



INTEGRATED IMAGING ON THE COLLECTIONS AT UCL SPECIAL COLLECTIONS

Sun Jieran

Supervisors: Prof Adam Gibson,
Dr Tabitha Tuckett

jieran.sun@ucl.ac.uk

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Executive Summary

As one of the projects of the Laidlaw scholarship program, UCL digitalisation suite accommodated one undergraduate student for six week to conduct multiple imaging techniques and image processing to answer the research questions raised by UCL special collections. In this project, a variety of objects including medieval manuscripts, rare books and a set of flooded deed underwent the process.

For the parchments which were used as binding material, some of its annotations were recovered under the illumination of ultraviolet light. Also, some of the inscriptions have been chemically treated, leaving some blue stain on top. These inscriptions were robust and showed clearly under infrared illumination. See Page 12-17.

The structure of the chemical coating on some parchments was studied and recorded by reflectance transformation imaging. With the current setting and wavelength combination, it is hardly achievable for multispectral imaging to penetrate the cover and show the inscriptions underneath. However, some processing techniques, such as principal component analysis and false colour alignment, can enhance the visibility of some of the covered inscriptions at the edge. See page 27-34.

Parchments with faded inscriptions are typical cases in medieval manuscripts.

Multispectral images captured under ultraviolet and royal blue light with filters applied showed the most promising results due to the contrast in fluorescence of the parchment and the ink. Also, contrast adjustment and PCA can be the joint practical operations for such cases. See page 37-41.

Many of the medieval manuscripts were covered and decorated with gold and vivid patterns as a symbol of social status. For conservation on the delicate decoration, the gold leaf cover on one of the parchment fragment was imaged. Reflectance transformation imaging has shown the edge and cleavage structure interactively by adjusting the lighting position. Also, specular enhancement has given more accurate information on the depth of the cleavage. See page 44-47.

A flooded deed that is believed to be related to the main building of UCL campus was also imaged by the multispectral imaging system. The inscriptions can be mostly recovered under ultraviolet light with filters applied. However, due to the thinness and transparency of parchments that have been flooded, inscriptions from the other side were also recorded on those images. However, this can be solved by image processing, including PCA and false colour alignment. See page 51-54.

For parchments covered by dirt, similar imaging manner has been applied to distinguish its inscriptions. However, due to the poor penetrating ability of lights in short wavelength, images captured under these lights were not the ideal choices despite the rich information shown. Meanwhile, false colour alignment has also been proved useful to deal with such cases as it can separate the two layers. See page 58-62.

Books are essential assets which show the prestige and social status of their owners, and their alternations of ownership can also be a critical indicator of significant social changes. However, inscriptions from previous owners were often deleted and covered by its later owner as an unspoken form of tradition. In this case, multispectral imaging was applied to recover the deleted inscriptions. Deleted inscriptions can be shown due to the different fading pattern between the inscriptions below and the one on top with respect to the increase of wavelength. Moreover, false colour alignment, by assigning different inscriptions with different colours, was able to separate the two layers. See page 71-77.

Lastly, some of the challenges arose when conducting imaging on a large number and variety of objects in terms of the time taken, storage and management of documents, and the adjustments of parameters. These issues are discussed in the report and should be addressed for future prevalent application of this system.

1. Introduction

As one of the projects of the Laidlaw scholarship program, a Laidlaw fellowship student from the University of Hong Kong spent six weeks in the UCL Digitalisation Suite intending to provide imaging solutions questions raised by UCL special collection. As a new multispectral imaging system with higher resolution had been installed in the UCL Digitalisation Suite before the student arrived, more detailed and accurate multispectral images can be captured. Meanwhile, image processing and reflectance transformation imaging have also been applied in this project.

UCL special collection is “one of the foremost university collections of manuscripts, archives, and rare books in the UK.” Various types of documents have been carefully collected and conserved there including medieval manuscripts, early printed books, a considerable number of 18th-century work as well as 19th and 20th-century collections of personal papers, archive materials and literature with significant historical and literary value. The highlights of the special collection include the Westminster School Archives, Orwell Archive which includes many of his personal papers, Paradise Lost by John Milton and more.

Due to the variety of the objects in the project, different imaging setups, capture sequences and parameters, and imaging processing methods were applied. Therefore, this study had the objective to apply multiple imaging techniques to deal with a range of objects in different sizes, composed of a variety of materials and inks, with distinctive conservation histories and varying ages. The following case studies were imaged during the six-week project:

- 1) Parchments used as binding material
- 2) Parchments with covered inscriptions
- 3) Parchments with faded inscriptions
- 4) Parchment with gold cover
- 5) Flooded Deeds

- 6) Parchment covered in dirt
- 7) Books with overlapping inscriptions

In the following parts of this report, Chapter 2 addresses the various methods applied in the project for imaging and image processing. Chapter 3 presents the different case studies shown above, and Chapter 4 concludes the report and aims for some of the operational protocols in conducting those imaging techniques.

2. Methods

2.1. Multispectral Imaging

Multispectral imaging aims at recording spatial and spectral information in one system to enable comparison and analytical study. In this research, multispectral images were captured as the artefact was illuminated in lights in different wavelengths, ranging from ultraviolet light to infrared light, totally 16 different wavelength options. Apart from the reflected light, fluorescence can also be captured by placing different filters in front of the camera lens. A monochromatic camera then captured different features that appeared and disappeared across the image sequence as the illumination varied. The multispectral imaging system comprises a 100-megapixel, monochromatic PhaseOne (Copenhagen, Denmark) camera, two light panels from Equipoise Imaging LLC (Ellicott City, MD) with Light Emitting Diodes (LEDs), and an Optec (Lowell, MI) 6-position filter wheel containing five filters.

2.2. Flat Field Correction

To correct for non-uniformities in the illumination, A process called flat field process was applied to multispectral images. In order to do so, a white, flat piece of card that reflects in all wavelengths were captured with the conditions of capturing the images of the objects. During this digital correction process, the value on each pixel of the multispectral image was divided by that on its corresponding flat field images and then multiplied by the average intensity of the flat field image for rescaling purpose.

2.3. Reflectance Transformation Imaging

Reflectance Transformation Imaging is a “computational photographic method that captures a subject’s surface shape and colour and enables the interactive re-lighting of the subject from any direction.” In this research, RTI was taken by capturing a series of images while having the flashlight shot in a dome-shape pattern. Then later, in RTI image building software, those images were superimposed to form an interactive dome sphere that allowed changing lighting positions with precise coordinates while showing the surface shadowing information accurately. RTI is usually applied when the surface structure, for instance, of the object is the interest to be explored.

2.4. Principal Component Analysis

Principal Component Analysis (PCA) is a multivariate statistical technique used for dimensionality reduction and is often applied to multispectral images. A new sequence of images, called principal components, is created in which the covariances between the original images are minimised. Usually, the majority of the useful information will be presented in the first few principal components, including the inscription data. Thus those principal components are usually extracted for false colour alignment, which will be discussed later.

2.5. False Colour Alignment

In false colour alignment, greyscale images are placed into red, green, and blue channels randomly to create a newly generated colour image. However, it is noticeable that the colours of a false colour image do not represent what would be normally obtained by bear eye in visible ambient light And therefore some of the faded or blurred information can be shown more clearly under a proper alignment.

3. Case studies

3.1 Parchment used as binding material

3.1.1 Introduction

It is a relatively common case in UCL special collection that the parchments from the 13th to 16th century are found to be recycled for various purposes other than its merely preserving information. These parchments were used as the outer cover to protect and maintain the condition of the bounded work. In this project, two parchments, MS FRAG/LAT/36, and MS FRAG/LAT/54 were imaged as representatives of parchments of this kind. By imaging and identifying the original inscriptions and the lately-added notations of the parchments, we can have a better idea of the conditions of those recycled parchments and the general category of books that they are used for binding and protection.

3.1.2 Materials and Methods

MS FRAG/LAT/36

This parchment is believed to be a leaf of a calendar, and it is believed that this parchment was taken from an obit book based on the inscription on recto side of the book. Also, as a calendar, it can be distinguished from the red header in the recto side that the leaf is for the month of November.

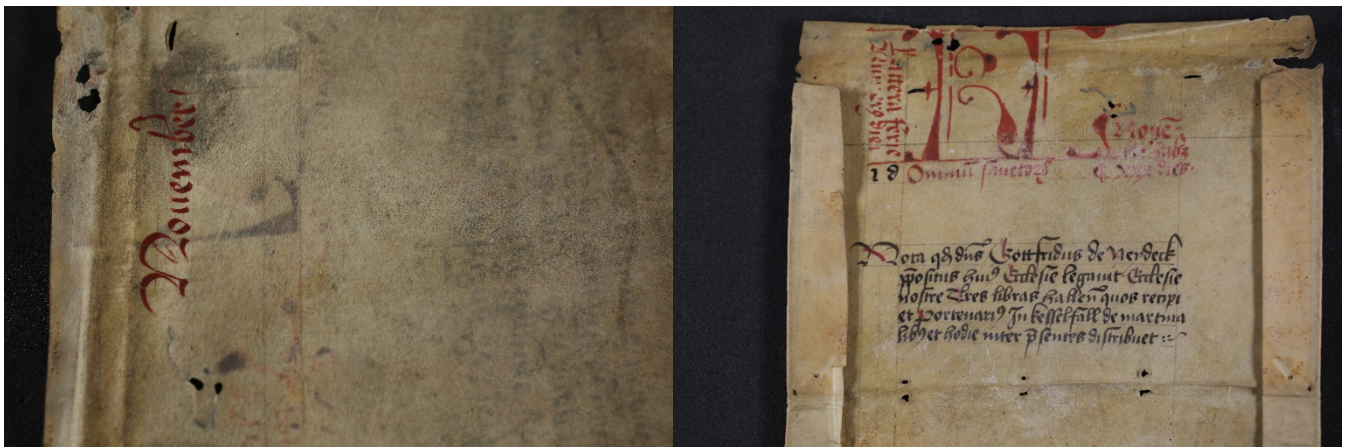


Figure.3.1-1: red header indicating that the leaf is for the month of November (left) and the inscription indicating that the book is from an obit book.

It is assumed that the parchment is from 15th to 16th century, and there is a faint but near-contemporary hand-written annotation at the top middle part of the verso side of the

parchment, which is believed to be related to the use of the parchment as binding material. Moreover, the expectation was set that by imaging and processing, the notation can be shown more clearly, giving a clue about the bound work.

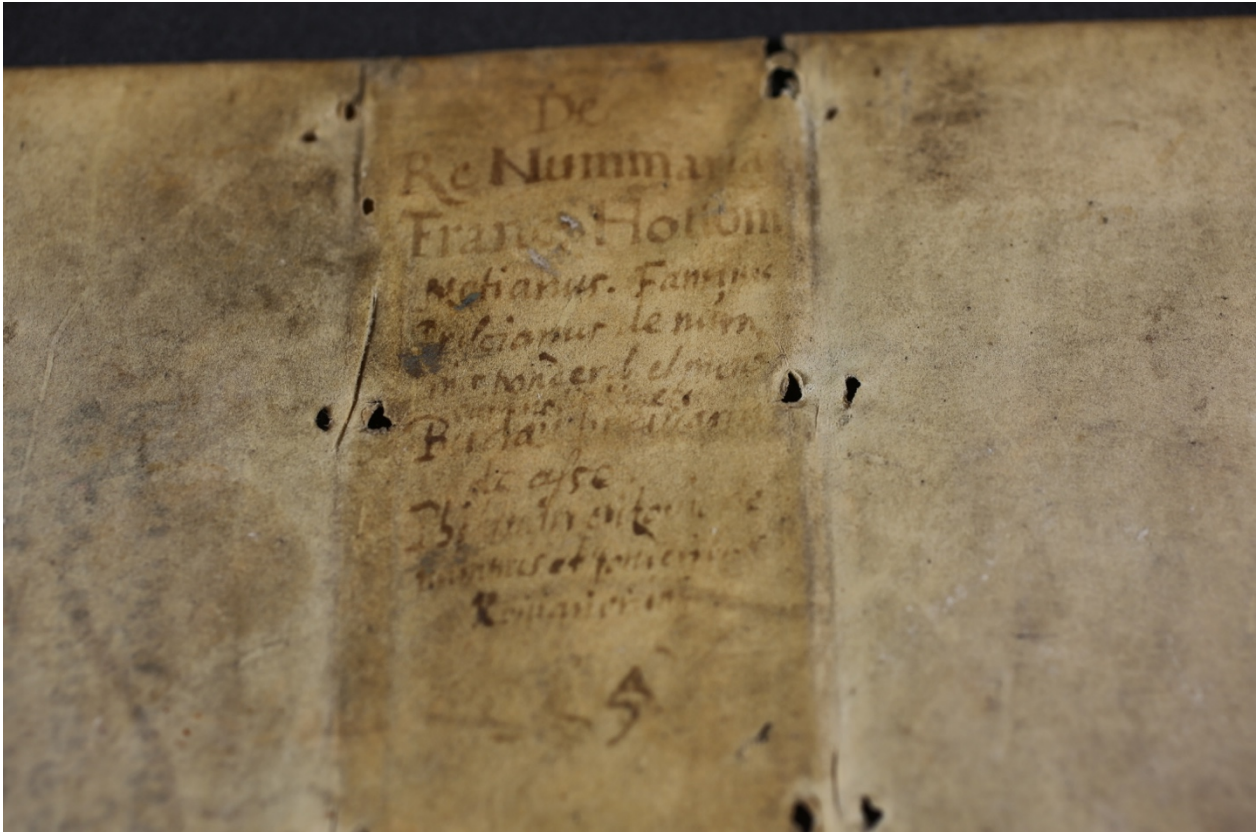


Figure 3.1-2 the notation on the verso side which can be related to bound work.

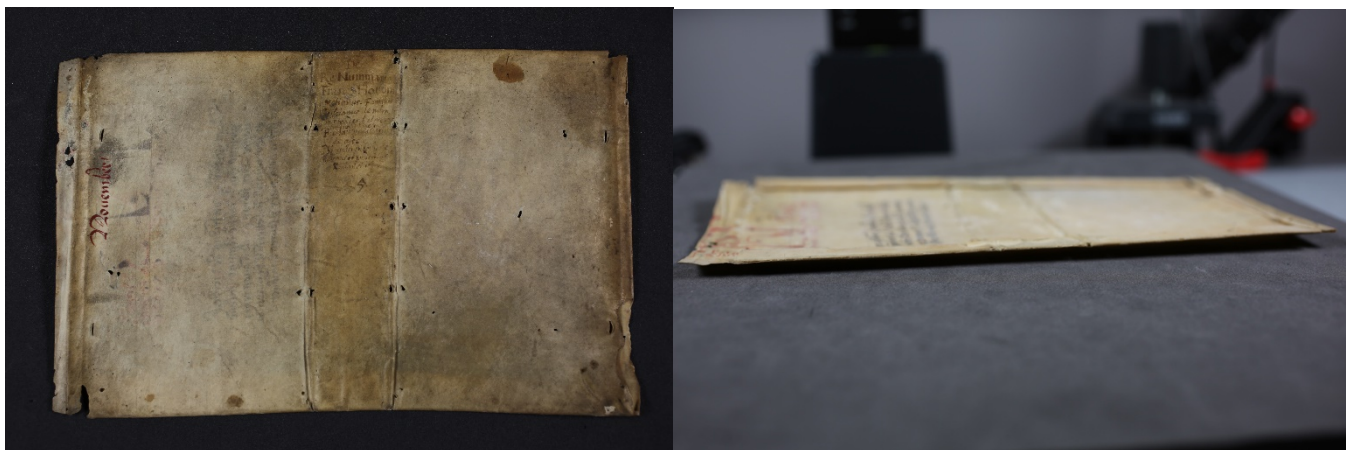


Figure 3.1-3 verso view (left) and side view (right) of the parchment.

MS FRAG/LAT/54

This parchment is believed to be a part of the bible. However, the original leaf of the bible was cut into two pieces, and this parchment is the bottom half of the leaf. As shown in figure 3.1-4, there are decorations in protogothic style in red and blue ink on the verso side of the parchment. Protogothic is a transitional minuscule script popular in the 11th to 13th century, which can be one of the proofs that the parchment is dated 13th century.

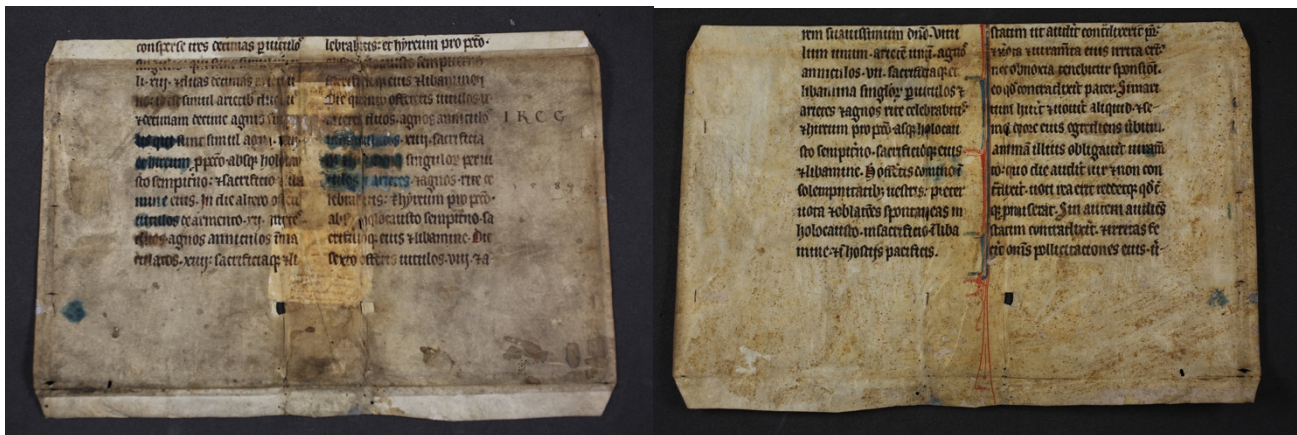


Figure 3.1-4 recto view (left) and verso view (right) of the parchment. From verso view the protogothic decoration can be seen between the two columns of word

Meanwhile, this fragment is also believed to be used as an outer cover of an octavo-sized book due to its faint annotation in the centre of the bottom margin on its recto side. Moreover, there were signs of blue chemical treatment to a specific portion of the words on the recto side. We hope that through imaging, we can have a better insight into the content of the annotation, as well as finding out the effect of the treatment..



Fig. 3.1-5 the annotation (left) which is related to the bound work and the chemical treatment (right)

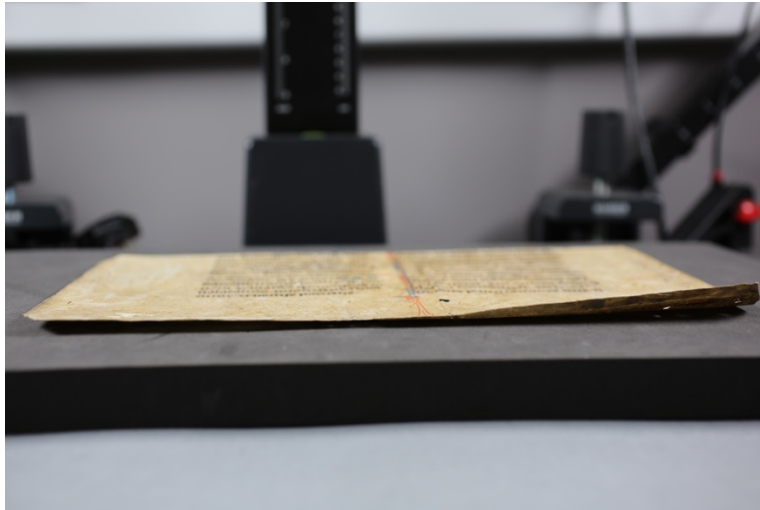


Figure 3.1-6 side view of this parchment

Methods

Multispectral images were captured on both verso and recto sides of the parchments, illuminating them in ultraviolet, visible and infrared light with red, green and infrared filters using the R.B. Toth Associates imaging system. Two tables containing the imaging parameters of the sequences are attached for the two parchments respectively. Table 1 is for MS FRAG/LAT/36, while Table 2 is for MS FRAG/LAT/54. As both of the capture sequences are 25 shots with same wavelength order, Table 2 will only show the shots with exposure and ISO value different from that in Table 1. These differences are due to different illumination of parchments. However, all sequences were taken with the aperture of f/8.0. Also, the first shot is the same as the 25th shot to test if there is any deviation during capturing. The measurement of the system is recorded in Table 3.

Even though as shown in Figure 3.1-6 and Figure 3.1-3, the two parchments are not entirely flat, but considering the depth of field of the camera and the scale of change in the height of the parchments, flat fields have been taken, and the photos are digitally flattered to have an even illumination throughout the images.

