Digital Analysis of the Inks and Pigments in the Manuscripts of John Gower's Poetry

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New Haven, Yale University, Beinecke Library, Osborn MS fa.1, containing Gower's *Confessio amantis* and some minor Anglo-French and Latin poetry, is both a lavishly illuminated codex, produced most likely in London ca. 1410-20, and a manuscript that has suffered much distress from water damage and from subsequent modern attempts to stop the growth of mildew (**Fig. 1**). As a result of that damage, there are lingering aftereffects for the codex, including large chunks of stained text and decoration (**Fig. 2**) and a wretched odor resulting from the application of a chemical named Thymol that was once used by conservators to stop unwelcome organic growth on the parchment.

In a 2011 presentation on this manuscript, Barbara Shailor noted that the very damaged quality of this codex had prompted a discussion with computer scientists at Yale about how to enhance the legibility of some of the rubrics (such as the one in the lower margin of the folio in (**Fig. 2**) that had been devastated by water, with text that had been washed away and was now very difficult to read.[1] Preliminary tests suggested that hyper- or multi-spectral imaging might be of assistance in reading the text, and indeed, it was and is of great help.[2] But the imaging also revealed other key information about differences in the red pigments as in **Figure 2**. It was this discovery that led the Yale team to want to pursue the potential of the imaging in connection with this and other manuscripts. Using multi-spectral imaging followed by pixel-by-pixel digital analysis, the Yale team was able to determine that the red pigment used for the rubrics in Osborn

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[1] Barbara Shailor, "Paleographical and Codicological Puzzles: New Haven, Beinecke Library Osborn MS fa.1," paper read at the second Congress of the International John Gower Society, Valladolid, Spain. See further Min H. Kim and Holly Rushmeier, "Radiometric Characterization of Spectral Imaging for Textual Pigment Identification," in *12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage – Short Papers*, ed. M. Dellepiane *et al.* (Eurographics, 2011); Min H. Kim, Holly Rushmeier, *et al*., "3D Imaging Spectroscopy for Measuring Hyperspectral Patterns on Solid Objects," *ACM Transactions on Graphics* 31 (2012); and Barbara Shailor, "The Yale Gower Manuscript, Beinecke Osborn MS fa.1: Paleographical, Codicological, Technological Challenges and Opportunities," in *John Gower in England and Iberia: Manuscripts, Influences, Reception*, ed. Ana Sáez-Hidalgo and R. F. Yeager (Cambridge: D. S. Brewer, 2014), pp. 77-85.

[2] Similar technology was used to recover of underwritten text in the so-called Archimedes palimpsest. See K. T. Knox, *et al*., "Multispectral Imaging of the Archimedes Palimpsest," in *Image Processing, Image Quality, Image Capture Systems Conference* (2001), pp. 206-210; R. L. Easton, Jr., K. T. Knox, and W. A. Christens-Barry, "Multispectral Imaging of the Archimedes Palimpsest," in *Proceedings of the 32nd Applied Imagery Pattern Recognition Workshop* (2003), pp. 111-16; and Emanuele Salerno, Anna Tonazzini, and Luigi Bedini, "Digital Image Analysis to Enhance Underwritten Text in the Archimedes Palimpsest," *International Journal of Document Analysis and Recognition* 9 (2007): 79-87.

fa.1 is not the same color as the red pigment used for the flourishing of this particular initial and others in the *Confessio Amantis* portion of the manuscript. This particular comparison is discussed in greater detail below.

This essay concerns the next steps taken by the Yale team in the multi-spectral imaging of the Yale Gower and the general methodology under which the team is interpreting, presenting, and publishing this new stream of infomation. The Yale project, "Digitally Enabled Scholarship with Medieval Manuscripts," is being funded by the Andrew W. Mellon Foundation and is a collaborative initiative between Yale medievalists, Yale computer scientists, and colleagues in the Stanford University Library. Alastair Minnis and Shailor are the primary investigators (PIs) on the portion of the grant that involves multi-spectral analysis of the Yale Gower manuscript. Through 2014 Minnis and Shailor have been assisted by Eric Weiskott, now a faculty member at Boston College. For support on the computational aspects of the project, Holly Rushmeier, Chair of Yale's Department of Computer Science, has been extraordinarily innovative in her scientific approaches to the problems, together with several of her post-doctoral students who worked on the multi-spectral imaging protocols and the creation of a database of multi-spectral information. The central aim of this essay is to demonstrate how multi-spectral imaging opens up a new category of evidence about some of the workshop practices instrumental in the creation of the Middle English literary canon. Multi-spectral imaging can provide some answers but also raises additional questions for scholars to consider.

