ca distribution is greater by far than that of iron. Taking into account that we have already detected it on the recto side, we may tentatively conclude that it reflects the use of a Ca-based compound in the leather preparation process.

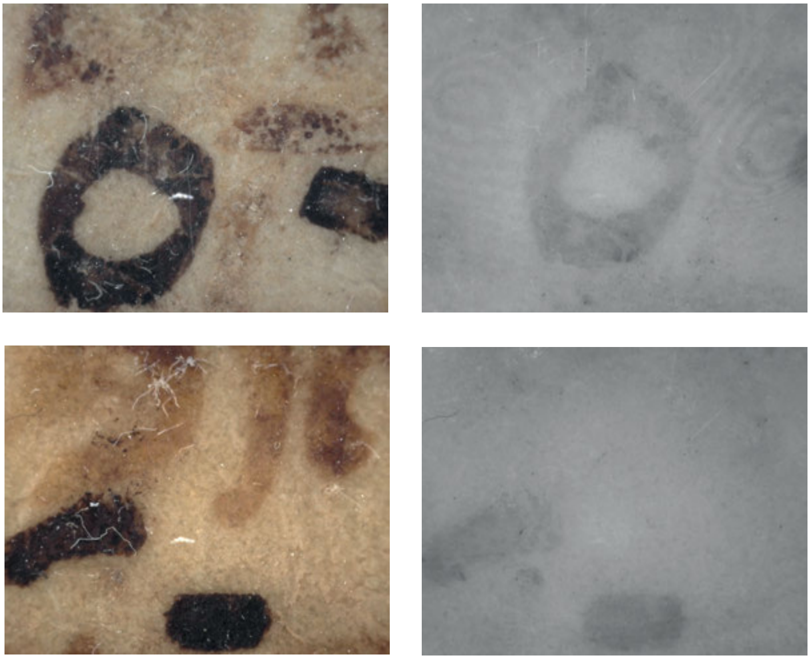

Fig. 6: Visible (left) and NIR (right) images of a text portion from the flesh (top) and grain (bottom) sides of the fragment TS 12.755 at 50x magnification, made with the Dino-Lite AD413T-I2V USB.

In summary, the primary text on the recto sides of the leather scroll fragment, TS Misc.26.53.17, is written in carbon ink, whereas the notes and the text on the verso side appear in iron-gall ink.

Our second example illustrates our ability to compare iron-gall inks using the XRF method. Here we would like to explore whether ink analysis confirms the codicological observations that attributed the fragments TS F17.4[10], TS 12.755[11] and TS 12.756[12] to the same Talmud manuscript.[13] All three fragments are palimpsests with the upper text written during the 10th century and attributed by palaeographic analysis to the scribe hand found in the manuscript Hébreu 1489 (9) kept at the Bibliothèque nationale de France (BnF).

10 Olszowy-Schlanger/Shweka 2013; Sokoloff 1979; Tchernetska 2002.
11 Olszowy-Schlanger/Shweka 2013; Sokoloff 1979.
12 Olszowy-Schlanger/Shweka 2013; Sokoloff 1979.
13 Sussman 2012.

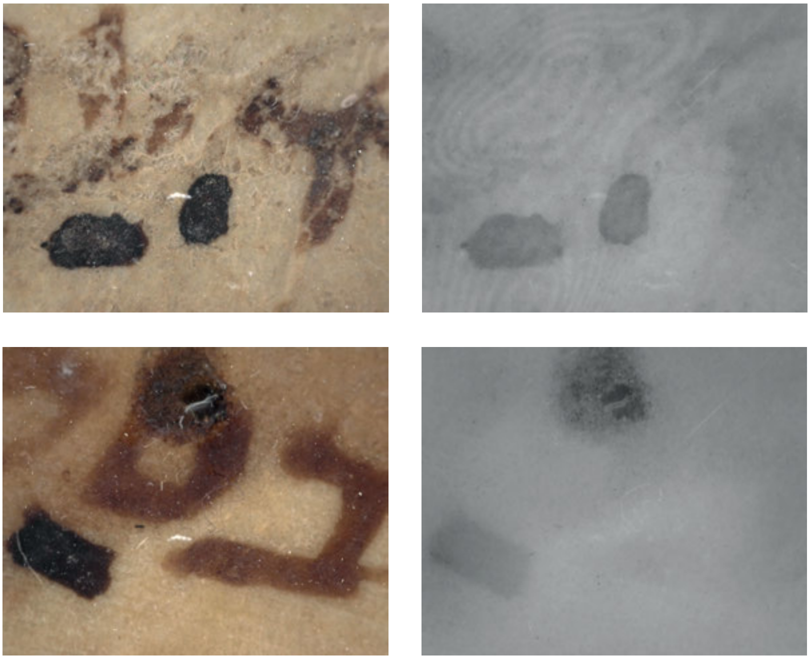

Fig. 7: Visible (left) and NIR (right) images of a text portion from the flesh (top) and grain (bottom) sides of the fragment TS 12.756 at 50x magnification, made with the Dino-Lite AD413T-I2V USB.