Principal Component Analysis was applied to multispectral images of both parchments, and false colour images were generated from the combination of multispectral images and principal components which can show the text with better contrast. D-stretch has also been applied with the same expectation.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	6	200
2	385	Ultraviolet	None	6	200
3	410	Violet	None	0.4	200
4	420	Violet Long	None	0.25	200
5	450	Royal Blue	None	0.2	200
6	480	Long Blue	None	0.125	200
7	510	Cyan	None	0.2	200
8	530	Green	None	0.2	200
9	550	Lime	None	0.125	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.2	200
12	640	Red	None	0.2	200
13	660	Long Red	None	0.2	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	0.5	200
16	940	Infrared	None	1.6	200
17	365	Ultraviolet	Green	8	200
18	410	Violet	Green	5	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	15	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	6	200

Table 1 Capture sequence of MS FRAG/LAT/36 recto and verso side

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
------------	------------	--------	--------	-------------	-----

1	365	Ultraviolet	None	8	200
2	385	Ultraviolet	None	8	200
3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.2	200
7	510	Cyan	None	1/3	200
8	530	Green	None	0.4	200
15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	10	200
25	365	Ultraviolet	None	8	200

Table 2 Differences in Capture sequence of MS FRAG/LAT/54 recto and verso side. All other shots are the same as that in Table 1

3.1.3 Results and Discussion

Multispectral Images

The notation was shown most explicit under royal blue and ultraviolet light with filters applied. This is due to the contrast of fluorescence of the parchment and the ink, whereas the parchment emits a significant amount of fluorescence under those wavelengths while the ink does not. Moreover, the high contrast enabled some of the faint inscription to be shown, while it also introduced some noise, which can make distinguishing the words more difficult. In that case, with the same ink and parchment, the imaging would have a better result if the surface was clean or if there was little contamination. So, cleaning the surface before capturing would be a highly recommended strategy.

Additionally, a typical pattern can be found that with the increase of wavelength, the ink reflected more light and appeared to be faint, indistinguishable with the parchment, which is a common characteristic of iron-gall ink. However, there is an interesting phenomenon in the case of MS FRAG/LAT/54 that the ink with blue chemical treatment will not be

faint w.r.t wavelength increment as shown in the graph below, the difference can be told by comparison between the treated inscription and the others. The reaction between the ink composition and the chemicals in blue stain may account for the occurrence of this case.

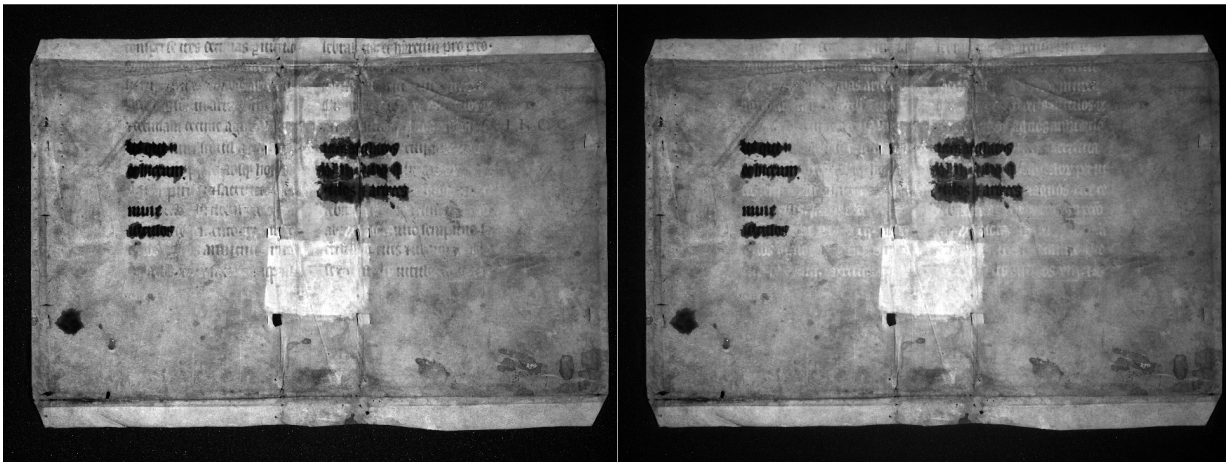


Fig.3.1-10 As wavelength increases from left to right, the inscriptions that have been treated still remain distinguishable

PCA and False Colour Images

By conducting principal component analysis, false-colour alignment and D stretch, some results which can show more information have been retrieved.

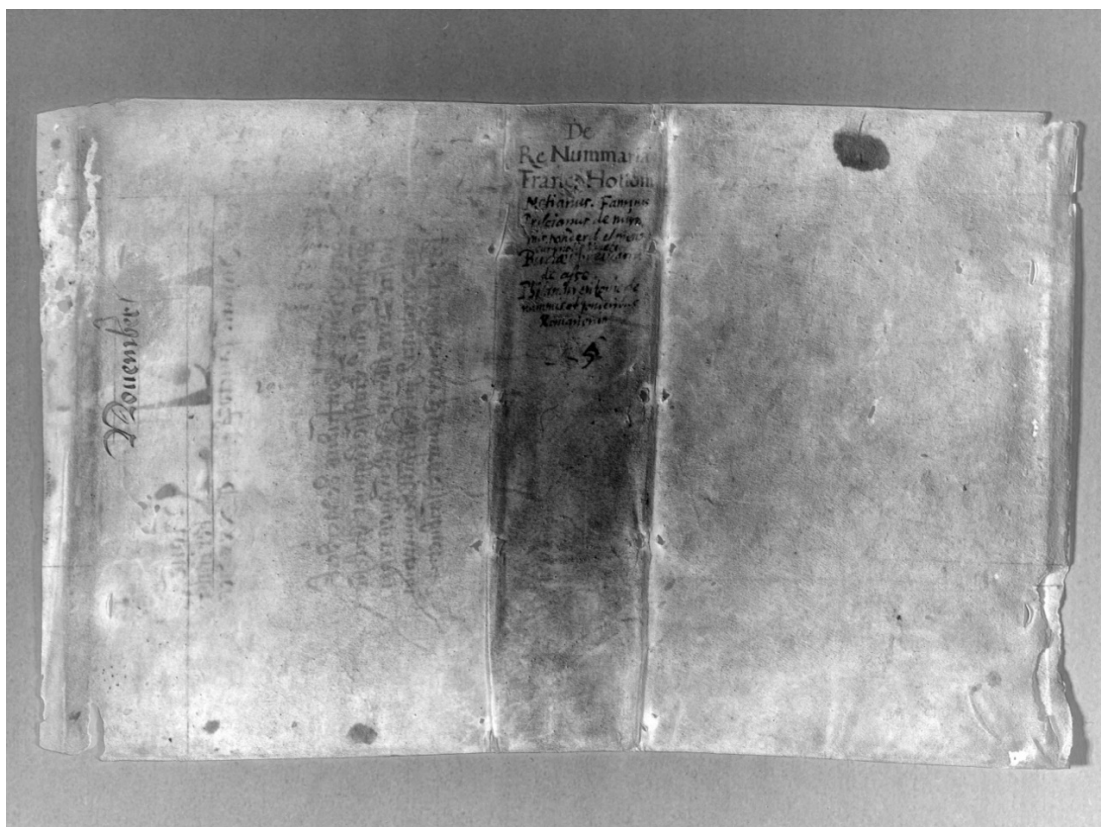


Figure 3.1-11 selected component generated by conducting PCA to the spectral image stack

Also, the false colour images were generated from a mixture of three principal components and two spectral images which contains the most information. In some of the false colour images, we have a better view of the results by increasing the contrast.

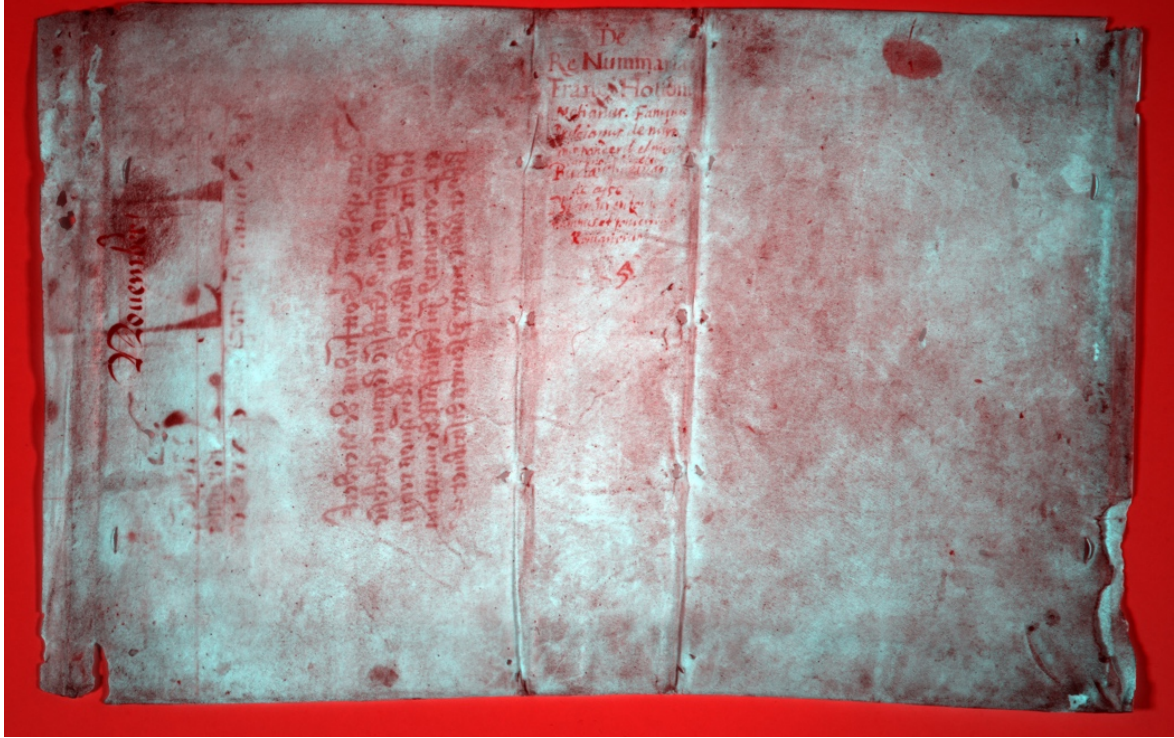


Figure 3.1-12 false colour photo by putting the 1st, 3rd principal components into Red channel and blur and green channel.

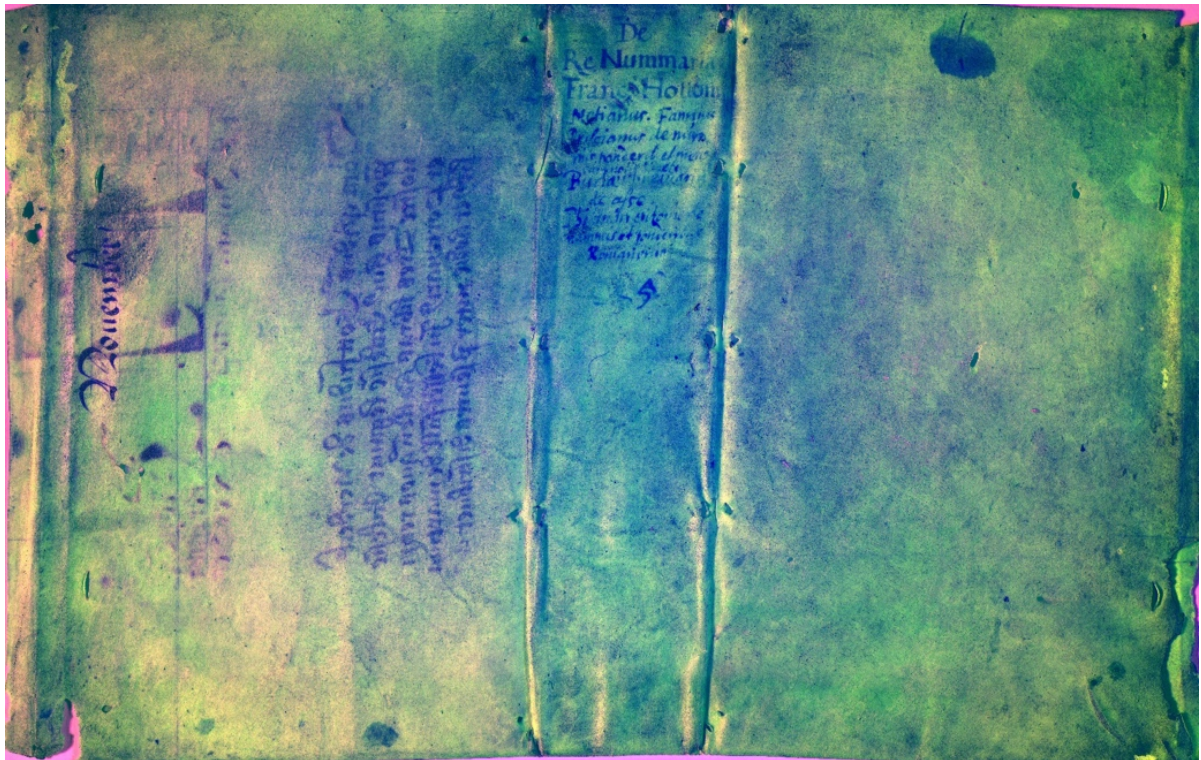


Figure 3.1-13 False colour image generated using D stretch. It is generated using the RGB photo in Figure 3.1-12 with Colourspace parameter l_m 0.26, A_m 0.70 and B_m 0.20.



Figure 3.1-13 Comparison of the inscription in both three cases above.

Similarly, in MS FRAG/LAT/54, the same pattern was applied to have false colour images generated.

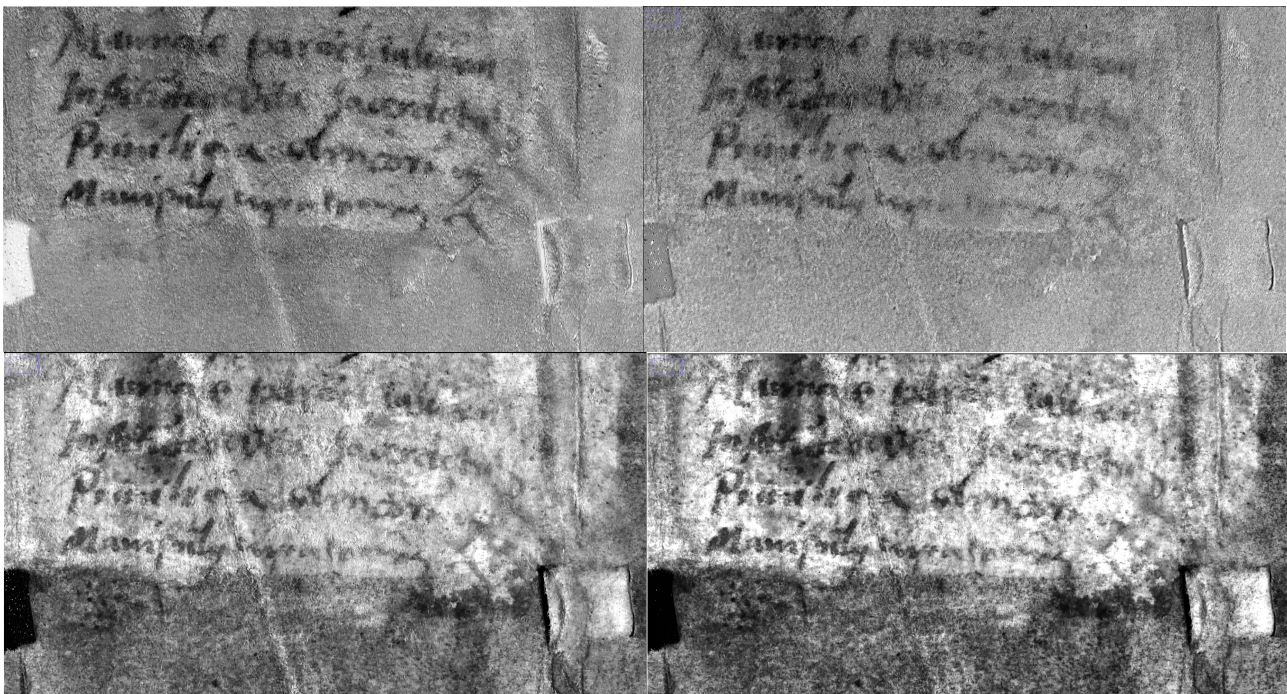


Figure 3.1-14 Four principal components are selected for false colour alignment.

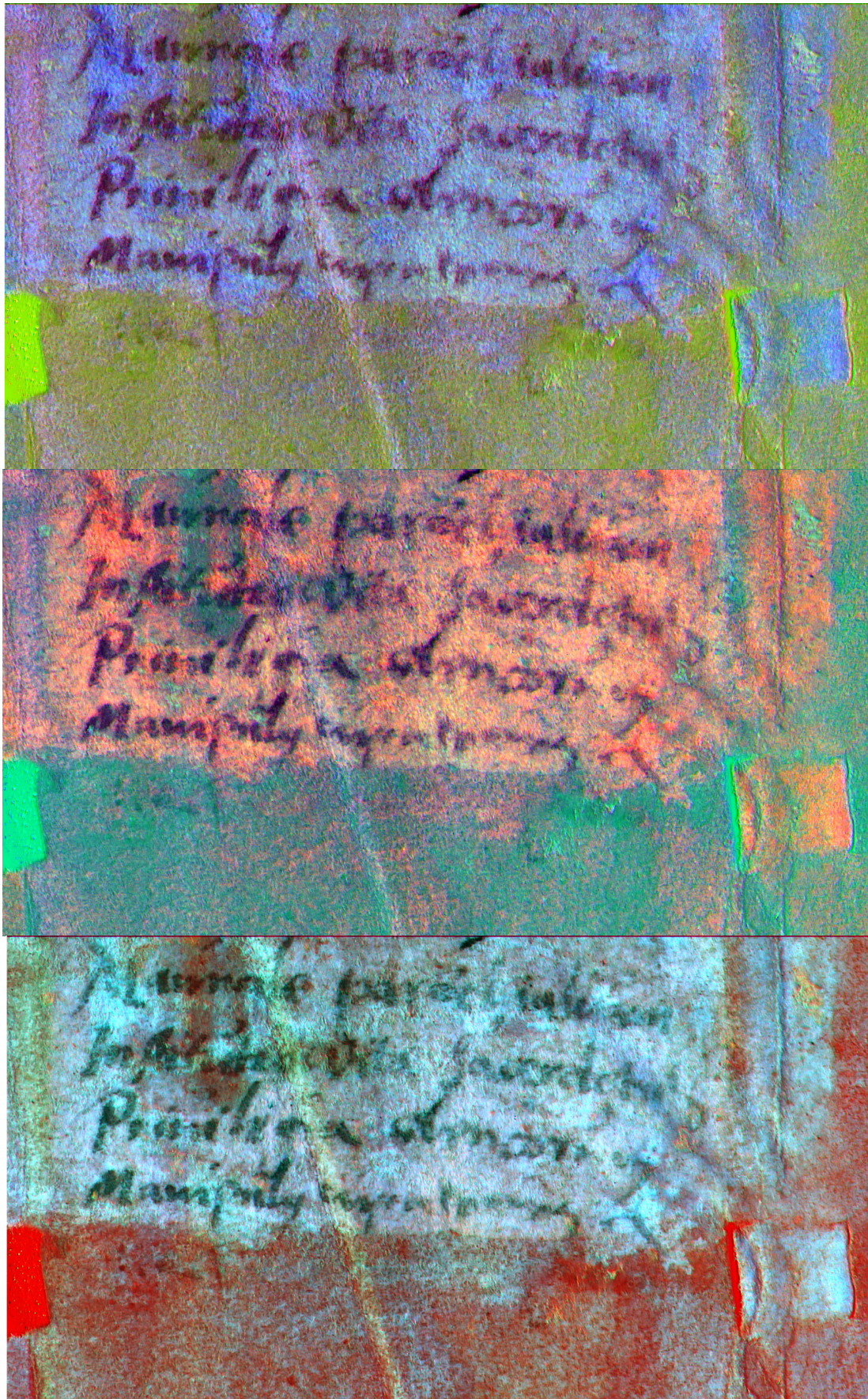


Figure 3.1-15 Three false colour alignment made by RGB channel misalignment using the images in Figure 3.1-14.

Interestingly, as shown in the principal component analysis, the blue ink and blue stain on the recto side have been marked to the same degree with the same luminance. This phenomenon can be treated as a sign that the chemical composition of the blue stain can be quite similar to that of the blue ink..