It is well to begin with a brief introduction to the methodology of the imaging and how one comes to state that two red pigments are different colors based on the evidence of the imaging, and not only on the ocular assessment that the two reds "look different" or "look similar." We used a specially constructed camera equipped with eight filters (**Figs. 3 and 4**). The set-up is portable and was shipped and carted by van in two trunks, thus far to the West Campus at Yale, the Huntington Library (San Marino, CA), the Oxford Bodleian Library and Oxford Corpus Christi College, Cambridge University Library and Cambridge Trinity College, and the National Library of Wales (Aberystwyth). In terms of the physical research procedure, all of the testing is non-invasive. There is no scraping or trimming of parchment necessary, but there is a conservation limitation in that a manuscript must be able to be opened sufficiently wide to photograph the selected leaves. The computer scientists generated a sequence of images with numerical equivalences for each of the colors in the inks and pigments in the manuscript (**Fig. 5**),

ranging from ultra-violet to infra-red. (The color bar chart in **Figure 5** is read from left to right and the numerical equivalences for each bar in the left column from top to bottom.) The methodology allows this fine-grained analysis to go pixel by pixel across the entire leaf. **Figure 5** shows the equivalences for one segment of the orange pigment appearing in the illuminated intial *W* on f. 1r in Huntington Library MS El 26.C.9 ('Ellesmere' Chaucer). Because the computer-generated data give the precise pixel location, it is possible to search an image pixel by pixel when this seems desirable. The pixel location is represented by the *x* and *y* notation toward the top of **Figure 5**.

To date the Mellon-funded Yale project has imaged fifteen manuscripts and fragments, concentrating on English manuscripts ranging across the period ca. 1385-1425.[3] The manuscripts were imaged either in their entirety, as in the case of the Yale Gower, or in part, as in the case of the Ellesmere Chaucer. The Yale team has imaged multi-spectrally a total of almost 1400 folios. The numerous directors, curators, and conservators of the respective rare book libraries were indispensible to the success of the venture. Since it was not possible to image all manuscripts completely, it was necessary to decide both which manuscripts and which key leaves of the manuscripts might be of interest. To this end, Minnis considered the recommendations of an Advisory Board composed of leading paleographical and literary scholars of late medieval English literature. For example, in the case of the Ellesmere Chaucer, where imaging was restricted by the Huntington Library to fewer than forty leaves, Kathleen Scott and Shailor, together with input from the scholarly work and advice of Estelle Stubbs and a close inspection of the manuscript in person, selected which leaves might be of most value to the project. On the advice of Ralph Hanna, Scott and Shailor were also cognizant of including images of so-called minor decoration – features such as paraph marks and flourished initials. These features, and the results of multi-spectral imaging of them, will form a primary focus of the following discussion.

The information obtained from multi-spectral imaging of these manuscripts is presently being processed by the Yale team and will be made available in an interoperable framework. That is, it will be possible for scholars to digitally juxtapose images from the same manuscript or different manuscripts, ideally both within the Yale project and across similar digital projects at

[3] MSS imaged thus far in whole or in part are: National Library of Wales 'Merthyr' fragment and MSS Peniarth 392D ('Hengwrt') and Peniarth 393D; Cambridge University, Trinity College, MSS B.15.17 and R.3.2 ('Trinity Gower'); Cambridge University Library, MSS Dd.4.24 and Kk.1.3; Yale, Beinecke Library, MS Osborn fa.1; Oxford, Bodleian Library, MSS Bodley 294, 758, 861, and 902 and Laud. Lat. 4; Oxford, Corpus Christi College, MS 198; and Huntington Library MS El 26.C.9 ('Ellesmere').