Figures 5–7 show visible and near-infrared micrographs of the upper inks of the three fragments. From the fading of the inks' colour under NIR illumination, we can conclude that all inks belong to the iron-gall type. Yet, no conclusion can be derived of the ink composition, since the colour of the inks greatly depends on the degree of degradation. To compare the inks' compositions, we have to use XRF analysis. It should be mentioned here that we could compare only the upper inks, since the under-text changed its original composition in the course of the process of palimpsest production.[14]

To obtain statistically relevant results, we conducted multiple line scans on each of the fragments. Figure 8 presents an average ink fingerprint obtained for each group. As one can see from the average fingerprint of the inks, the fragments TS 12.755, TS 12.756 and TS F17.4 were indeed written with the same ink. The addition of vowels, however, was conducted in a different ink that contained almost three times more copper than that of the main text.

14 Cohen et al. 2016.

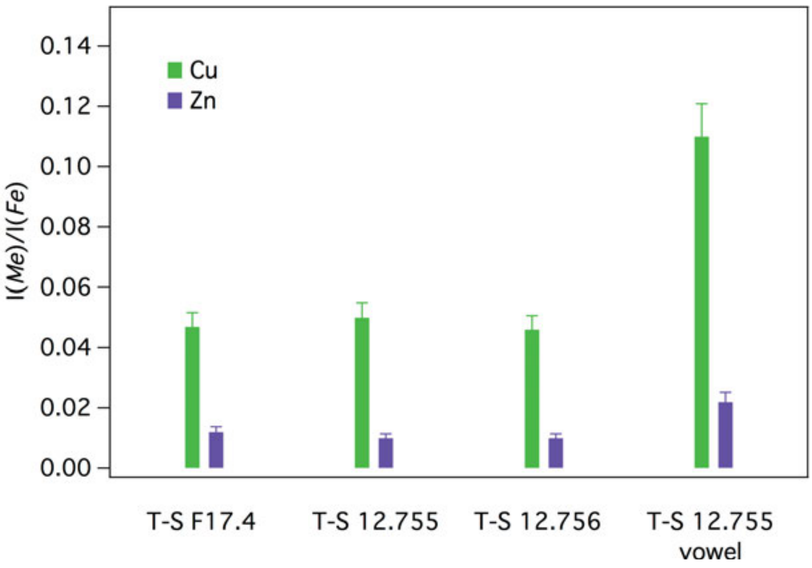

Fig. 8: Comparison of the fingerprint of the manuscripts TS F17.4, TS 12.755, and TS 12.756. Intensities of the metallic components, copper (Cu, green) and zinc (Zn, purple), are normalized to iron (Fe).

6 Conclusions

We demonstrated that, using reflectography and XRF analysis, it is possible to sort the inks by type. In the case of the iron-gall inks, we can use the ink fingerprint, i.e. the amount of the vitriol components normalized to iron, to make direct comparisons of the ink composition.

We would also like to stress that, though the methods of material analysis listed above have been successfully employed in the field of cultural heritage and conservation, including on ancient and medieval manuscripts,[15] they have not yet been used to study fragments from the Cairo Geniza. Therefore, we believe that the current PhD research project is a pioneering study that will provide new insights into the history of Hebrew writing materials and their production techniques and materials and thus contribute new data to the field of Hebrew palaeography.

15 E.g. Hahn et al. 2008, Rabin et al. 2014.

Acknowledgements

This research was partly undertaken within the scope of the scientific project Z02 'Material-science Methods of Reconstructing the History of Manuscripts' at the SFB 950 'Manuskriptkulturen in Asien, Afrika und Europa' / Centre for the Study of Manuscript Cultures (CSMC), University of Hamburg, funded by the German Research Foundation (DFG). We are grateful to Ben Outhwaite for his great interest in this work, to the staff of the conservation department (and especially Rebecca Goldie for her readiness to open and close fragments), and to the imaging department – the former head of the department, Grant Young, the current head of the department, Maciej Pawlikowski, and his colleagues Blazej Mikula and Scott Maloney – for hosting us. Many thanks to Daniel Stoekl Ben Ezra from the EPHE for discussions. Special thanks to Olivier Bonnerot, for his constant support.

Abbreviations

AS	Additional Series, Taylor-Schechter Genizah Research Unit, Cambridge University Library
BL	British Library
CUL	Cambridge University Library
Misc.	Miscellaneous, Taylor-Schechter Genizah Research Unit, Cambridge University Library
NS	New Series, Taylor-Schechter Genizah Research Unit, Cambridge University Library
TS	Taylor-Schechter Genizah Research Unit, Cambridge University Library

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