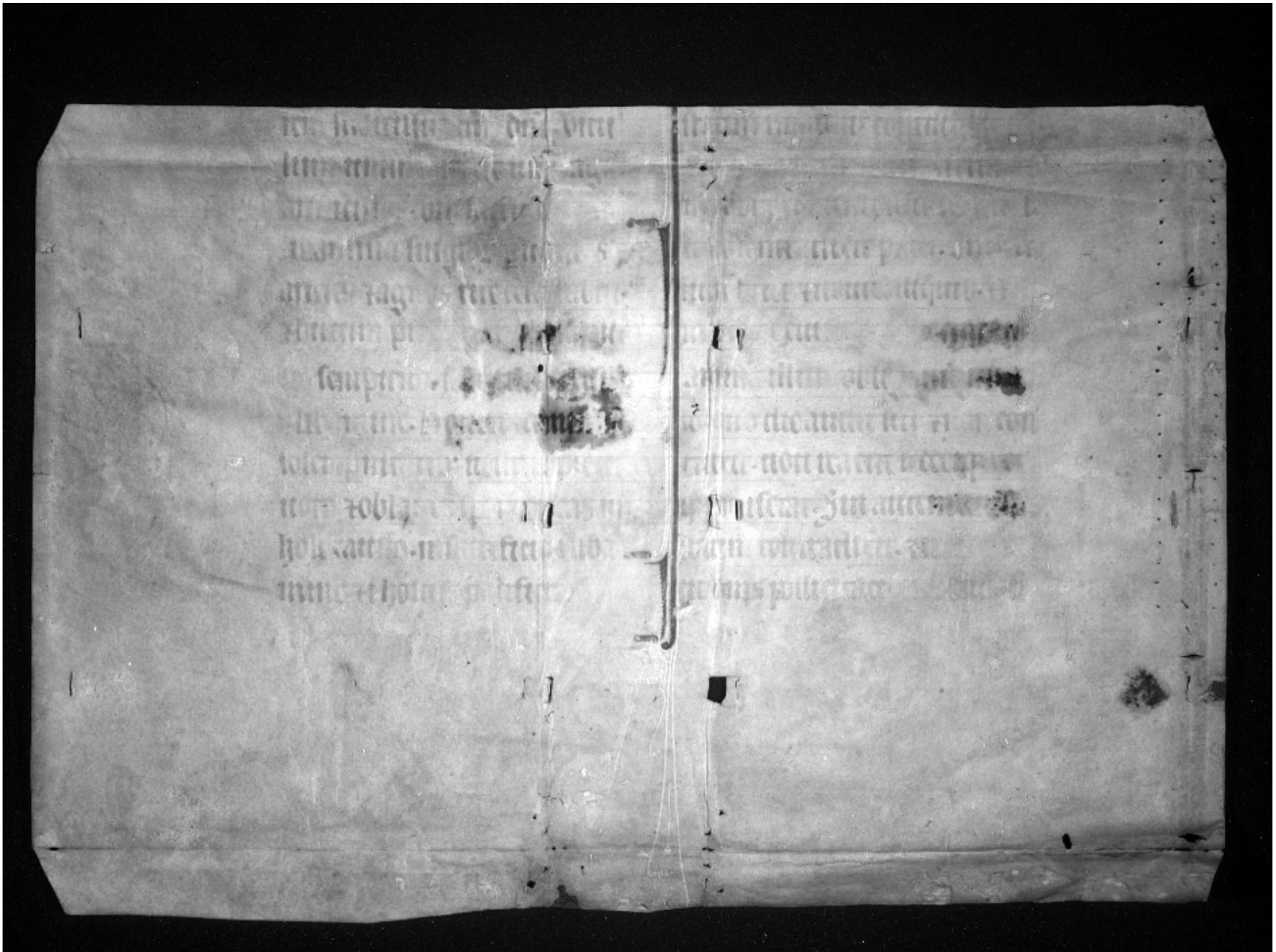


Figure 3.1-16 PCA that aligned the blue stain and blue ink with the same degree of illuminance

3.1.4 Conclusion

For parchment, the contrast in fluorescence between parchment and ink can be a tool to image more information. More stacks can be taken using ultraviolet light with various filters. However, it is also noticeable that more noise will also be included using such combination, and cleaning and demoulding the parchment before imaging would be recommended.

The ink on the parchment has seen a tendency to become fainter and fainter as the wavelength increases, which indicates the ink to be iron-gall ink. However, in MS FRAG/LAT/54, the inscription, with the same ink but blue chemical treatment, has shown a robust contrast to the parchment even with the increase of wavelength. Later PCA has shown that the chemical components of the blue chemical can be similar to blue ink used on the parchment for decoration. This feature may give us a solution to capture the underneath inscriptions with iron-gall ink. With this treatment, the inscription will maintain distinguishable under infrared light, and the long wavelength of infrared light enables penetration of the surface layer. However, more problems regarding the conservation of the parchment should be considered before taking this into practice.

For parchment with faint annotation, the PCA>False Color Image pattern is effective. The false colour image can give us a better contrast and likely to give us a desirable result. However, with false color, some noise can also be amplified and thus affect the final result. More delicate alignment might be required for further improvement.

3.2 Parchments with covered inscriptions

3.2.1 Introduction

Parchments in 12th and 13th century were used for various purposes other than recording information, and therefore various modifications were applied to those parchments including painting them with other colour, attaching leather covers on top of them, as well as gluing and folding them into particular shapes. Considering the time when those modifications are made, i.e., 15th to 16th century during the transition from parchments to paper books, those modifications were appropriate as it made those parchments more suitable in protecting paper books. However, as time has shown the value of those old medieval parchments, we want to use imaging techniques to recover those hidden and damaged inscriptions. In this project, three parchment manuscripts, MS FRAG/LAT/ 18, MS FRAG/LAT/45, and MS/FRAG/LAT/11, were imaged, as their inscriptions are covered by different kinds of material. Multiple imaging techniques, including multispectral imaging, reflectance transformation imaging, and false colour alignment, were used to determine the property of the cover and content of the inscription underneath.

3.2.2 Material and Methods

MS FRAG/LAT/11

This double-leafed parchment is quarto size parchment is believed to be a fragment of psalter, for many of the inscriptions on its recto side has shown words as “Psalmus” and “Psalmus David” marked in red, which is an important feature of psalms in protogothic style.



Figure 3.2-1 recto side of the parchment which shows the sign of a psalm.

Another important trait of psalm in protogothic and early gothic style is that red capitals are used to signify the start of a new line in the psalms, and red rubrics and large red initial letters for the start of a new psalm. This pattern can also be found in the parchment, shown in Figure 3.2-2.



Figure 3.2-2 Both sides of the parchment. The red capitals and red rubrics initial letters are shown in several places in the parchment.

Both recto and verso sides of the manuscript were captured. It is noticeable that in recto there is a clear rectangle shape imprint with darker colour. Various reasons can attribute to such feature. It is possible that the parchment was folded and the imprint is due to folding and sticking of the other part of the parchment, while others suggest that the

parchment was used as binding material for another book, and the imprint is due to the dark cover of the protected book. In this research we will use imaging techniques to tell which explanation is more favourable in this case.

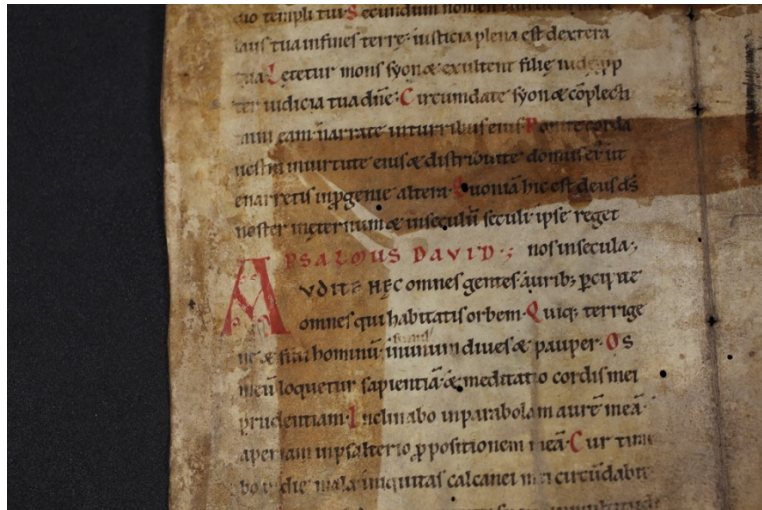


Figure 3.2-3 closer look of the imprint on recto side of the parchment.

MS FRAG/LAT/18

Due to its poor condition and extensive chemical coating on the verso side, it was illegible to identify the original content of the parchment. However, the Capital initial “RE” in face 3. recto might suggest that this parchment was from the Book of Revelation, the final book of the New Testament.



Figure 3.2-4 parchment Face 3. Recto with inscription Re on top. Zoom-in of the two letter on right.

Another feature of this manuscript was that the parchment was in poor physical conditions. Face 1 and 2 of the parchment were damaged and several of the top lines of

the inscription have been cut off from the parchment body. For face 3 and 4, several extensive tear and pest holes were found, not to mention the torn and ceased edges of both faces and the chemical coating on their verso sides which covered most of the inscriptions. However, the initials in blue and red ink can still be seen.



Figure 3.2-5 chemical coating on verso sides of the parchment (Left top and down); the extensive tear on face 4 of the parchment (right top); and the cut edge on face 2 of the parchment (right down).

Both verso and recto side of face 1 and 2 of this parchment were imaged. Similarly, we hope to discover more information of the chemical coating and the inscription underneath.

MS FRAG/LAT/45

This parchment was part of a bifolio manuscript. Even though the content of the parchment remained unknown, it is interesting that this parchment was written in small cursive style instead of protogothic and gothic style which was typical at the age of this parchment. Also, multiple annotations were made at the margin with the latest one showing “de reditu peccatorum” (the return of sin) in later hand. This might give a clue that the content in the parchment was religious-based.



Figure 3.2-6 the recto side of the parchment, with small cursive script and many annotations on its side; on the right is the inscriptions in later hand that means "the return of sin".

At the bottom of the verso side of the parchment, there are leather covers which block an essential amount of inscription. On recto side, there was a rounded-shape green sign on the top and between the two columns. As both sides were imaged, we hope to have a better view of the sign and the inscriptions after processing.



Figure 3.2-7 the leather cover that block large portion of the inscription below.

Methods

Multispectral images were captured for both sides of most part of each parchment manuscript. For MS FRAG/LAT/11, multispectral images were taken with Aperture 8.0 despite the manuscript was not entirely flat. The photos were digitally flattened by flat

field correction, then PCA was conducted to show more explicitly the relation of inscriptions with ink in different colours. After that, false colour alignment with the help of D-stretch was conducted to show more information of the faded inscriptions at the bottom of verso side of the parchment. Additionally, RTI was conducted to verso side of the parchment to examine the surface structure around the imprint area. As for MS FRAG/LAT/18 and MS FRAG/LAT/45, they underwent similar process while the shutter time for multispectral imaging varied due to the specific conditions of the parchment. It is worth mentioning that the surface of all three parchments have a certain degree of curvature, which might require change of depth of field and aperture.



Figure 3.2-8 side view of MS FRAG/LAT/11 and MS FRAG/LAT/45 on left and right. Their surfaces are all not flat but within the depth of field.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	6	200
2	385	Ultraviolet	None	6	200
3	410	Violet	None	0.4	200
4	420	Violet Long	None	0.25	200
5	450	Royal Blue	None	0.2	200
6	480	Long Blue	None	0.125	200
7	510	Cyan	None	0.2	200
8	530	Green	None	0.2	200
9	550	Lime	None	0.125	200
10	600	Amber	None	0.5	200

11	630	Red Orange	None	0.2	200
12	640	Red	None	0.2	200
13	660	Long Red	None	0.2	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	0.5	200
16	940	Infrared	None	1.6	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	5	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	8	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	30	800
23	530	Green	Infrared	30	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	6	200

Table 3.2-1 Shot sequence of MS FRAG/LAT/11

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	8	200
2	385	Ultraviolet	None	8	200
6	480	Long Blue	None	0.2	200
8	530	Green	None	0.4	200
9	550	Lime	None	0.125	200
15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
17	365	Ultraviolet	Green	13	200
20	410	Violet	Red	15	800
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800

24	000	Dark	None	20	800
25	365	Ultraviolet	None	8	200

Table 3.2-2 Shot sequence of MS FRAG/LAT/18, showing only shots in sequence difference from MS FRAG/LAT/11

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	10	200
2	385	Ultraviolet	None	10	200
3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.4	200
7	510	Cyan	None	0.4	200
8	530	Green	None	0.6	200
9	550	Lime	None	0.2	200
11	630	Red Orange	None	0.4	200
12	640	Red	None	0.4	200
13	660	Long Red	None	0.4	200
14	740	Infrared	None	0.5	200
15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
18	410	Violet	Green	8	200
20	410	Violet	Red	15	800
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	8	200

Table 3.2-3 Shot sequence of MS FRAG/LAT/45, showing only shots in sequence difference from MS FRAG/LAT/11\

3.2.3 Results and Discussion

Multispectral Images

Similar to many other manuscript written in 12th to 13th century, most of the inscriptions in these three parchments have shown the pattern of fading with the increase of wavelength of the light. This reverse relation is a typical feature of iron-gall ink, which was the major component of the black inscriptions on those parchments.

However, for colour-ink inscriptions such as the initial letters in red and blue ink, some interesting pattern can be observed with the increase of wavelength. In MS FRAG/LAT/11, with only 30nm increment of wavelength from 600 (Lime) to 630 (Red Orange), red ink disappeared completely as shown in Figure 3.2-9. This drastic change might suggest that the red ink was made from different material that reflected to a very specific wavelength period.

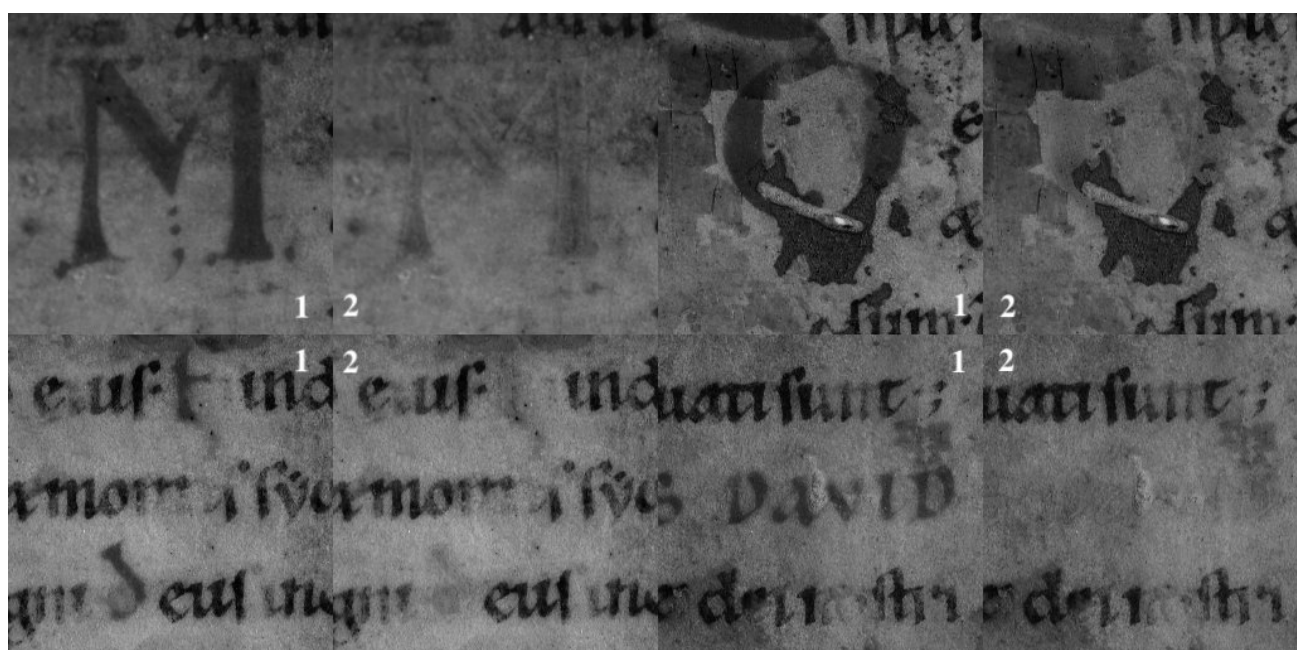


Figure 3.2-9 contrast of reflection of inscription in red ink from 600nm(1) to 630nm(2).

Similarly, in the case of MS FRAG/LAT 18, as some of the initial letters in this parchment was written in red and blue ink, one for letter and the other one for decorative pattern, the two inks showed a reverse pattern with respect to the increase of wavelength. However, it can also be observed that when the light reaches the wavelength of (940) infrared, all inscriptions, despite their various colours, became blur and faded. This

feature may indicate that both red and blue inks were composed of similar ingredients as iron-gall ink, with some added or replaced that gave them a different colour visually.



Figure 3.2-10 Three Capital initials decorated in red and blue ink on recto side of parchment MS FRAG/LAT/18.



Figure 3.2-11 "P" letter in the left of Figure 3.2-10 with respect to the increase of wavelength from 450 nm (royal Blue) to 930nm (Infrared).

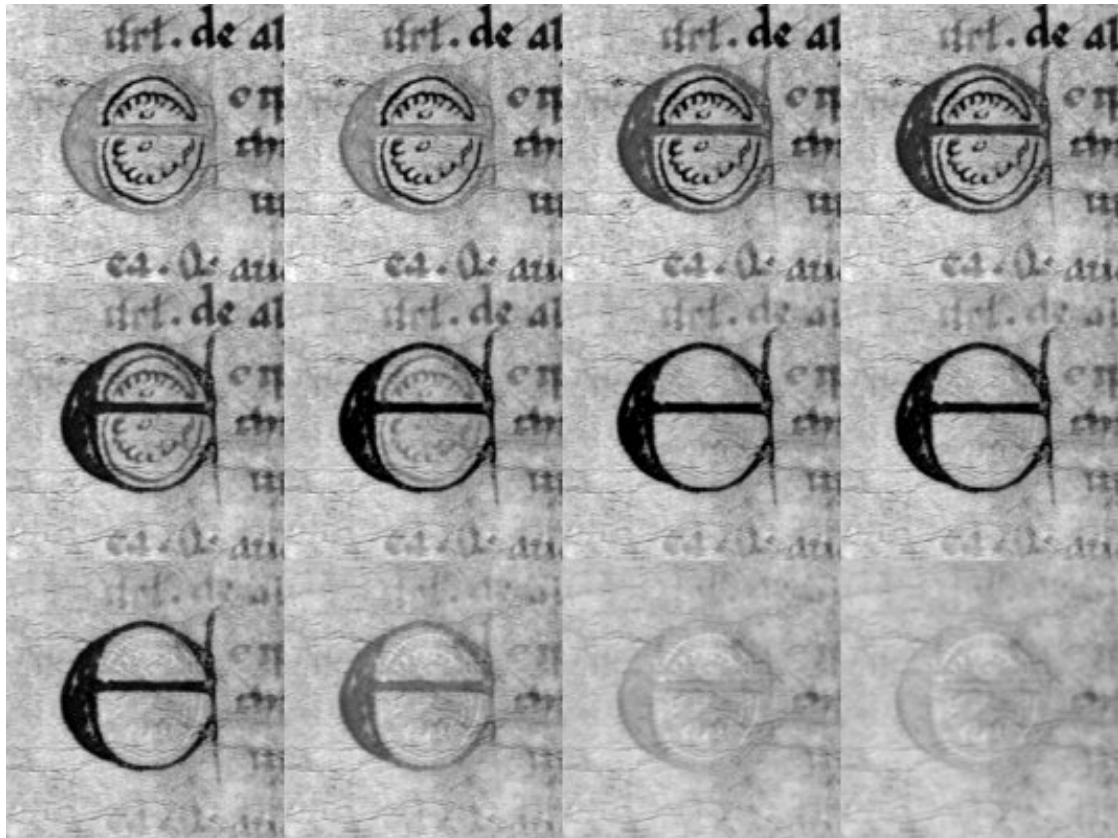


Figure 3.2-12 “e” letter in the middle of Figure 3.2-10 with respect to the increase of wavelength from 450 nm(royal Blue) to 930nm (Infrared).



Figure 3.2-13 “T” letter in the right of Figure 3.2-10 with respect to the increase of wavelength from 450 nm(royal Blue) to 930nm (Infrared).

When the parchment was under light with shorter wavelength such as royal blue and ultraviolet light, the inscriptions and surface of the coating were shown the clearest. However, in this case we wanted to find out the inscriptions underneath the coating, therefore lights with shorter wavelength failed to show any related information as they cannot penetrate through the cover. Thus higher wavelength were illuminated with a better expected result. Given that the ink would fade under light with higher wavelength, a delicate balance between penetration ability and fading of inscriptions could be found and established. In Figure 3.2-14, we can see the contrast of parchment under ultraviolet light and Long red light, where penetration started to make a difference.

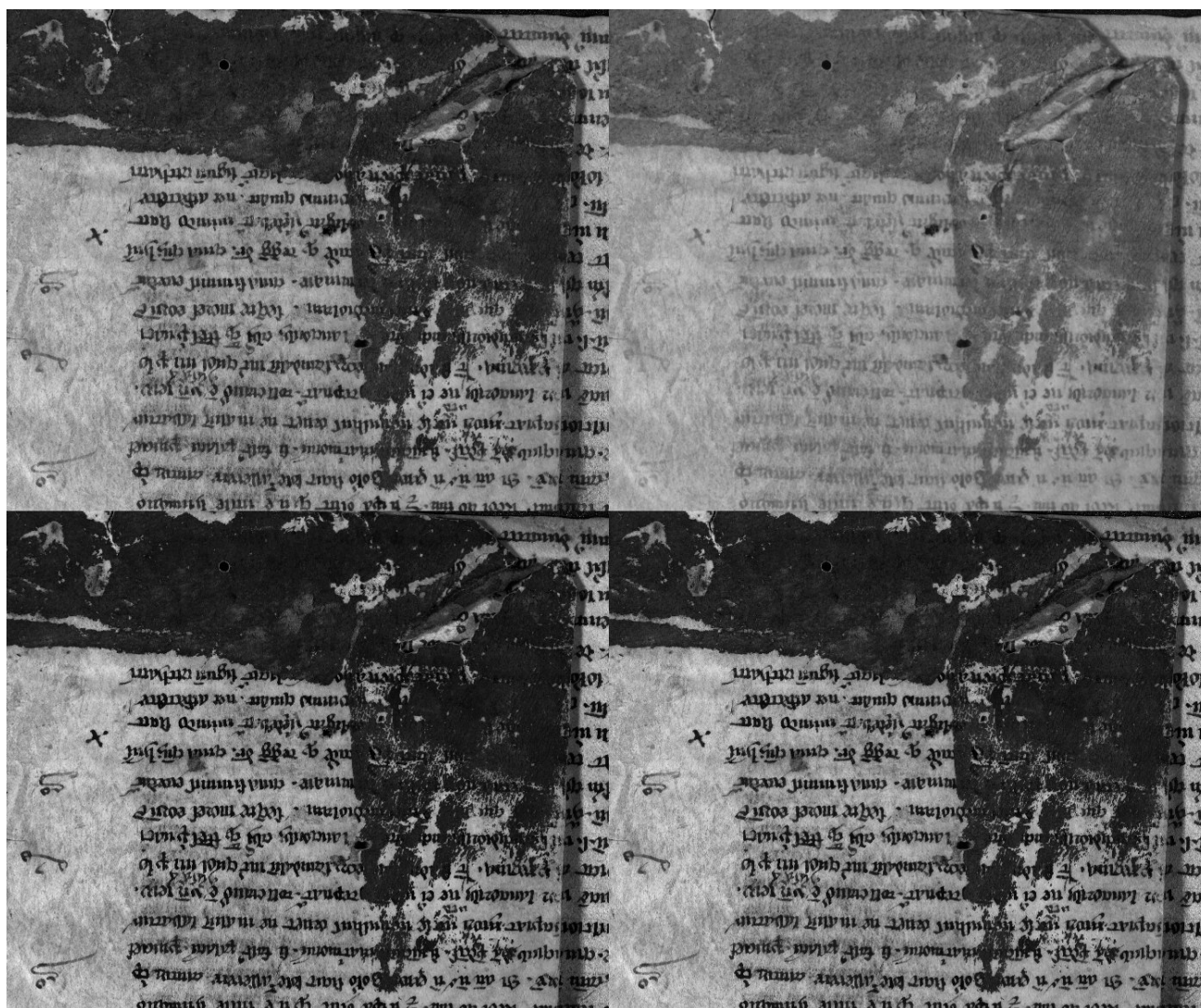


Figure 3.2-14 MS FRAG/LAT/45 captured under 385nm wavelength (left bottom), 510nm (right bottom), 630 (left top) and 740 (right top)

PCA and False colour alignment

There were some good results from PCA and false colour alignment, with the help of D stretch, some of the hidden inscriptions were shown. Among principal components, some were made out of the combination of shots that penetrated the cover and shots with high contrast. In this case, the component showed the underneath inscription with higher contrast and a relatively clear boundary, which made those inscriptions legible.