other institutions, in order to look at the results of multi-spectral imaging comparatively. The metadata (as in bar charts and the numerical equivalences) will be linked to the digital images for manuscripts within the Yale project. Eventually, it will be possible for members of the Advisory Board to the project and all other scholars to gain access to this metadata and also to annotate the images with comments and observations. The Yale computer scientists are working to create a manual that will explain the use of the software called Hyper3D that has been developed to analyze the metadata.[4]

The remainder of this essay will discuss what has been revealed thus far in the various manuscripts imaged by the Yale team. In order to suggest how this data can be useful to scholars, the following exposition focuses on comparisons of inks and pigments within the Yale Gower, followed by a sampling of comparisons with the inks and pigments in different parts of the complex Trinity College Cambridge MS R.3.2 ('Trinity Gower'). It is worth emphasizing at the outset that multi-spectral imaging does not determine the composition of the inks or pigments but rather whether they are similar or different in their spectral reflectance values. 'Spectral reflectance value' is simply a numerical expression of color (in this case, the coordinates and chromatic value of a pixel in a digital image).

Figure 6 represents a comparison of the blue pigment of the flourished initial on folio 1r of the Yale Gower to the blue of the 1-line initial on f. 13r. It is important to note that we are in two different quires, yet the blue of these two initials is remarkably similar. Rushmeier and her team have marked the bar graph image in **Figure 6** and others appended to this essay for ease of exposition. Continuing the analysis of colored pigments in the Yale Gower, **Figure 7** compares two red inks from the concluding leaves of the manuscript, where the Anglo-French poetry was copied. What is remarkable in this portion of the codex is that the shade of the red used for the rubrication and the shade of red used for the flourishing do have the same spectral values. Here the shades of red both "look" similar, and they do test to be similar. This is in stark contrast to the results for red inks in the *Confessio amantis*, discussed above and presented in **Figure 2**.

A similar comparative methodology can be employed for the Trinity Gower, with its multiple scribes and potentially different inks and pigments. This codex has received much attention because of its structure and the interaction among the five copyists identified in a

[4] Min H. Kim, Holly Rushmeier, *et al.*, "Hyper3D: 3D Graphics Software for Examining Cultural Artifacts," *ACM Journal on Computing and Cultural Heritage* 7 (2014)

landmark article by Ian Doyle and Malcolm Parkes.[5] First the Yale team made comparisons among some of the segments within the Trinity Gower, then cross-referenced these with the results from the Yale Gower. **Figures 8, 9,** and **10** show ff. 6r, 10r, and 53r, respectively attributed to Scribes A, B, and A. **Figure 11** shows f. 7v of the Yale Gower. In each case the spectrographic analysis highlights the pigments of the body of the initials and the accompanying tracery, and in each case the Yale team was following up on the suggestions of Simon Horobin and Dan Wakelin about certain aspects of the Trinity Gower codex that intrigued them. Wakelin had raised questions about the shades of blues and reds in these initials for folios 6r, 10r, and 53r, since these leaves are acknowledged to be the work of two different scribes. And it seemed important then to include a comparable image from the Yale Gower to see what might be discovered on that basis.

While it is not possible to illustrate in a short space a complete range of possible comparisons, it may still be useful to offer examples of the types of comparisons that it will be possible for scholars to make. **Figure 12** shows that the red in one-line flourished initials and the red in the flourishing of the 3-line blue initial are remarkably the same, and this is true for these particular bits in the work of both Scribes A and B in the Trinity Gower. **Figure 13** shows that the tracery around the 1-line red initials (whatever color descriptor is used to describe this greyish shade) is the same in the work of Scribes A and B on these leaves. **Figure 14** shows that the red in the flourishing of these blue initials in the work of Scribe A and B and the shade of the red flourishing in the *Confessio Amantis* portion of the Yale Gower are remarkably alike. This last comparison is especially exciting and promising, as it connects pigments across manuscripts of Gower's poetry.