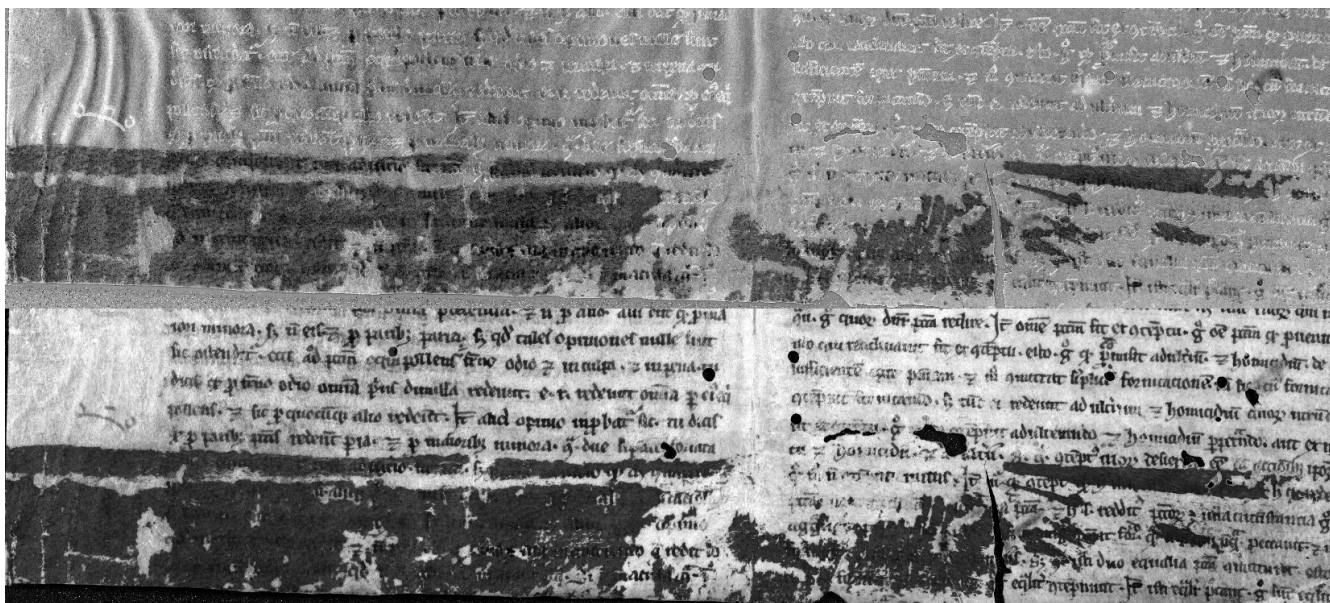


Figure 3.2-15 MS FRAG/LAT/45 figure of two principal components with a clear boundary of the inscription underneath.

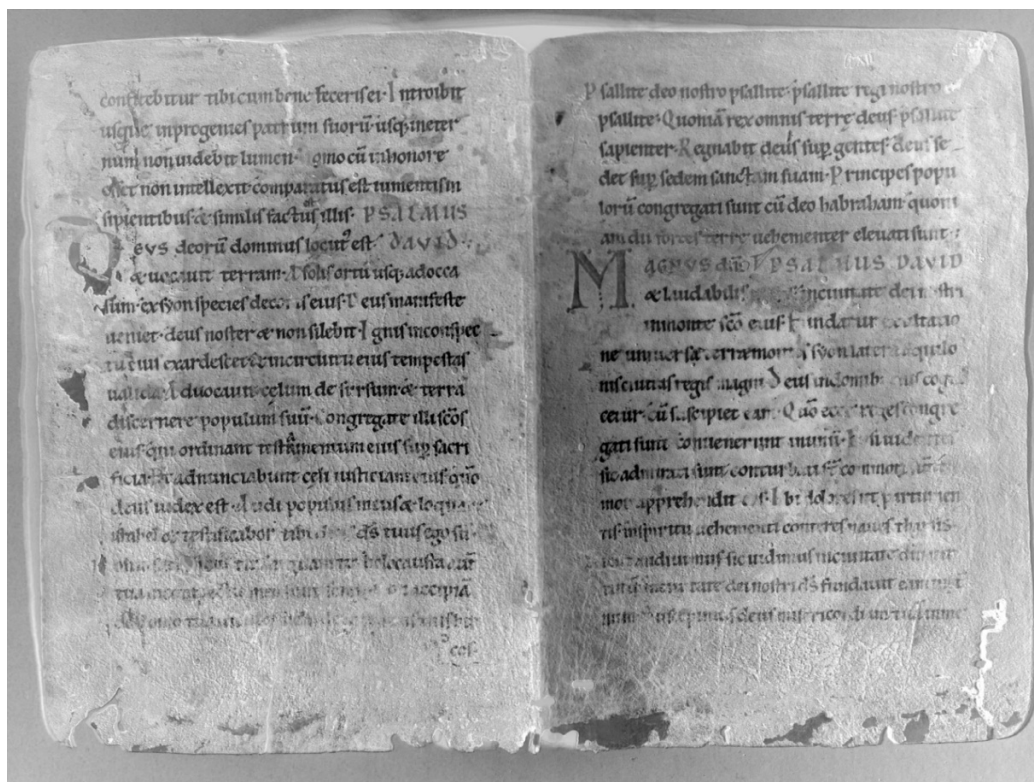


Figure 3.2-16 MS FRAG/LAT/11 principal component that shows the blurred inscription around the bottom of the inscription

As for false colour image generation, three principal components were selected in each parchment for alignment. For parchments with cover, if lighter colour can be assigned to the coating while darker ones aligned to the inscriptions, it will be much clearer to view the content. With such expectation, multiple combinations have been applied and some of the desirable results were shown below.

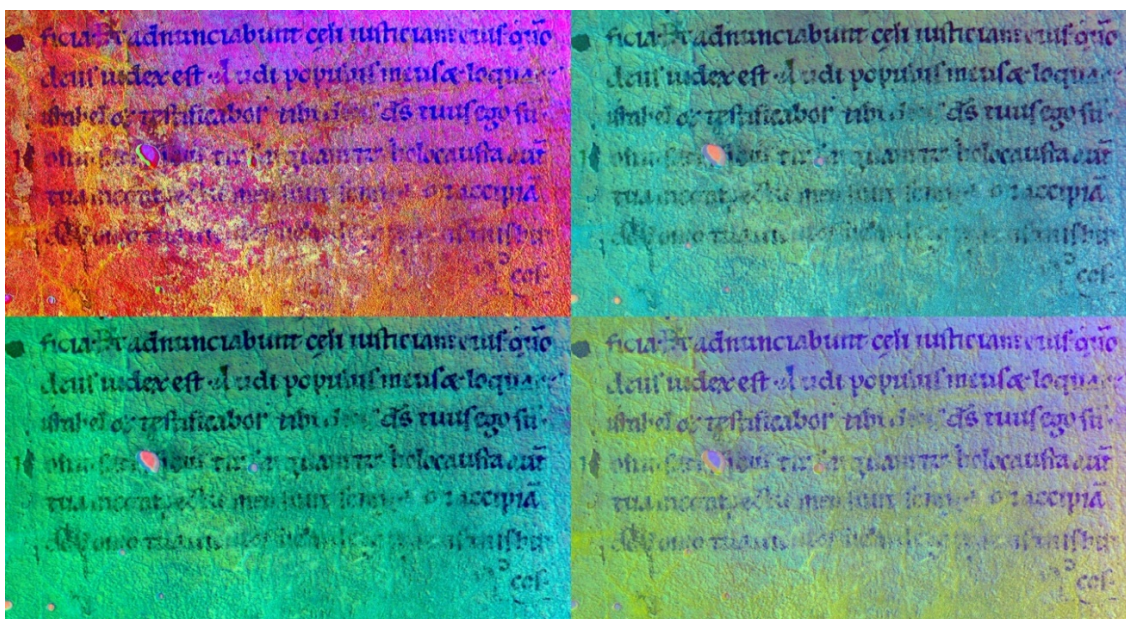


Figure 3.2-17 MS FRAG/LAT/11 false colour alignment for Face recto of the parchment, some faded inscription on top can be shown.



Figure 3.2-18 MS FRAG/LAT/11 For Face V, four combination has been tried out and those faded area around the bottom are shown better result as below.

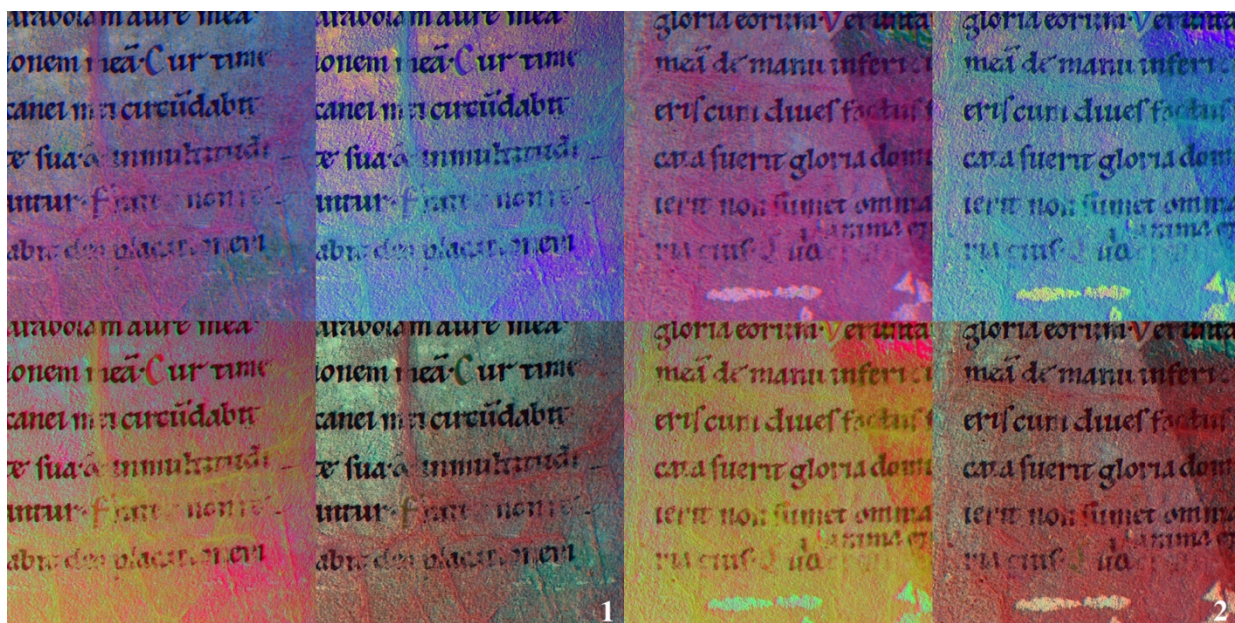


Figure 3.2-19 MS FRAG/LAT/11 Two Zoom in of the false colour alignment, both of the two faded part are clearer compared to that of the original captures.

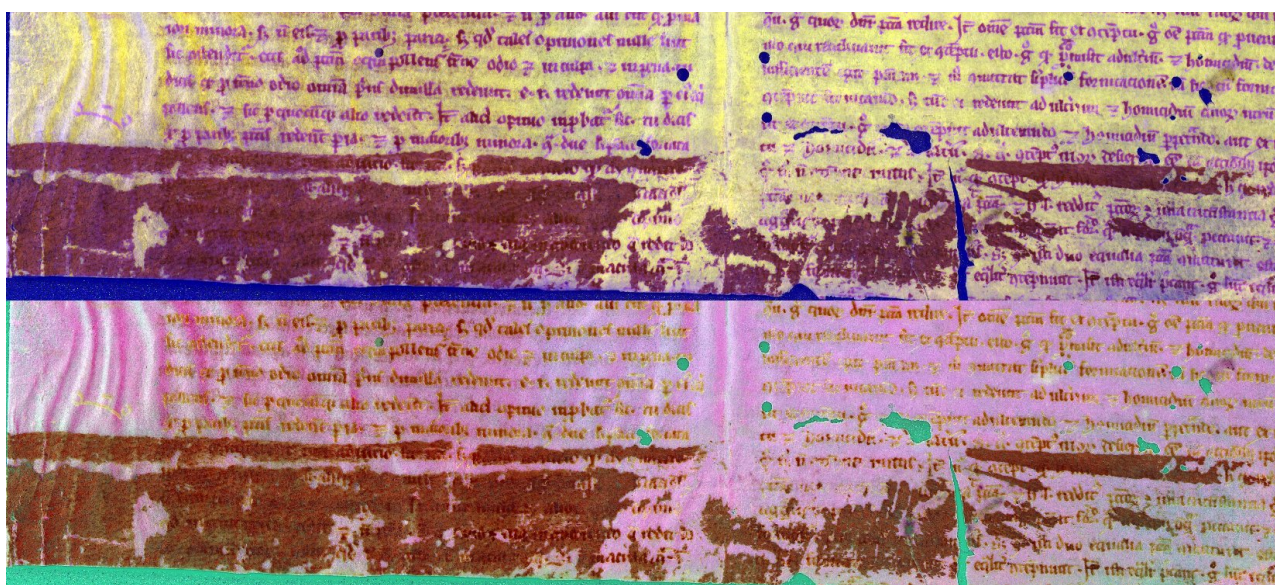


Figure 3.2-19 MS FRAG/LAT/45 False colour alignment with which the inscription underneath can show clearer.

Reflectance transformation imaging (RTI)

With the help of RTI, the surface structure of the parchment and cover can be explicitly shown, especially for at the edge of the coating.

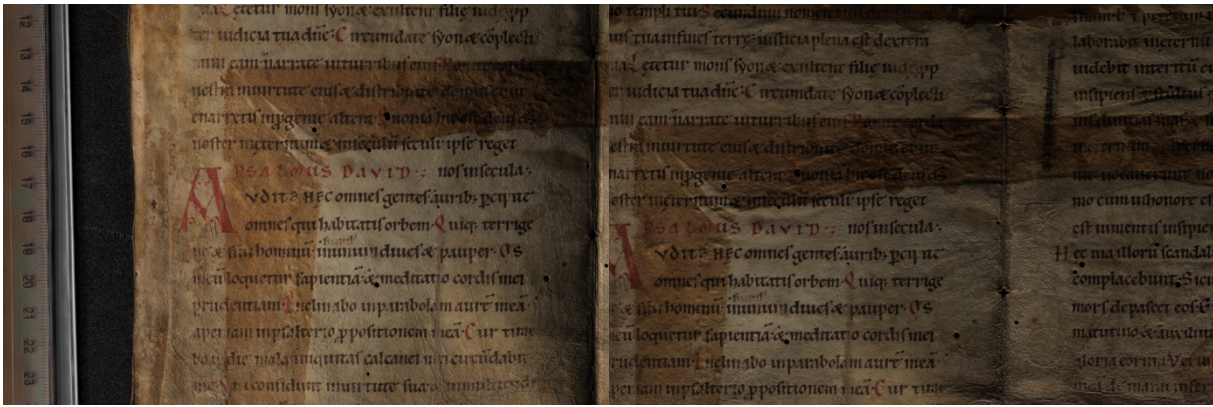


Figure 3.2-20 MS FRAG/LAT/11 RTI showing no clear sign of folding in the covered coated area.

3.2.4 Conclusion

For the case of parchment covered by chemical coating, multiple imaging techniques including multispectral imaging, reflectance transformation imaging and false colour alignment should be integrated to have the best analysis on the thickness of the coating, and have the best view of the inscriptions.

However, it must be admitted that with the current wavelength option and equipment, it was hardly possible to penetrate the coating while keeping the contrast of the inscription due to the feature of iron-gall ink, which is the component of most of the inscriptions. Thus further research and hyperspectral imaging could be applied to have more delicate results.

Meanwhile, it should also be acknowledged that for ink with different colours, different pattern can be shown with the increase of the wavelength. In this case, red and blue ink showed a nearly opposite manner, while all ended invisible when wavelength reaches 940 nm (infrared). This suggested that those ink may have a similar component with iron-gall ink but with some replacement or modification in its composition which gave them different visual colours.

3.3 Parchments with faded inscriptions

3.3.1 Introduction

It is a common condition among manuscripts in UCL special collection that the inscriptions on parchments were faded and scratched. In this research, MS FRAG/HEB/1 was selected as a representation of manuscripts of this kind. Four sides of the parchment were imaged and each of them represented a different case that can be treated differently. Integrated methods including multispectral imaging, contrast and brightness adjustment and false colour alignment were applied with the expectation of establishing reliable operational protocols to increase the legibility of the parchments.

3.3.2 Material and Methods

MS FRAG/HEB/1

the manuscript consists of two folios which all have broken edges and faded inscriptions. The text on the manuscript is believed to be from Book of Genesis beginning at Chapter 7, verse 18 on f.1. Further investigation to the context shows that the book is bilingual and each verse in Hebrew is followed immediately by an Aramaic translation.



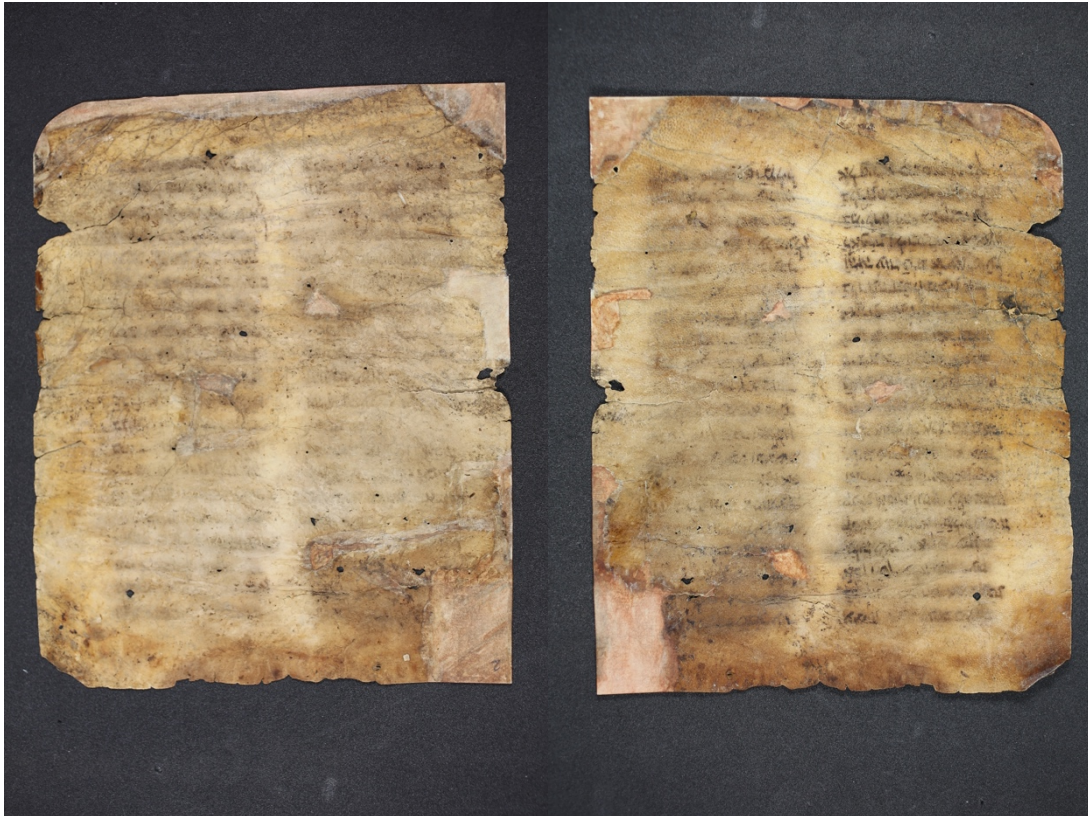


Figure 3.3-1 images of the manuscript in natural light, four sides, f.1 recto(right up), f.1 verso (left up), f.2 recto (right bottom) and f.2 verso (left bottom), have been captured. The inscriptions on the parchment has been heavily damaged.

Closer observation showed us the evidence of conservation and renovation around the edge of the parchment. A reddish fabric material was attached to smoothen the edges and stabilize its structure. However, the grey pattern around the connection between the parchment and fixing material may result from decay of the material overtime. In this sense, some conservational operations like attaching other material to the original parchment may not be ideal and might even be harmful to the parchment in the long run.

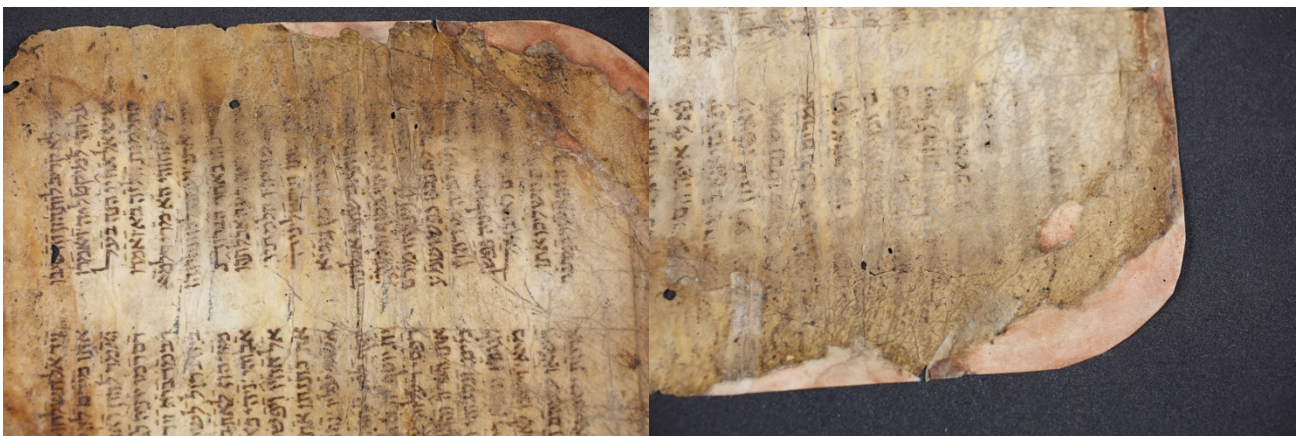


Figure 3.3-2 A closer look of some of the amendments made for this parchment. Decay of fixing material can be seen in the left photo.

Method

Multispectral images were taken on both side of both two folios of the parchment with the aperture set at 8.0. As all the paper and ink of the four sides were the same, the parameters in the shot sequence remained the same. Although some of the multispectral images were good enough in terms of legibility, some operations including reverse colour and contrast adjustment were applied to further enhance its quality. Moreover, PCA and false colour alignment were conducted on the images and some of the selected results are shown in result section.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	6	200
2	385	Ultraviolet	None	6	200
3	410	Violet	None	0.4	200
4	420	Violet Long	None	0.25	200
5	450	Royal Blue	None	0.2	200
6	480	Long Blue	None	0.125	200
7	510	Cyan	None	0.2	200
8	530	Green	None	0.2	200
9	550	Lime	None	0.125	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.2	200
12	640	Red	None	0.2	200
13	660	Long Red	None	0.2	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	0.5	200
16	940	Infrared	None	1.6	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	5	200
19	365	Ultraviolet	Red	20	800

20	410	Violet	Red	8	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	30	800
23	530	Green	Infrared	30	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	6	200

Table 3.3-1 Shot sequence of the four sides of MS FRAG/HEB/1

3.3.3 Results and Discussions

Multispectral Images

For manuscripts with faded inscription, shorter wavelength will enhance the contrast between inscription and parchment, which is common among mediaeval manuscripts. Under shorter wavelength such as ultraviolet light and royal blue, the parchment omitted strong fluorescence while the ink did not. Thus the parchment became lighter while ink became darker, resulting in showing more information.

However, for f.1 recto side of MS FRAG/HEB/1, dirt attaches on its surface was also captured under short wavelength, leading to a considerable amount of noise. So, cleansing the surface and longer wavelength light could be considered for better outcome.



Figure 3.3-3 Best Multispectral Images of F.1 recto side, they are taken in ultraviolet light (385nm, right) and violet light(410nm, left)



Figure 3.3-3 Best Multispectral Images of F.1 verso, taken in ultraviolet light(385nm, left), and best image for F.2 recto side, taken in violet light (410nm, right)

PCA and Contrast Adjustment

By conducting PCA, we had the chance to have principal components that separated the outer layer and inscriptions underneath. Some of those components showed a decent result of the inscription.



Figure 3.3-4 Selected PCA on 2R and 1V side of the manuscript.

For some of the inscriptions, we selected certain principal components and increase the contrast of the inscriptions, and reversed the colour of the inscription if necessary. Some of the result showed more details of the content.



Figure 3.3-5 some of the results of the contrast adjustment for the manuscripts. Some of the inscriptions appear to be clear.

3.3.4 Conclusion

The cases of fading inscriptions are common in medieval manuscripts. In this case, multispectral images were proved to be effective in showing the inscriptions on the manuscripts. The inscriptions are shown the clearest under ultraviolet light and royal blue light with filter applied.

However, it is also noticeable that in some cases the images under lights with shorter wavelength tend to be less satisfying due to the dirt on the cover and the amount of noise captured in the images. In such cases, it is recommended to have the parchment cleansed before capturing, or to have lights with longer wavelengths illuminated on it.

For image processing, several techniques are employed to enhance the visibility of the inscriptions. In this research, contrast adjustment, especially regional contrast adjustment, can show important information regarding the edge and boundary of the inscriptions and the parchments. Also, by applying principal component analysis, some of the inscriptions were separated and shown clearly.

3.4 Parchments with Gold Cover

3.4.1 Introduction

In some of the medieval manuscripts, various luxuriant decorations were attached on them as a way of emphasizing the sanctity of the content, or the status of its owner. These decorations usually include large coloured initial letter, decorative drawings and patterns between columns, as well as covers and stickers. In this research, a fragment of parchment was found to have a letter “D” covered with gold leaf. Even though the gold cover was extensively broken, it was still a delicate piece of art that showed the sophisticated techniques of people in the medieval time. By imaging the manuscript, we are able to make a detailed observation of the level of erosion of the gold cover, which would be helpful for further conservation.

3.4.2 Material and Methods

MS FRAG/LAT/28

This parchment was a leaf from a psalter, as one of the common patterns of psalter in 14th century was the red capital letter which indicated the beginning of a new line in the psalms. As suggested by its quarto size volume and religion related content, it can be inferred that the parchment may have been for private devotional use.



Figure 3.4-1 the overview of the parchment MS/FRAG/LAT/28, the gold cover can be shown clearly and the red initials appears throughout the parchment, signifying the beginning of start of new lines in the psalms.

Also, it can be shown at the verso side of the parchment that there is an illuminated initial D with faded blue-green decoration and three lines height. The letter was covered in broken gold cover. Besides the cover wrote a brief marginal gloss introducing a new chapter. The letter was covered in broken gold cover. Besides the cover wrote a brief marginal gloss introducing a new chapter.



Figure 3.4-2 partial view of the parchment on the gold D letter. The underneath blue-green decoration can be shown despite that it is fading. And the margin note lies besides the D letter, introducing a new chapter of the psalm.

Methods

To image the edge of erosion on the gold cover, an integration of multispectral imaging and reflectance transformation imaging was incorporated for detailed images with high resolution. Both sides of the parchment were imaged by multispectral imaging as shown in table 3.4-1 while the recto side of the parchment, with the gold cover, went through reflectance transformation imaging. As the accurate information of the erosion has already been recorded, processing such as contrast adjustment and false colour alignment were not applied in this case as they may cause some deviation from the actual value in the pixel.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	6	200

2	385	Ultraviolet	None	6	200
3	410	Violet	None	0.4	200
4	420	Violet Long	None	0.25	200
5	450	Royal Blue	None	0.2	200
6	480	Long Blue	None	0.125	200
7	510	Cyan	None	0.2	200
8	530	Green	None	0.2	200
9	550	Lime	None	0.125	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.2	200
12	640	Red	None	0.2	200
13	660	Long Red	None	0.2	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	0.5	200
16	940	Infrared	None	1.6	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	5	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	8	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	30	800
23	530	Green	Infrared	30	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	6	200

Table 3.4-1 the parameter of the multispectral imaging applied in the parchment MS FRAG/LAT/28

3.4.3 Results and Discussions

Multispectral Images

In this case, several multispectral images with high contrast in luminance of the gold leaf and the parchment were selected as they showed a clear boundary of the erosion. In Figure 3.4-3, nine images were selected, all of which were taken under light with short wavelength, from ultraviolet to cyan, many with filters applied. As in shorter wavelength, the parchment has stronger fluorescence emission comparing to that of the longer wavelength, which deepened the contrast as the parchment was brighter while the gold leaf remained the same. However, as the multispectral images were captured from the top view, the side views of the broken gold cover remained undetected, therefore the depth of the erosion cannot be fully determined merely by multispectral images.



Figure 3.4-3 a montage of nine selected multispectral images of the gold leaf, from the left top corner to the right bottom corner, column by column, the photos are respectively shot 17, shot 18, shot 1, shot 2, shot 5, shot 6, shot 20, shot 21, shot 22 as referred in Table 3.4-1.

Reflectance Transformation Imaging

In order to record the information of the depth of the erosion more accurately, reflectance transformation imaging was conducted. Through the RTI viewer, more information can be obtained by the shadow from the edge of the remaining gold leaf.



Figure 3.4-4 shadowing from the edge of golden cover by RTI viewer. By conducting RTI imaging we are able to record the depth information as the length of the shadow corresponds to the depth of the erosion.

Furthermore, with specular enhancement, the edge and structure of the gold leaf can even be shown in more details. However, despite the fact that specular enhancement can sketch the surface structure more accurately, it will also result a certain degree of deviation as processing on images will modify its original information recorded on the pixel.



Figure 3.4-5 two cases of specular enhancement from different light direction for MS FRAG/LAT/28

3.4.4 Conclusion

It is common that medieval manuscripts with gold decoration can go through some stage of erosion resulting in cleavage or damage on its cover. Combination of multispectral imaging and reflectance transformation imaging can be applied for conservation of the fragment.

For gold cover, it appeared that images taken in light with shorter wavelength show a clear edge of the cleavage as a result of the difference in luminance of parchment and the gold leaf. Moreover, the brightness of the cleavage on multispectral images can give us a rough picture of the degree of damage of the gold cover. However, to acquire more accurate information, reflectance transformation imaging was applied and the depth of the damage was recorded by the length of the shadowing due to their corresponding relationship. Specular enhancement in RTI viewer can present more accurate information on surface structure of the gold leaf, however, it can also bring about modification on original information of the photo which may cause some deviation.

3.5 Flooded Deeds

3.5.1 Introduction

As a long-standing and vigorous university, University College London has witnessed various important historical events including World War II. During the epic war, UCL was severely damaged and many of its building, including the main building of UCL, had to go through reconstruction after it. Even though many of the archives and rare books had been removed from UCL for conservation, some of them, including the deed of UCL main building, were drown and damaged in a flood during the preservation.

In this research, a fragment of flooded pieces of deeds were imaged to find out its illegible content. It was inferred that the deed had content related to the exact location and area of occupancy of UCL main building. Due to the time limitation of this project, it was practically difficult to image the whole set of fragments. However, by setting up an successful case that made the content of one fragment legible, we will be able to duplicate the process and apply it on other fragments, and hopefully recover the majority of its content and resume its legal effect.

3.5.2 Material and Methods

Material

The chosen fragment of the deed was a single-layer, partially legible quarto size sheet. As such case was common among the fragment set, this particular one was selected for this research. As an approximately 19th century document, the deed was written in round-secretary hand which made it relatively easier to read and distinguish comparing to other medieval hand written styles. It was noticeable that the surface of the sheet was not as flat as it was flooded before, which may require special attention if the depth of field of the camera is too narrow.



Figure 3.6-1 both sides of the selected fragment of the flooded deed. The content is only partially legible and the edge is extensively damaged due to the flood.



Figure 3.6-2 side view of the selected fragment. There are obvious concave and convex shape on the surface of the fragment due to the flood.

Methods

As the focus of this object was its content, multispectral imaging were applied to both sides of the fragment for a full record of its luminance under different wavelengths, as shown in Table 3.6-1.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	8	200
2	385	Ultraviolet	None	10	200

3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.4	200
7	510	Cyan	None	0.4	200
8	530	Green	None	0.6	200
9	550	Lime	None	0.2	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.4	200
12	640	Red	None	0.4	200
13	660	Long Red	None	0.4	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	8	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	15	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	8	200

Table 3.6-1 Shot sequence and shot parameter of the multispectral imaging applied on selected fragment of the deed.

Additionally, processing on those images including principal component analysis and false colour alignment were applied on the multispectral images for better contrast result and content legibility.

3.5.3 Results and Discussions

Multispectral Images

The inscriptions were shown the clearest when lights in short wavelength was applied with red and green filters. This is due to the contrast of fluorescence emitted from the fragment and the ink. Some of the good results were selected in Figure 3.6-3. However, the inscriptions at the edge and central area still remained illegible due to the severe damage and poor physical condition.

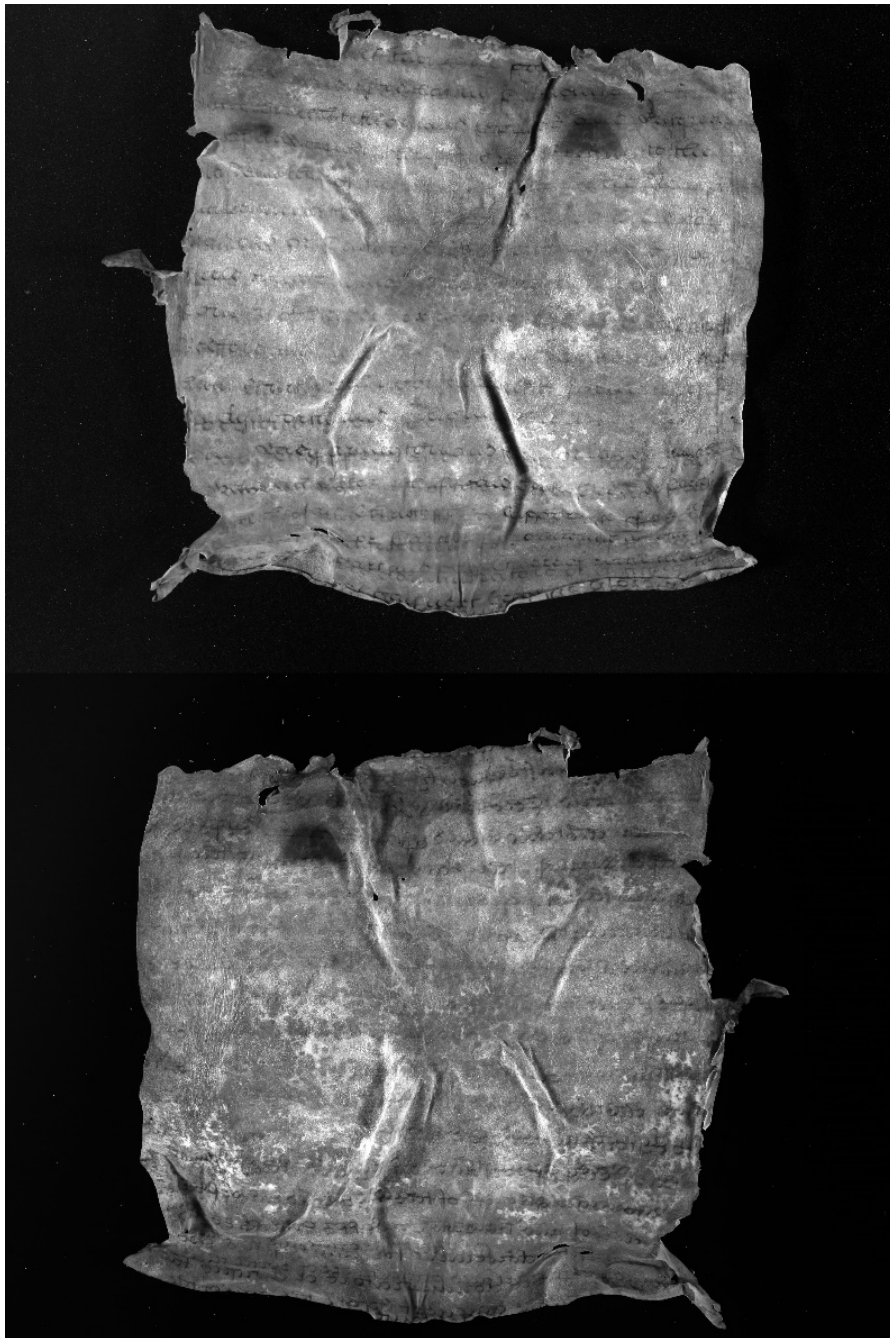


Figure 3.6-3 Two selected multispectral images with clearest inscriptions on recto side (up) and verso side(down).They are taken with Violet light in green filter(up) and Royal Blue light with red filter(down).

However, as the flooded manuscript was thin and relatively easy to be penetrated, some of the inscriptions from the verso side were also captured and superimpose with that of the recto side, resulting in an illegible but clear inscriptions. This could be solved by image calculator and false colour alignments, but more testing is required for a reliable path for such cases.

PCA and false colour alignment

By conducting PCA and false colour alignment, some of the details of the inscriptions can be legible, and even some of the inscriptions at the edges and the central area can be shown with a relatively higher contrast.

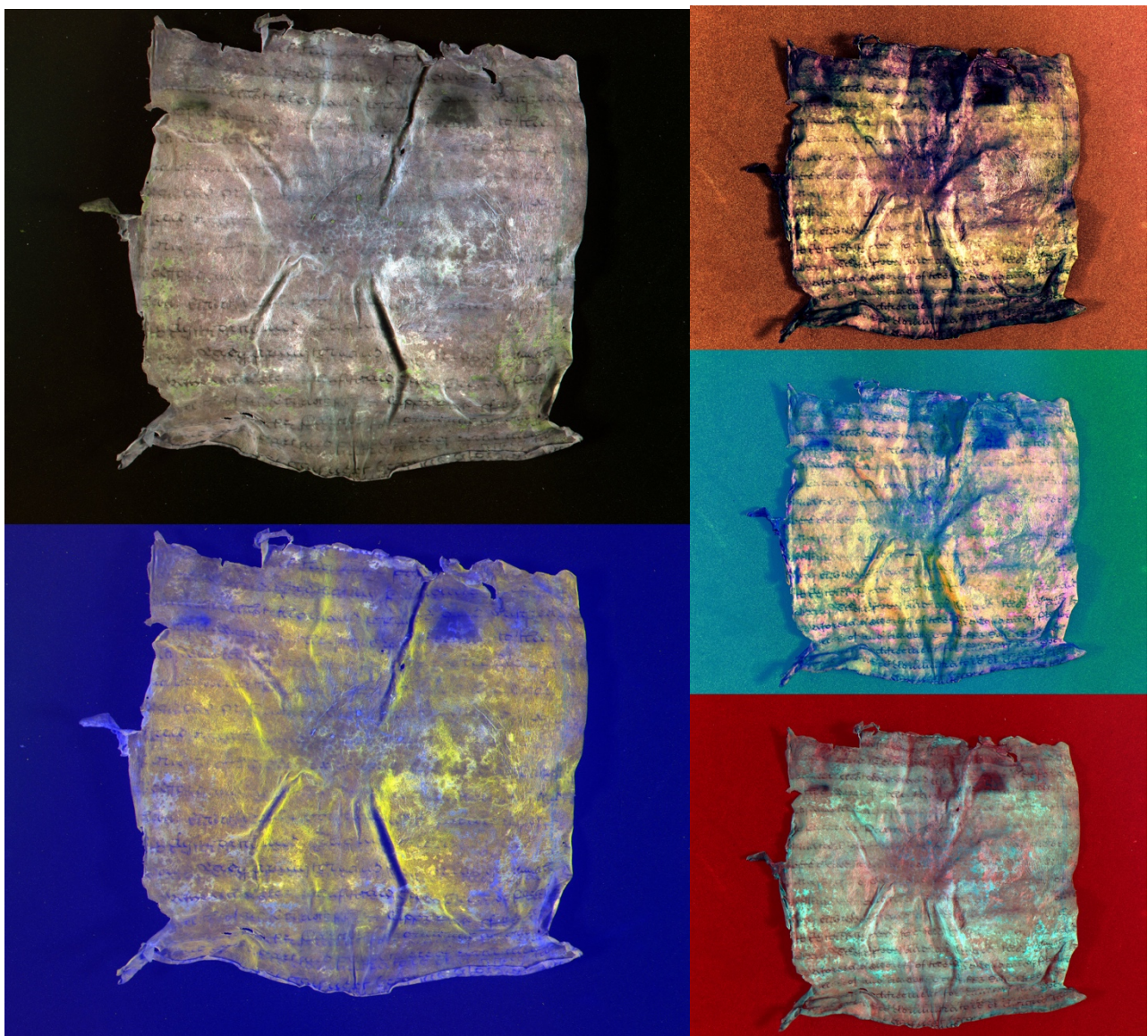


Figure 3.6-4 selected false colour alignment result, each of them are made of false alignment of four of the principal components of multispectral images. The inscriptions at the bottom is relatively clearer.