Figure 15, by contrast, which compares the blue of the body of the 3-line initials, shows some similarity and some difference. The reds on these folios are similar, as just discussed, but the blue on f. 53r (in a part by Scribe A) is slightly different from that in ff. 6r and 10r, the works of Scribes A and B. What is more striking is the difference in spectral values registered by the Yale Gower. This comparison of images raises a number of questions, such as, Why is the blue on f. 53r different in this section of the Trinity Gower, and What is the significance of the difference registered in the blue in the Yale Gower? Once the database of multi-spectral

[5] A. I. Doyle and M. B. Parkes, "The Production of Copies of the *Canterbury Tales* and the *Confessio Amantis* in the Early Fifteenth Century," in *Medieval Scribes, Manuscripts & Libraries: Essays Presented to N. R. Ker*, ed. Parkes and Andrew G. Watson (London: Scolar, 1978), pp. 163-210

information hosted at Yale is fully established for all the manuscripts that have been imaged, it will become possible to search across it to find every instance of similarities of blues and reds, to say nothing of orange, rose, green, *etc*. A more general methodological question that must also be asked at that point is, What is the range within each spectral band that will constitute a reasonable similarity or an acceptable difference? The bar graph for f. 53r in **Figure 15** would make an interesting test case. Once again, it is not yet possible to determine the make-up of the pigments with this kind of imaging, and certainly one might consider that the proportions of and/or the different elements in the mixing of pigments would be one source of difference.

In particular cases thus far, the "differences" registered in the bar graphs were significant enough to establish definitive degrees of difference. The same is true of the lovely flourishing of two gold initials in the Trinity Gower (**Fig. 16**). The comparison of this greyish or bluish or silvery flourishing reveals two distinctive differences that have been circled on the bar graph in **Figure 16**. The first initial is in the first quire by Scribe A, and the second initial is in the work of Scribe B. Visual inspection by Shailor of the flourishing in the various segments of this manuscript did suggest that a range of shades were used for flourishing the gold initials. Moving this line of inquiry further along, we would propose that scholars would also want to consider the patterns of the designs and how one might correlate patterns, colors, and thus work stints by different artists of the minor decoration. And then one might pursue how all of the patterns and colors correlate with the stints of the five scribes.

To conclude the discussion of color pigments, consider **Figure 17**, which compares four different flourished paraph marks, from different parts of the Ellesmere Chaucer. When Scott and Shailor looked at this phenomenal production and compared the codex with the facsmile reproduction, while also reviewing the descriptions of the colors found in the work of various scholars, they noted that people saw colors and shades of colors quite differently. Moreover, the shades that were supposed to be re-created in the facsmile appeared to Scott and Shailor woefully inadequate for a sophisticated understanding of the production of the manuscript. To take one example of the issue of pigment nomenclature: What are the various shades that are represented in the four paraph marks in **Figure 17**? The expectation of the Yale team is that we will be able to devise charts that bring together the numerical equivalences of colors with descriptive terms such as lavendar, purple, blue, grey, *etc*., so that the issue of nomenclature might become clearer and more precise.

Finally, the methodology of multi-spectral imaging allows comparisons of black and brown inks as well as colored inks. **Figures 18, 19,** and **20** offer the opportunity to ask (and potentially answer) three questions about shades of ink in the Trinity Gower. Many more questions are possible, but further comparisons fall beyond the scope of this short essay. Is the ink similar on f. 3r (Scribe A) and f. 9r (Scribe B)? Yes, this is likely according to the bar graphs in **Figure 18**. On f. 34v, is the small module of script for the marginal annotation written in an ink similar to that used for the text? This is in a quire copied by Scribe C. The inks also appear to be the same, according to the comparison in **Figure 19**. But on f. 37v (**Fig. 20**), in comparing the ink in the small module of script used for annotation in the lower margin to that used for the text, there is a small degree of difference that suggests that the text and annotation might not have been written at the time with the same batch of ink. The difference in spectral value, centered in the red spectrum, is circled on the bar graph in **Figure 20**.

The foregoing discussion represents a very small fraction of the possibilities for making comparisons with the existing database of multi-spectral images. Looking toward the future, the Yale team anticipates that a database with searchable metadata will allow comparison across multiple manuscripts of the texts of Gower beyond Yale and Trinity College (and expanding also to early manuscripts of Chaucer). Finally, once the methodology has been honed on London manuscripts of Chaucer, Gower, and Langland, it will become possible to ask the same questions of manuscripts thought to be copied and decorated outside of London.