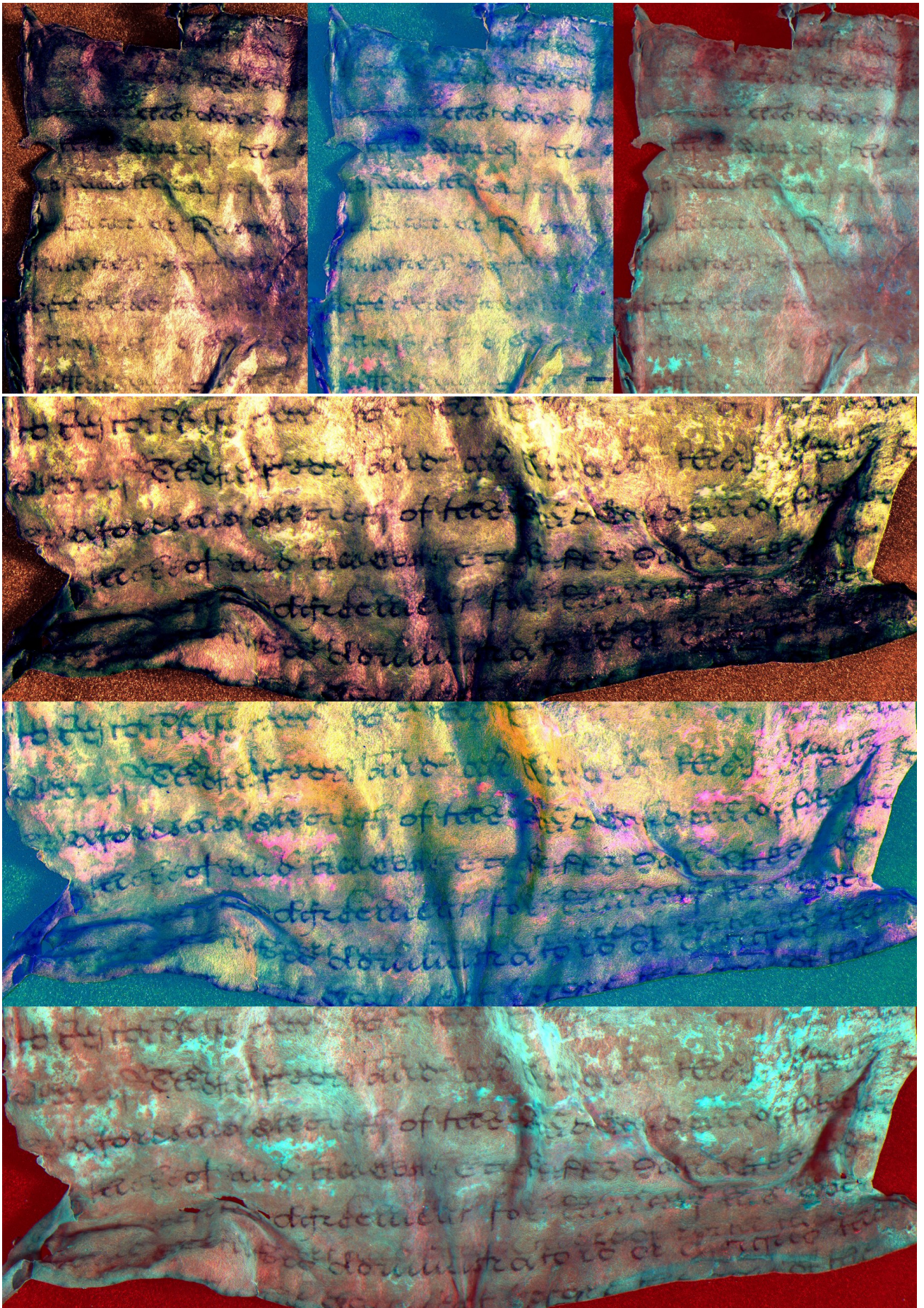


Figure 3.6-5 part of the false colour photos that can show a clear inscriptions.

3.5.4 Conclusion

For flooded deeds which may contain important information regarding university property, multispectral imaging with image processing such as principal component analysis and false colour alignment can be a good choice in content recovery.

The inscriptions on the deed show the clearest under short wavelength such as ultraviolet light and royal blue light, and with the filter applied, less noise will be captured by the camera and thus the inscriptions can be shown even clearer. However, as the paper was thin and easy to be penetrated, some of the inscriptions from the back side of the paper can also be captured, leading to the superimposition of two sides of the inscription. This may be solved by techniques such as image calculator and false colour alignment.

For cases of which the content was the focus, false colour alignment and PCA can be powerful tools to separate each layer and enhance the contrast between inscriptions and the fragment. By attaching colours to different principal components, some of the marks from the other side can also be separated and hence make the inscriptions legible.

3.6 Parchment covered in dirt

3.6.1 Introduction

Due to the poorly developed conservation techniques in the medieval age, it is common that some of the manuscripts and archives from that time have gone through a certain degree of damage. Cases such as scratched inscriptions, faded ink and chemical cover were common and particularly in need for conservation. In this research, a parchment covered in dirt was imaged to analyse its content before going through conservation. This process, by determining and recording its condition, can help us better conduct and evaluate the conservation afterwards.

3.6.2 Material and Methods

MS FRAG/LAT/15

The manuscript was a double folio parchment from a religious commentary. Due to the condition of the parchment, its title cannot be identified while the age was estimated to be around 14th century. The content was religious-based, possibly related to the New Testament as suggested by the red rubrics on its verso side.

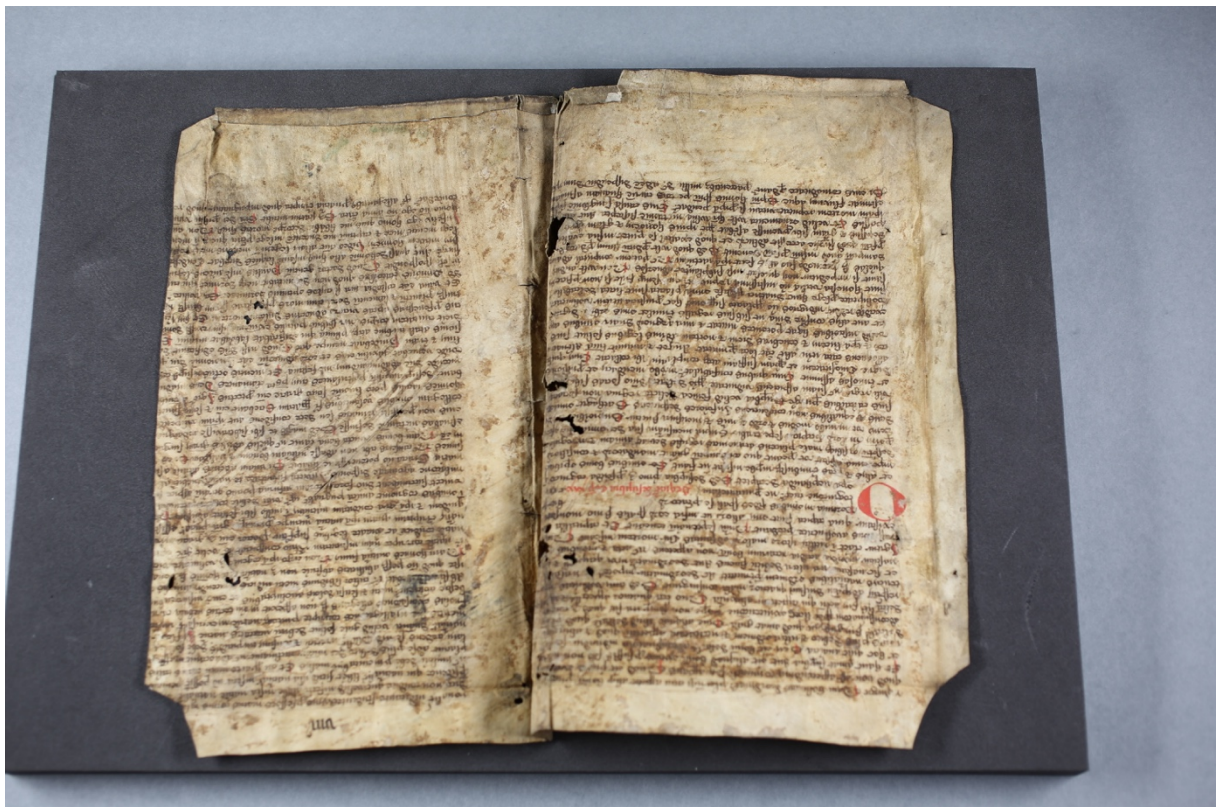


Figure 3.7-1 verso side of the parchment with red rubrics, initials and highlights suggesting the content to be religious-based.

Both folios of the manuscripts headed VIII, which might suggest the chapter from which they were taken. Also evidence of later annotations have been found in recto side of f.1. The surface of the manuscript was not flat with convex and concave structure. As the verso side cannot be open flat for multispectral imaging, its shadow may cause loss of information that required a complementary shot.

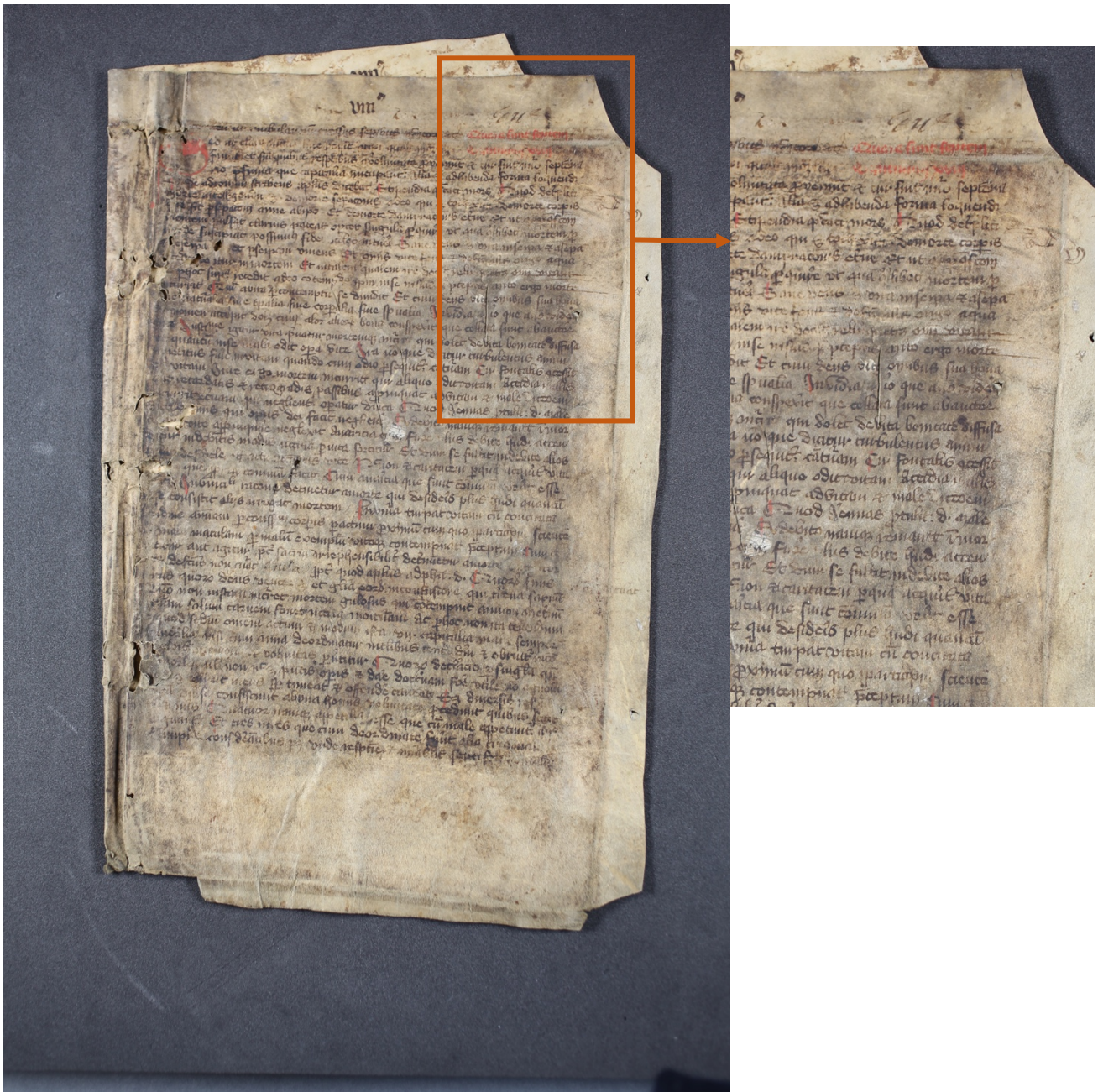


Figure 3.7-2 recto side of f.1 of MS FRAG/LAT/15 which shows the evidence of later annotation (right). The zoom-in view on the right provides us with a better observation of the annotations as well as some red highlights.

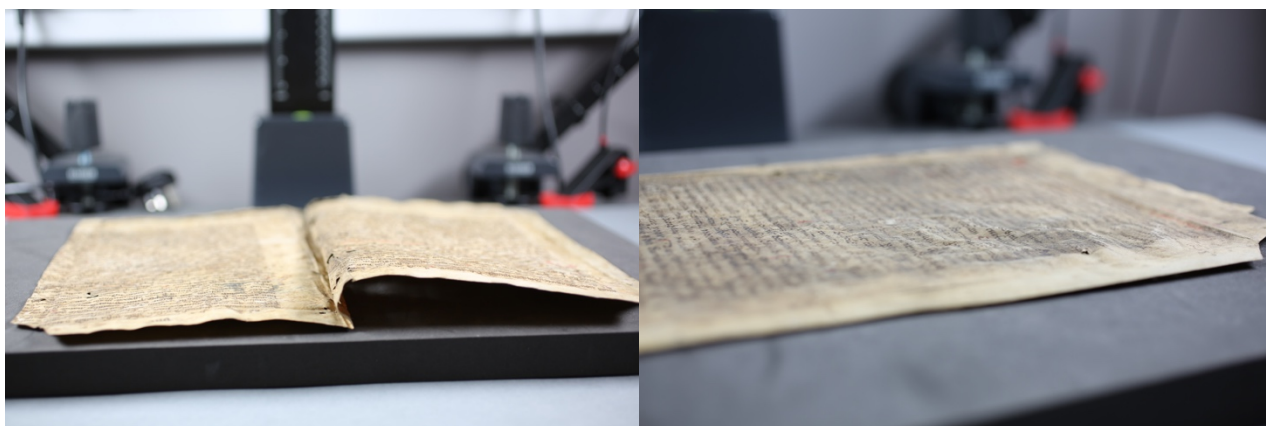


Figure 3.7-3 side view of the flipped open verso side of the manuscript (left). It can be observed that the surface of the manuscript is not flat and accompanied with convex and concave structure.

Methods

Multispectral imaging was taken on both sides of the manuscript to get a full record of the information of inscriptions. Given that the verso side of the manuscript cannot be open flat, two set of shots were taken on its verso side for better focus and also, to eliminate the effect of shadow. Shot sequences are shown in Table 3.7-1.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	10	400
2	385	Ultraviolet	None	10	400
3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.4	200
7	510	Cyan	None	0.4	200
8	530	Green	None	0.6	200
9	550	Lime	None	0.2	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.4	200
12	640	Red	None	0.4	200
13	660	Long Red	None	0.4	200
14	740	Infrared	None	0.5	200

15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
17	365	Ultraviolet	Green	13	200
18	410	Violet	Green	8	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	15	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	8	200

Table 3.7-1 Shot sequence and shot parameter of the multispectral imaging applied on both sides of MS FRAG/LAT/15.

Also, processing including PCA and false colour alignment were applied to the multispectral images for a clear inscriptions. The expectation was that by assigning the dirt with lighter colour and the inscriptions with darker ones, we would be able to observe the inscriptions with a clearer edge through the dirt.

3.6.3 Results and Discussions

Multispectral Images

As a common property of most of the medieval manuscripts, the inscriptions were shown the clearest under short wavelength such as ultraviolet light and royal blue light. As the parchment fluorescents strongly under those lights, the contrast between ink and parchment was enhanced, resulting in a clear boundary and edge of inscriptions. However, lights such as ultraviolet light and royal blue cannot penetrate well onto the surface of the manuscript due to their short wavelengths. And given that the manuscript was covered heavily by dirt, the results from lights with short wavelength were not ideal as the dirt blocked a considerable amount of inscriptions. The balance between penetration and inscription contrast should be taken for the best outcome.



Figure 3.7 selected multispectral images that shows a clear inscriptions while considering the balance of penetration and inscription contrast. They are taken in Green light with infrared filter (left) and Royal blue light with infrared filter (right) respectively.

PCA and false colour alignment

By conducting PCA and false colour alignment, some of them showed really good results that the inscriptions were shown clearly. Some of the principal components and false colour images have been selected in the following figures.

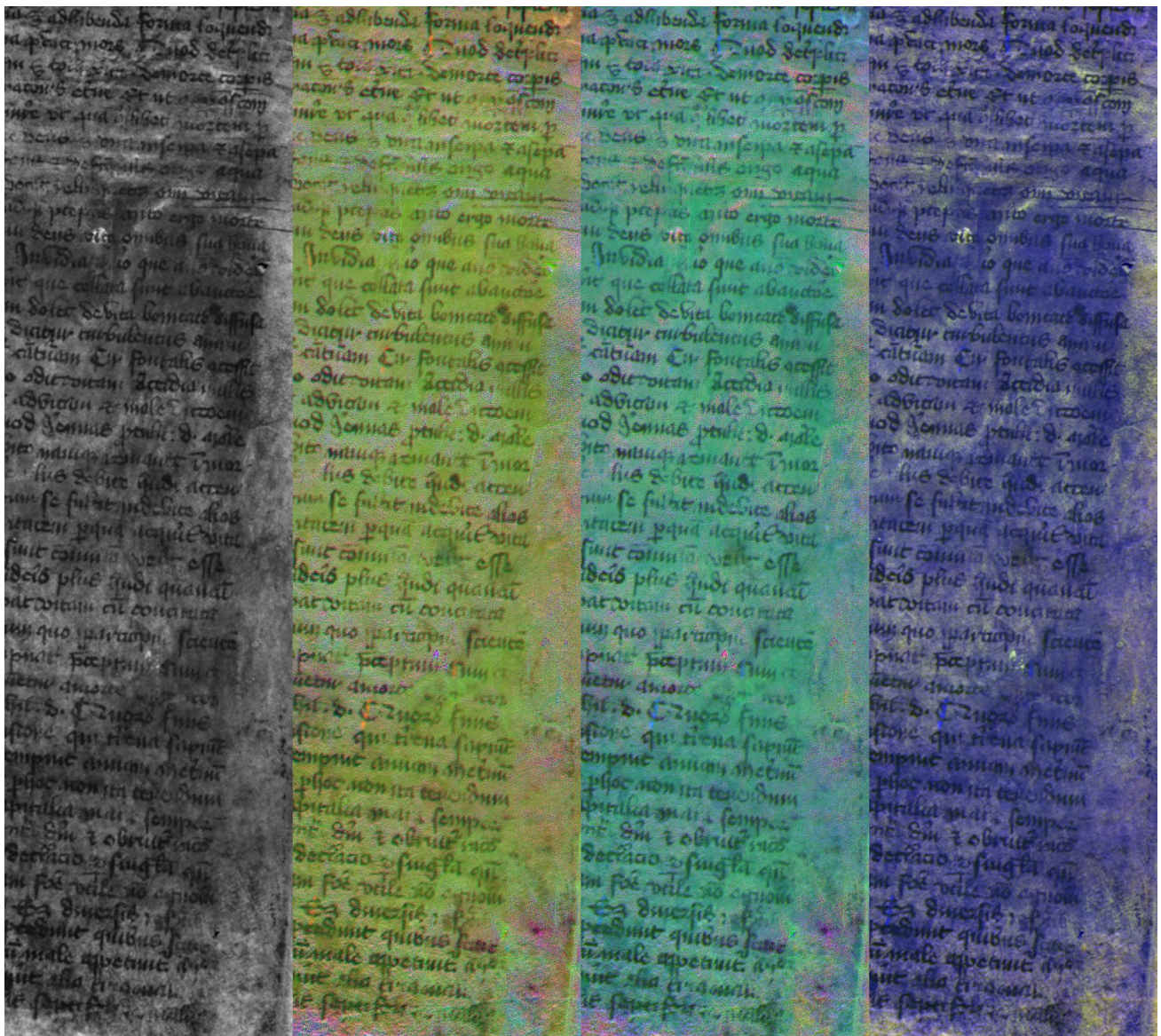


Figure 3.7 Selected partial zoomed-in photos of the false colour alignment on recto side of f.1 of the parchment. Some of them, by applying the dirt into a lighter colour, can show the inscriptions underneath clearly.

D-stretch was also applied to have more subtle changes of the false colour alignment. With the adjustment of different red, green and blue channels and parameters, we were able to enhance the contrast of some of the fading inscriptions while maintaining the brightness of some of the dark section covered in dirt.

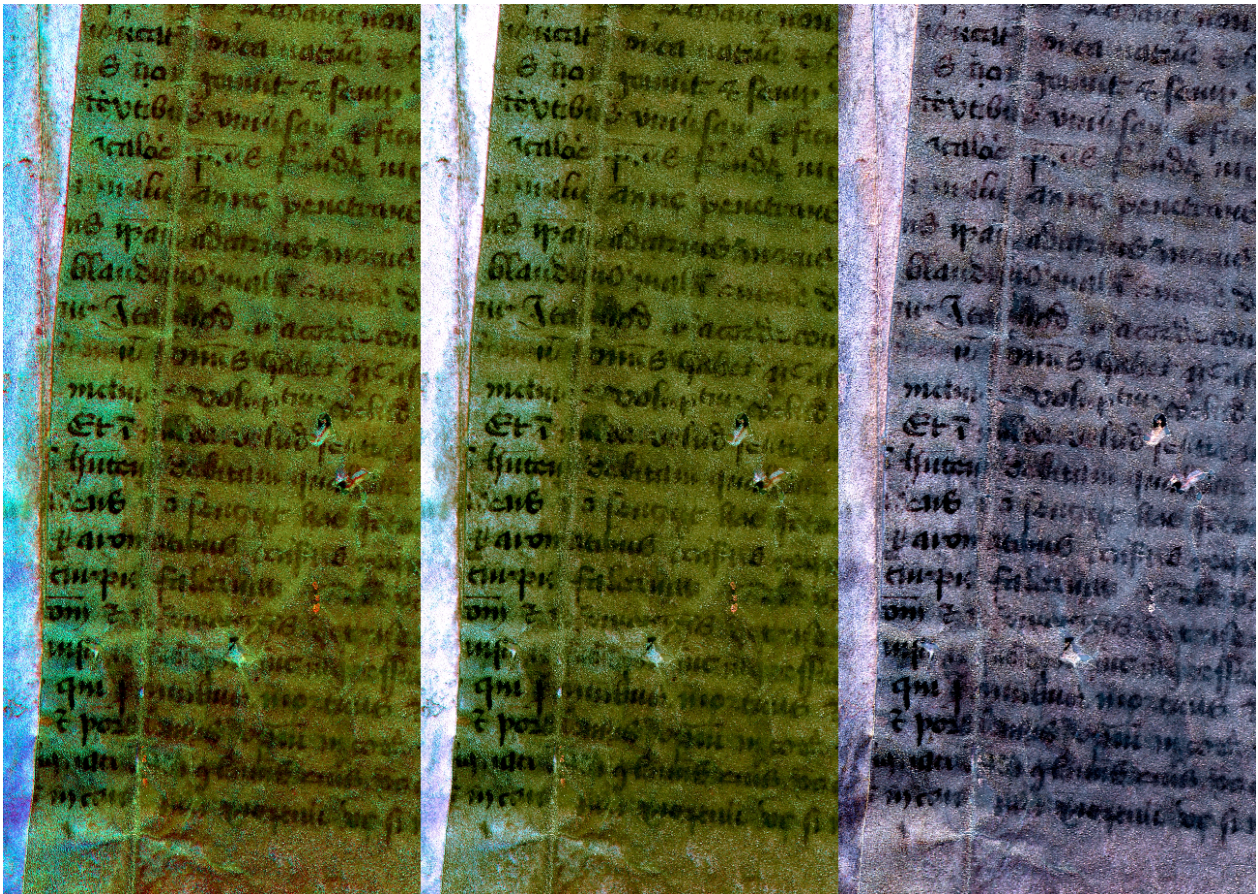


Figure 3.7 Selected partial zoomed-in photos of the D stretch results on recto side of f.2 of the parchment.

Also, some of the results in PCA showed red inscriptions and rubrics with high contrast. This process can also be applied to other manuscripts in this project, and it was inferred that such operations can be a reliable pattern if the red inscription is the content of interest.



Figure 3.7-3 Selected principal components that shows the red ink in a clear and obvious contrast, the red ink is shown in black (left) and white (middle and right) respectively.

3.6.4 Conclusion

The manuscript in this research was one of the representatives of many other similar cases that have gone through a certain degree of damage and were in need of conservation. The imaging conducted on the manuscript can help with the preparation and evaluation of the conservation as it provided overall information of the content and condition of the manuscript.

For parchments covered in dirt, multispectral imaging could be applied but the images under lights with short wavelength were not the ideal choices due to the noise they showed. However, this problem can be fixed by applying false colour alignment and principal component analysis. Also, a balance between penetrating ability and the contrast between parchment and inscriptions should be considered when selecting multispectral images for PCA and false colour alignment.

3.7 Book with overlapping inscriptions

3.7.1 Introduction

In UCL special collection, there were various rare books that had been previously persevered by different owners for centuries. As each of their owners treated their books as an important asset. It was an important acknowledgement to write their name on the title page of the book to claim their authority. During the alternation of book ownership, many of them would choose to write their name precisely on top of the signature of its previous owner as a form of tradition.

Meanwhile, it is an important research topic in UCL special collection to find out the transfer of ownership of important books, its alternation can be an essential indicator that was closely associated with the socioeconomic environment of that time back in history. Hence, being able to distinguish every one of the book owners, including those whose signature has been deliberately lined through or covered, can be the cornerstone for such researches.

In this project, three books of such case underwent imaging to find out those deleted or erased inscriptions. As these books were chosen from different ages, it was hoped that a standard imaging routine for books of such case could be developed.

3.7.2 Material and Methods

Strong Room Ogden A.264

The book is named *The Faerie Qveene* : disposed into twelue bookes, fashioning XII. morall vertu, or Faeriwe queene for short. It was an English epic poem as well as an allegorical work with two sections, respectively Books I-III and Books IV-VI. By telling stories following several knights and record their adventures in the poetic form, the books can be interpreted into several levels of allegory, including as praise of Queen Elizabeth I.

The book we have in the strong room collection of UCL is a second edition of books I-III. According to its annotation on the title page, it could be inferred that this book had been owned by a considerable number of people and was treated well. Some of the

inscriptions on its rear end page has been cut off and only half of them can be shown, suggesting that some treatment including tailoring of the book has been conducted, but none of its content was cut off.

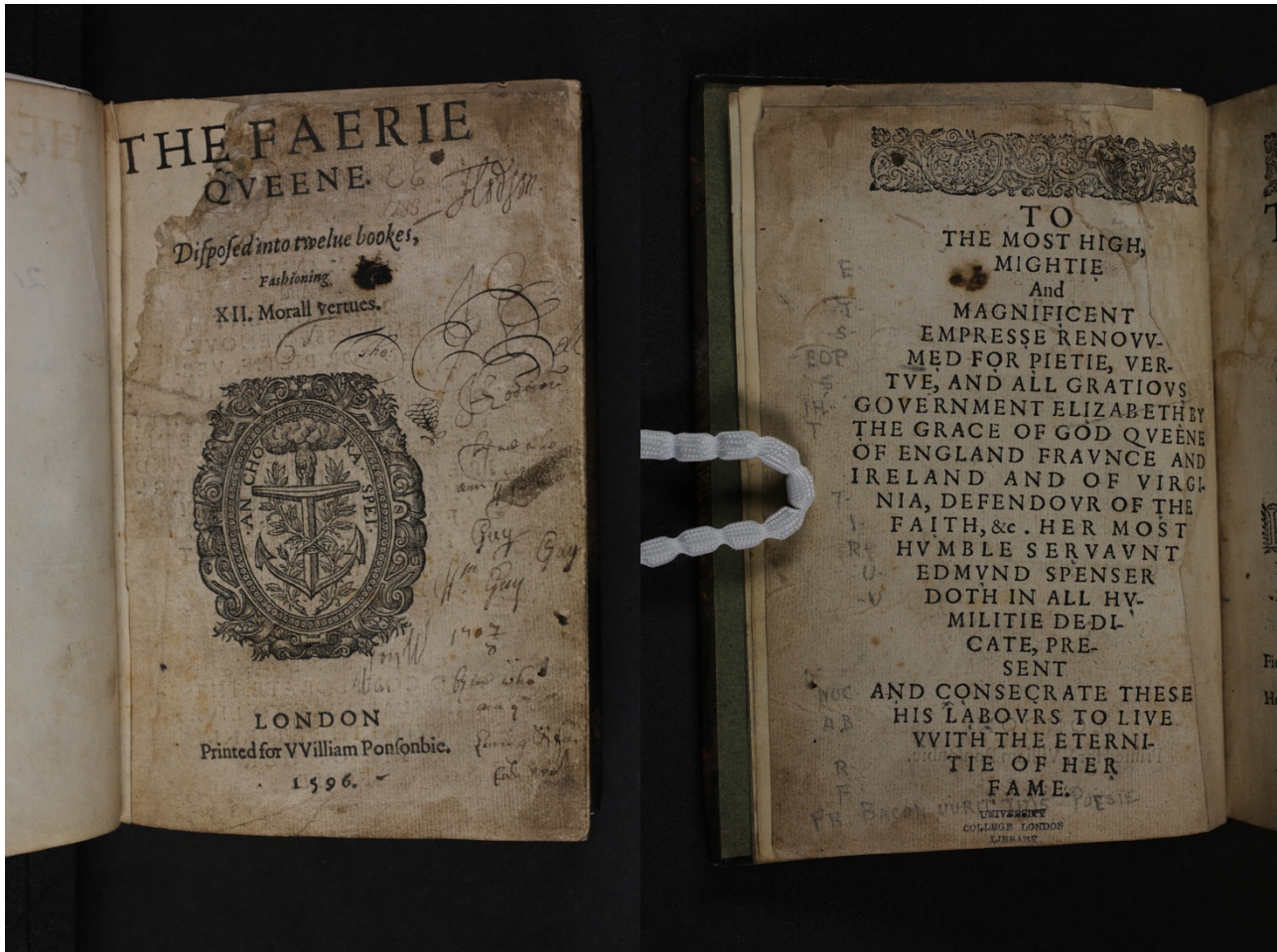


Figure 3.8-1 the recto (left) and verso (right) side of the title page. It can be shown that there are multiple inscriptions on the title page (left) which is believed to be from different owners of the books. It is also believed that the pencil mark on the verso side of the title page is made by Ogden.

For this book, our focus is on the scratched inscriptions on the title page, whereas the signature of one of the owners was covered by the ink mark from what was believed to be deliberate ink splashing by its later owners.



Figure 3.8-2 the inscription that has been covered by ink mark on title page, which is marked out by the white frame.

INCUNABULA QUARTO 1_e

This book is named *Liber de proprietatibus rerum Bartholomei anglici*, or commonly known as *De proprietatibus rerum*. It is a book that covers various scientific and religious topics in the medieval age. The author, Bartholomeus Anglicus, was an early 13th-century scholastic of Paris and a member of the Franciscan order. This book was written when Bartholomew was at the school of Madgburg in Saxonia and was intended to the audience of students and general public. However, it is still carefully noted and cited from other materials and references by Bartholomew, which made it an important and valuable work in studying the scholastic work in medieval age.

The book in this project was made in 15th century with contemporary binding of stamped and stained pigskin over wooden boards. The book was carefully persevered and were even installed with two clasps made of metal and leather, although one is damaged.



Figure 3.8-3 the book has a contemporary binding with wooden cover, although it is obvious that the metal corner protection has been removed, the book is generally in good condition to read.

Multiple inscriptions have been left on its title page and rear end page, which are all believed to be made by its previous owner.



Figure 3.8-4 the inscriptions on the end page(right) and title page(left) of the books. It can be shown that some of the inscriptions has been lined through and deleted.

In this project, these two pages are imaged to find out the deleted inscriptions.

RCP 9978

The book is named *Caii Plinii secundi historiae naturalis libri XXX*. It is a book focus on the whole of the natural world, and it is one of the volume of the *Naturalis Historiae* (Pliny), one of most important historical work focusing on the development of the natural world and life. This book also covered a considerable amount of topics including botany, physiology and pharmacology.

As a collaboration, this book was owned by the Royal Collage of Physicians. As is showed in the title page, the book had alternated its ownership with the new owner signing his name right on top of its previous owner, leaving an overlapping inscription illegible for librarian to interpret.

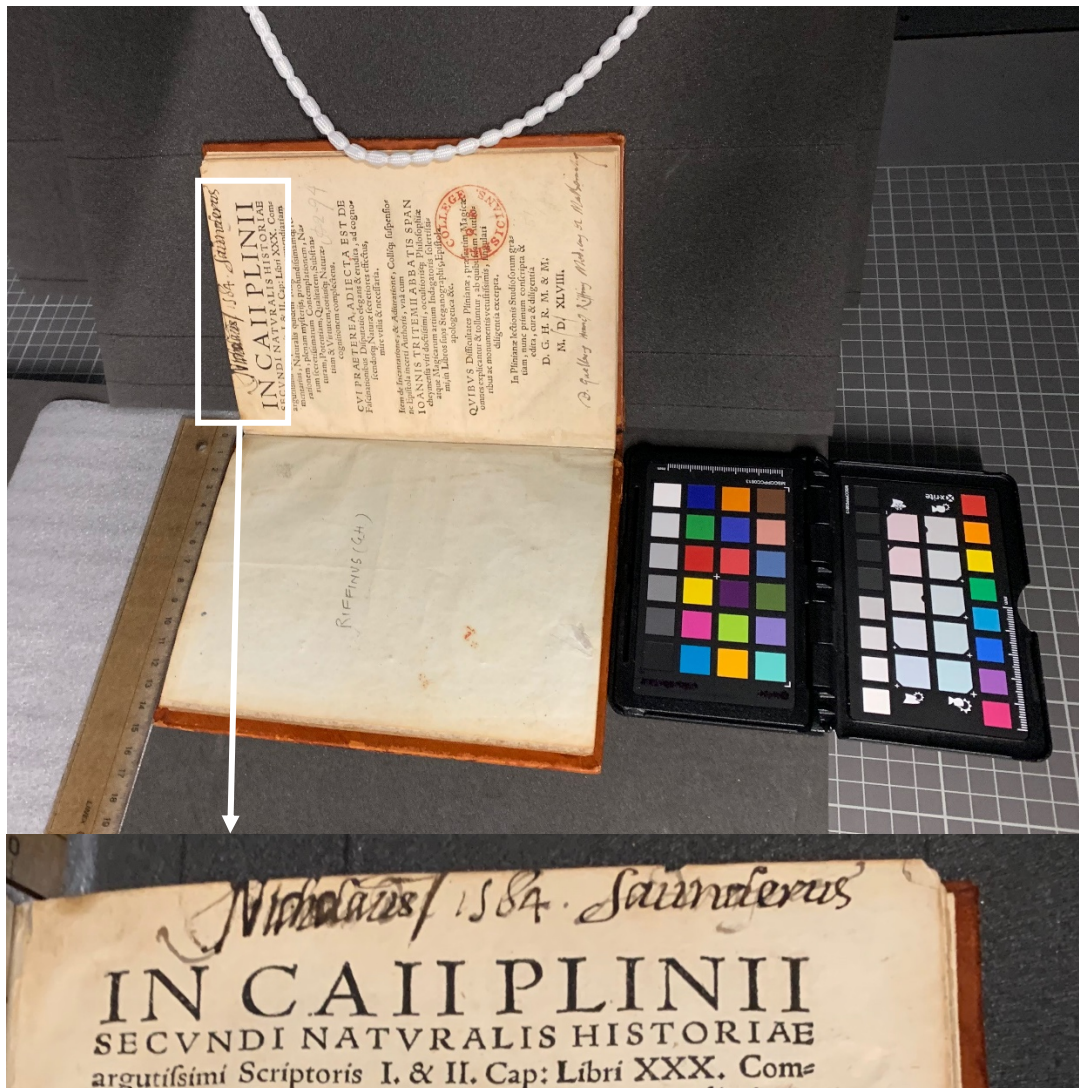


Figure 3.8-5 the overlapping inscription on the title page of the designated book, a zoomed-in image is shown for more details of the overlapping inscriptions.

With the expectation of recovering what's beneath the new inscription, imaging was applied to its title page, recto and verso side.

Methods

Multispectral Imaging has been applied to all three objects on the pages of interest. It was expected that with the combination of different spectral information we were able to recover and read the illegible inscription or show the faded information. Three tables were listed below as the shot sequence and information of the three object, it was worth noticing that Table 3.8-2 and 3.8-3 show only the shots with different shot parameter from Table 3.8-1.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	8	200
2	385	Ultraviolet	None	8	400
3	410	Violet	None	0.4	200
4	420	Violet Long	None	0.25	200
5	450	Royal Blue	None	0.2	200
6	480	Long Blue	None	0.2	200
7	510	Cyan	None	0.2	200
8	530	Green	None	0.4	200
9	550	Lime	None	1/8	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.2	200
12	640	Red	None	0.2	200
13	660	Long Red	None	0.2	200
14	740	Infrared	None	1/3	200
15	850	Infrared	None	1.6	200
16	940	Infrared	None	2.5	200
17	365	Ultraviolet	Green	13	200

18	410	Violet	Green	8	200
19	365	Ultraviolet	Red	20	800
20	410	Violet	Red	15	800
21	450	Royal Blue	Red	10	200
22	450	Royal Blue	Infrared	20	800
23	530	Green	Infrared	20	800
24	000	Dark	None	20	800
25	365	Ultraviolet	None	8	200

Table 3.8-1 Shot sequence and shot parameter of the multispectral imaging applied on both sides of the title page of Strong Room OGDEN A 264.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	10	400
2	385	Ultraviolet	None	10	400
3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.4	200
7	510	Cyan	None	0.4	200
8	530	Green	None	0.6	200
9	550	Lime	None	0.2	200
10	600	Amber	None	0.5	200
11	630	Red Orange	None	0.4	200
12	640	Red	None	0.4	200
13	660	Long Red	None	0.4	200
14	740	Infrared	None	0.5	200
15	850	Infrared	None	1.6	200

Table 3.8-2 Shot sequence and shot parameter of the multispectral imaging applied on both sides of the title page and rear end page of INCUNABULA_QUARTO_1_e. Only those different from Table 3.8-1 are selected and shown.

Shot Index	Wavelength	Colour	Filter	Exposure(s)	ISO
1	365	Ultraviolet	None	10	200
2	385	Ultraviolet	None	10	400
3	410	Violet	None	0.8	200
4	420	Violet Long	None	0.4	200
5	450	Royal Blue	None	0.4	200
6	480	Long Blue	None	0.4	200
7	510	Cyan	None	0.4	200
8	530	Green	None	0.6	200
9	550	Lime	None	0.2	200
10	600	Amber	None		200
11	630	Red Orange	None	0.4	200
12	640	Red	None	0.4	200
13	660	Long Red	None	0.4	200
14	740	Infrared	None	0.5	200
22	450	Royal Blue	Infrared	30	800
23	530	Green	Infrared	30	800
25	365	Ultraviolet	None	10	200

Table 3.8-3 Shot sequence and shot parameter of the multispectral imaging applied on both sides of the title page of RCP 9978. Only those different from Table 3.8-1 are selected and shown.

Meanwhile, several types of processing on those multispectral images were conducted including principal component analysis, false colour alignment and image calculation. With the expectation of showing some of the faded inscriptions and enhance the contrast of some of the underneath inscriptions. Several attempts have been made and some of them showed a better result in the way expected. This will be discussed in details in results and discussion section.

3.7.3 Results and Discussions

Multispectral Images

The inscriptions are shown the clearest under lights in short wavelength with filters applied. However, for case as RCP9978, the enhancement of inscription would not help with the separation of the inscriptions underneath, thus in such case PCA and false colour alignment should be applied for deserved outcome. And for INCUNABULA QUARTO 1_e, several severely faded inscriptions were shown under ultraviolet light with red filter as shown in Figure 3.8-6. The shown inscription were zoomed in and shown. Also, another similar case is found on the title page of INCUNABULA QUARTO 1_e and is shown in Figure 3.8-7.



Figure 3.8-6 under the ultraviolet light with red filter applied, an invisible inscription are shown at the rear end page of INCUNABULA QUARTO 1_e.

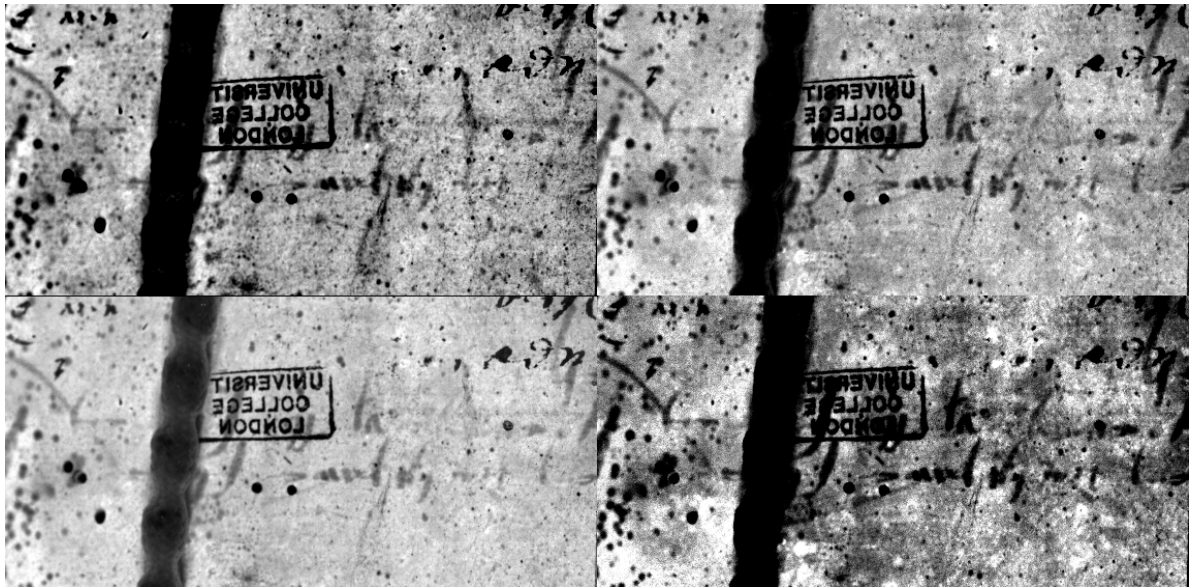


Figure 3.8-7, four multispectral images has shown the strongly faded inscription on the title page of INCUNABULA QUARTO 1_e. They are respectfully shot 17 to 20 (left up, right up, left down and right down).



Figure 3.8-8. Multispectral Images taken under ultraviolet light with red filter for the title page of Strong Room Ogden A 264.

Also, six photos of the rear end page of INCUNABULA QUARTO 1_e were selected in Figure 3.8-9 that showed the fading of ink with the increase of wavelength of the light applied. This was a common pattern of iron-gall ink, and this can also be integrated together to see the inscription underneath.

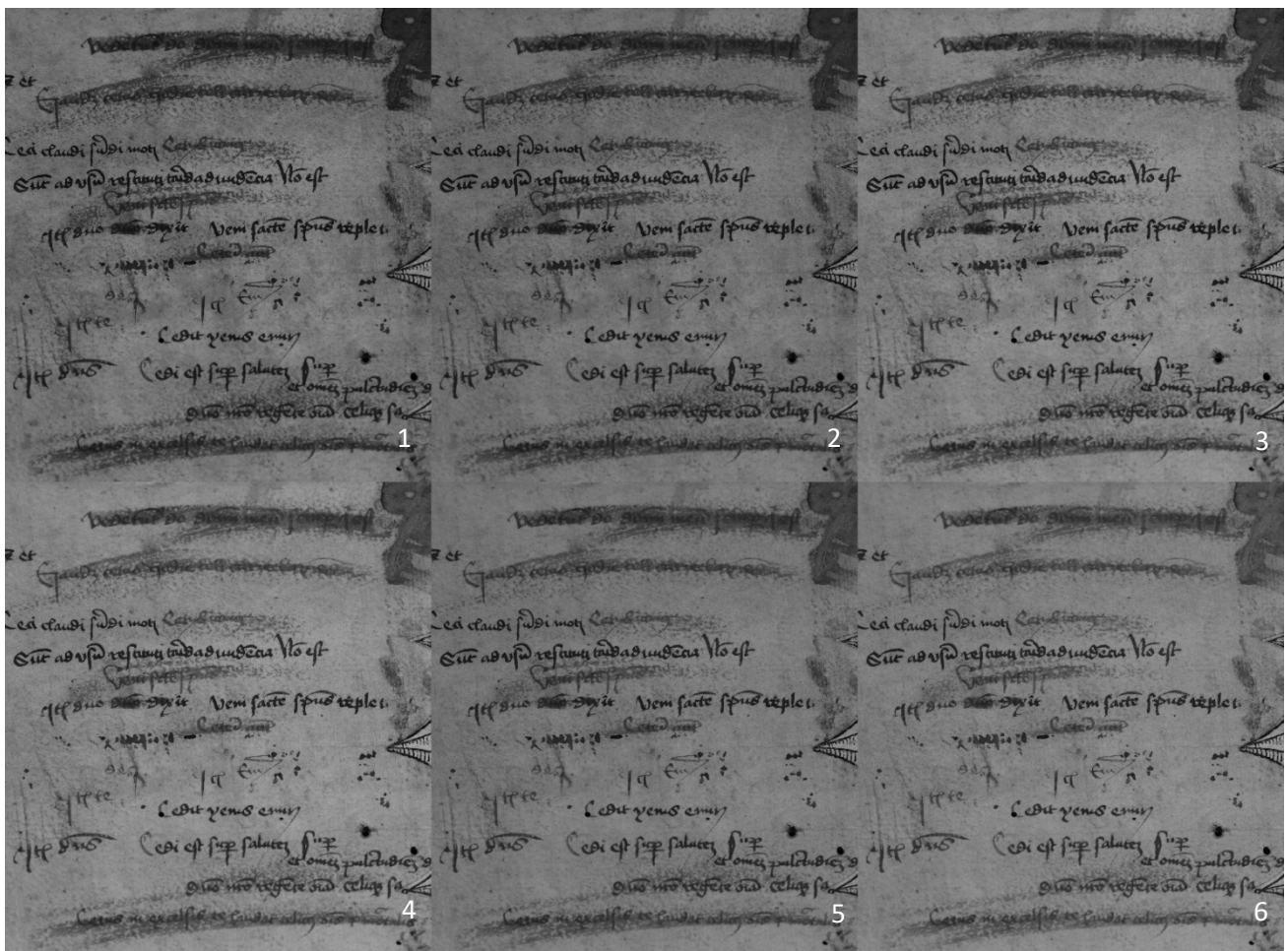


Figure 3.8-9 multispectral images under increased wavelength, both the lines on top and inscriptions are fading. The images are correspondingly shot 9 to 14. While as the lines are fading faster, the underneath inscriptions can be shown clearer in image 5 and 6.

PCA and false colour alignment

With the help of PCA and false colour alignment, many operations were available. For Strong Room Ogden A 264, we are able to attach the ink mark with a lighter colour while the inscriptions underneath with a darker one. As shown in Figure 3.8-10, some parts of the inscription can be shown clearer. For INCUNABULA QUARTO 1_e, we were able to enhance the contrast of the faded inscriptions with its surroundings and hence make it more legible. As for the case of RCP 9978, by aligning false colour, we are able to

separate the two layers of inscriptions by assigning them with slightly different colour and thus make it possible to read the inscriptions underneath.



Figure 3.8-10. Attaching a brighter colour of the ink mark while leaving the inscriptions with darker colour, we are able to distinguish some of its inscriptions on the title page of Strong Room Ogden A 264.

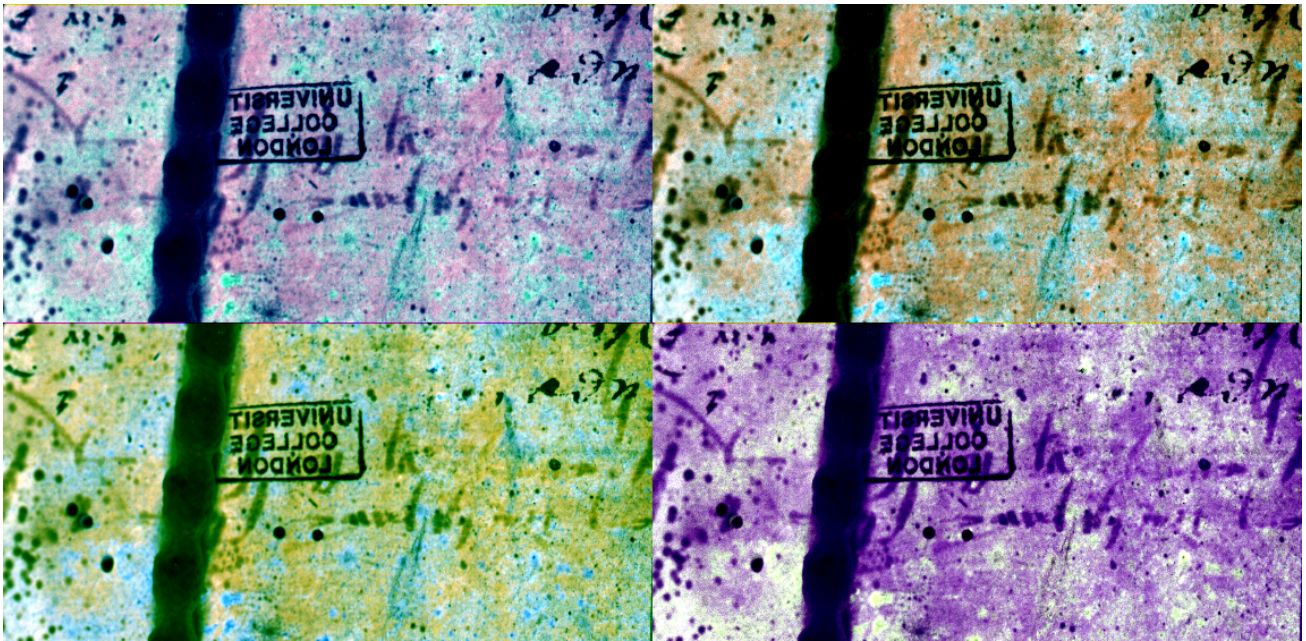


Figure 3.8-11. False colour alignment on the faded inscriptions on the title page of INCUNABULA QUARTO 1_e. false colour enhance the contrast between the inscriptions and its surroundings.



Figure 3.8-12 false colour alignment for RCP 9978. By attaching the top and bottom layer inscriptions with different colour, we are able to partially read the underneath inscriptions.

Image Calculator

For cases as RCP 9978, image calculator was employed. The ideal situation was by deducing the pixel value of the top layer, the bottom layer can be shown with less

interference and hence can be more legible. In this project several calculation has been conducted and some of them have shown a convincing result.

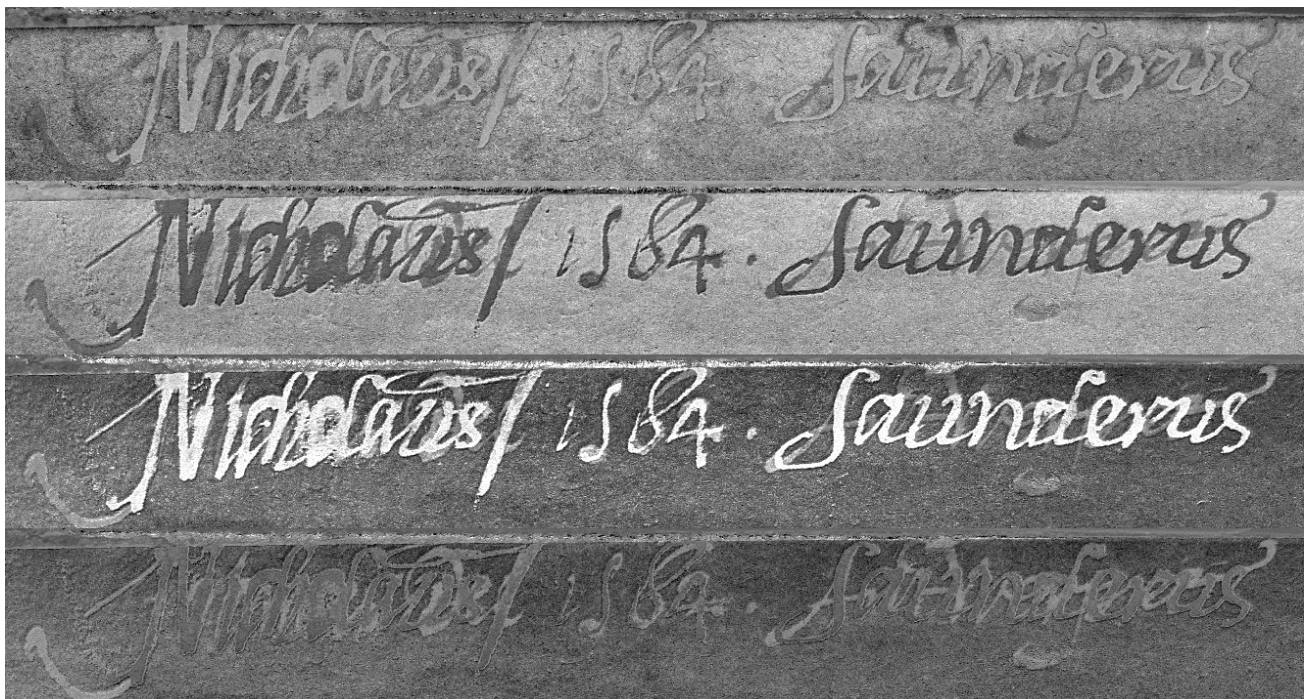


Figure 3.8-13 result of image calculation for RCP 9978. What was shown in the bottom is the ideal case that the underneath inscriptions are brighter and can be connected easily.

3.8.4 Conclusion

Some of the medieval books, due to their long history and frequent alternation of ownership, have gone through some degree of damage in various cases. Among those different types of damages, one common type was the overlapping inscriptions on the title page and end page of the book, as the inscriptions were usually related to the ownership of the book, which was an important topic to be studied, getting to know the inscriptions with the help of imaging techniques is essentially important.

In this project, multispectral imaging has been applied to all three cases and some of them have shown a convincing results. Some of the fading inscriptions on the title page of INCUNABULA QUARTO 1_e were shown. Also, due to the difference in the pattern of fading of the ink mark and underneath inscriptions, some of the deleted inscriptions on the title page of Strong Room Ogden A 264 can also be legible.

With the help of PCA, false colour alignment and image calculator, more operations were available. For instance, we were able to separate the two layers of inscriptions on the title page of RCP 9978 by assigning them with different colours and image deduction.

The combination of multispectral imaging and various processing on the multispectral images have shown promising results. This pattern of operations can be developed to solve similar problems as such.

4. Conclusion

A variety of different objects in UCL special collection underwent multispectral imaging to answer a range of research questions. Firstly, multispectral images were taken for those manuscripts that were used as binding materials. With those annotations that indicated the book they wrapped, several images were selected as it showed the clearest inscriptions. The results showed that, generally speaking, images captured under short wavelength with filter applied had desired outcome in showing the inscriptions as a result of difference in fluorescence of the ink and parchment. Also, PCA was applied to the objects. Results showed that some of the principal components were efficient in distinguishing ink with a different colour, red and blue inks for instance. False colour alignment proved to be efficient in dealing with such cases as the fading inscriptions could be attached with a darker colour. However, false colour alignment can also amplify the noise of the images and therefore affect the result. So more delicate assignment of the colour channels may be required.

Several parchments with coating and chemical covers were also imaged to study the structure of cover and also the inscriptions underneath. However, as shown in the images, it had to be admitted that with current techniques and settings, it was hardly feasible to penetrate the chemical cover to determine if the underneath inscriptions still exist. But by carefully balancing the penetrating ability and the fading of ink, some of the covered inscriptions in MS FRAG/LAT/11 can be recovered. Moreover, the processing on multispectral images, PCA and false colour alignment, can also be useful in selecting out some of the covered signs. As for the structure of the chemical cover, RTI was applied, which proved to be useful in understanding the coating techniques of that time by showing a clear structure at the edge of the cover.

A parchment with gold leaf decoration, MS FRAG/LAT/28, was imaged as well for better conservation. The gold leaf was important for research involving in decoration of medieval religious books. As the focus of this research being the surface structure of the gold decoration, reflectance transformation imaging was conducted, and several of its processing including specular enhancement was applied for more accurate boundary

information. Results were convincing and reliable as the detailed recording of the positional information can be measured by the length of the shadow in registered light position.

Some flooded deeds that were assumed to be related to the main building of UCL have been imaged in this project. Multispectral imaging and image processing including PCA and false colour alignment were applied to one of the representative deeds in this project. The inscriptions, even though flooded, have shown much clearer and legible under short wavelength with filter applied. However, as the flooded parchment was thin and easy to be penetrated, the inscriptions from the other side were recorded in the multispectral images, which can be separated and possibly solved by PCA and false colour alignment.

In this project, one case that the parchment was covered in dirt was imaged. Multispectral imaging and image processing were combined together for better results. For multispectral images, the images captured with ultraviolet light and royal blue light illuminance showed the most information. However, as those light were in short wavelength with poor penetration ability, the dirt covered on top of the parchment was also recorded and some of the inscriptions are therefore blocked. However, with false colour alignment, the dirt can be attached with lighter colour while the inscriptions underneath with darker ones. Some of the results showed us rich information of the inscriptions and were selected in the case study.

Several rare books were also imaged in this project. Some of the books were decorated with many stickers and patterns which showed the social status of its owner. As a symbol of asset, books were usually carefully preserved and underwent multiple transition of ownership. Its transition were the important process to be studied as it was closely related to the socioeconomic change and historical events of that time. However, the inscriptions left by the previous owners were usually covered deliberately its later owner for many purposes. For this project, three books with similar situations were imaged to recover its deleted inscriptions. Results have been shown that those inscriptions were shown the clearest under ultraviolet light and lights with short

wavelength. But the deleted inscriptions can be shown the clearest if lights with higher wavelength applied due to the different pattern of fading of the inscriptions underneath and on top. Also, PCA and false colour alignment proved to be efficient in this case as it can separate the two layers of inscriptions by aligning it with different RGB channels. Also, image calculator was applied. By subtracting the pixel value of different principal components, it was also feasible to separate the different layer of inscriptions.

Despite the effectiveness of the newly installed system, several important operational protocols should still be followed to avoid redundant procedures and harm to the artefacts due to the lights emitted during imaging. For instance, the setup of both of the object and the system can be time consuming; depending on the software for capture and processing, technical problems might occur including mismatch of lights and capture time, problems with shot sequence duplication. Moreover, the time taken will be multiplied for multiple objects as the system needs to be adjusted accordingly. Capturing on books would sometimes requires several set of shots for one object because the book cannot be open flat and the depth of field may not be wide enough to cover all the information of interest. Also, imaging on books require subtle settings that should be checked regularly to avoid vibrations and displacement. Time can be saved by imaging objects of similar sizes and compositions together so that the set ups, capture sequences and even the flat field taken can remain the same.

The large quantity of data from the images captured and later processing is difficult to store and manage. For the large amount of file, an index system on the file name should be established to keep the files in place. Also priority should be decided and given among the objects, and detailed record of the shot sequence, system setup and processing parameter should be taken for repeating the experiment later.

The variety of artefacts involved in this project require different imaging setting that should be determined by the user. These parameters include exposure, aperture and choice of wavelength sequence and filter combination. The adjustments on these mentioned above could be trivial and requires knowledge of the material and the technology. However, identifying and setting the optimal shot sequencing and its

relevant parameter specifically for different types of artefacts can make this techniques more accessible for future research and refinement.

Overall, multispectral imaging and reflectance transformation imaging can successfully extract and present information from various types of artefacts which can be difficult to determine in traditional ways. It is a novel and efficient method with potential in digitalisation on historical documents. And I hope we can witness the future development of this techniques with more dedicated and passionate researchers.

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And lastly I wish to thank Lord Laidlaw of Rothiemay who gave me the opportunity to do this wonderful project on imaging of historical documents, and Ms. Audrey Chung for coordinating the program. I am sincerely grateful to all of you, without whom I would never make this happen.

6. Bibliography

“UCL museums and collections,” *Wikipedia*. [Online]. Available:

https://en.wikipedia.org/wiki/London_Metropolitan_Archives. [Accessed: 06-Sep-2019]

“Reflectance Transformation Imaging,” *Cultural Heritage Imaging*. [Online]. Available:

<http://culturalheritageimaging.org/Technologies/RTI>. [Accessed: 06-Sep-2019]

“The Faerie Queene” *Wikipedia*. [Online]. Available: https://en.wikipedia.org/wiki/The_Faerie_Queene.

[Accessed: 06-Sep-2019]

“Bartholomeus Anglicus,” *Wikipedia*. [Online]. Available:

https://en.wikipedia.org/wiki/Bartholomeus_Anglicus. [Accessed: 06-Sep-2019]

D. Mattes, D. R. Haynor, H. Vesselle, T. K. Lewellen, and W. Eubank, “PET-CT Image Registration in the Chest Using Free-form Deformations,” *IEEE Trans. Med. Imaging*, vol. 22, no. 1, pp. 120–128, 2003.

R. L. Easton Jr. et al., “Standardized system for multispectral imaging of palimpsests,” in *Computer Vision and Image Analysis of Art*, 2010, vol. 7531, pp. 1–11.

“Bartholomeus Anglicus,” *Wikipedia*. [Online]. Available:

https://en.wikipedia.org/wiki/Bartholomeus_Anglicus. [Accessed: 06-Sep-2019]

“Naturalis Historia,” *Wikipedia*. [Online]. Available:

[https://en.wikipedia.org/wiki/Natural_History_\(Pliny\)](https://en.wikipedia.org/wiki/Natural_History_(Pliny)). [Accessed: 06-Sep-2019]

“MS FRAG/LAT 11,” *UCL Archives Catalogue*. [Online]. Available:

[http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=12&dsqSearch=\(\(text\)=%27MS%27\)AND\(\(text\)=%27FRAG/LAT%27\)\)](http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=12&dsqSearch=((text)=%27MS%27)AND((text)=%27FRAG/LAT%27))). [Accessed: 06-Sep-2019]

“MS FRAG/LAT 15,” *UCL Archives Catalogue*. [Online]. Available:

[http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=15&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=15&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)). [Accessed: 06-Sep-2019]

“MS FRAG/LAT 18,” *UCL Archives Catalogue*. [Online]. Available:

[http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=18&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/Dserve/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=18&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)). [Accessed: 06-Sep-2019]

“MS FRAG/LAT 28,” *UCL Archives Catalogue*. [Online]. Available:
[http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=28&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=28&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)).
[Accessed: 06-Sep-2019]

“MS FRAG/LAT 36,” *UCL Archives Catalogue*. [Online]. Available:
[http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=36&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=36&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)).
[Accessed: 06-Sep-2019]

“MS FRAG/LAT 45,” *UCL Archives Catalogue*. [Online]. Available:
[http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=45&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=45&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)).
[Accessed: 06-Sep-2019]

“MS FRAG/LAT 54,” *UCL Archives Catalogue*. [Online]. Available:
[http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=54&dsqSearch=\(\(text\)=%27MS/FRAG/LAT%20%27\)](http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=54&dsqSearch=((text)=%27MS/FRAG/LAT%20%27)).
[Accessed: 06-Sep-2019]

“MS FRAG/HEB 1,” *UCL Archives Catalogue*. [Online]. Available:
[http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=1&dsqSearch=\(\(\(\(text\)=%27MS/FRAG/HEB%27\)AND\(\(text\)=%271%27\)\)](http://archives.ucl.ac.uk/DServe/dserve.exe?dsqServer=localhost&dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Catalog&dsqPos=1&dsqSearch=((((text)=%27MS/FRAG/HEB%27)AND((text)=%271%27))). [Accessed: 06-Sep-2019]