Winterthur/University of Delaware Program in Art Conservation

On The Light Stability of Robert Rauschenberg's *Cardbird I-VII* Series

Daisy Diamond[1], Rosie Grayburn, Ph.D.[2], and Jeffrey Warda[3]
ARTC-673 Research Report, May 2025

Abstract: In 1971, Robert Rauschenberg created a series of seven prints, each in an edition of 75, titled *Cardbird I–VII*, in collaboration with the innovative printmaking studio, Gemini G.E.L.. The series transforms found cardboard with printed imagery into richly layered multiples. Concerns have emerged over the light sensitivity of the offset lithograph inks used for the printed imagery of the cardboard surface, prompting this study to investigate the material composition and extent of color shifts. Material characterization included the following: fillers in the paper were further identified with X-ray fluorescence (XRF) spectroscopy and Raman spectroscopy, potential CMYK synthetic organic pigments were investigated in this series for the first time with Raman spectroscopy and fiber optic reflectance spectroscopy (FORS), and two distinct coatings were identified with reflectance Fourier transform infrared spectroscopy (r-FTIR). The color shift is confirmed to be light-induced, with the most sensitive color–the magenta component of the CMYK offset lithograph– corresponding to a Blue Wool (BW) 1-2 in both actual before/after exhibition color measurements and accelerated aging tests with microfade testing (MFT). These findings expand on existing insights into Rauschenberg's collaborative material practices and provide critical information for developing effective preservation strategies for this innovative series.

Keywords: Robert Rauschenberg, photo-offset lithograph, X-ray fluorescence spectroscopy, Raman spectroscopy, fiber optic reflectance spectroscopy, reflectance-Fourier transform infrared spectroscopy, ultraviolet fluorescence imaging, spectrophotometry, microfade testing

1. INTRODUCTION

Robert Rauschenberg (1925–2008) embraced collaborative and experimental approaches, transforming printmaking, photography, drawing, sculpture, and performance into cross-disciplinary practices that blurred the boundaries between art and life. In 1970, Rauschenberg moved to Captiva Island off the Gulf Coast of Florida and became increasingly drawn to the aesthetics as well as conceptual possibilities of found materials, including cardboard (Bois and Elliott 2007, 10-11). It was during this period in 1971 that Rauschenberg created a series of seven prints, each in an edition of 75, titled *Cardbird I-VII*, in collaboration with the printmaking studio founded by Kenneth Tyler, Gemini G.E.L. in Los Angeles (fig. 1). In this series, Rauschenberg transformed found cardboard boxes from impermanent and ubiquitous materials into objects of meaning and beauty. He engaged with the waste and softness of cardboard to challenge materialism and disposability under capitalism (Bois and Elliot 2007, 10-12; Blaut 1997; Hunter and Rauschenberg 2006, 67; Rosenthal 1993, 10; Tomkins 1980, 295).[4]

---

[1] Graduate Fellow, Winterthur/University of Delaware Program in Art Conservation (WUDPAC); 2024-2025 Research Fellow, Robert Rauschenberg Foundation (RRF)/Voices in Contemporary Art (VoCA)/WUDPAC.
[2] Scientist and WUDPAC Affiliated Associate Professor, Winterthur Museum, Garden & Library.
[3] Senior Conservator, Paper and Photographs, Solomon R. Guggenheim Museum; Conservation Research Mentor, VoCA.
[4] Rauschenberg also used cardboard in artwork series including his *Cardboards* (1971-1972), *Venetians* (1971-1973), and *Early Egyptians* (1973-1974) wall reliefs and sculptural works (Robert Rauschenberg Foundation).

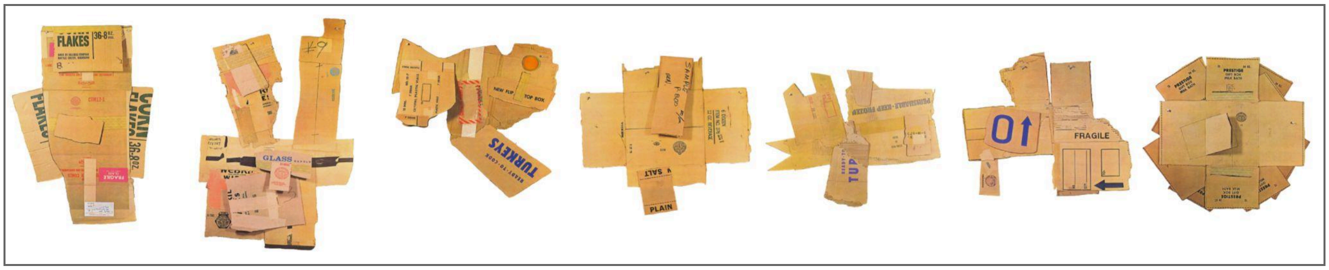


Figure 1. *Cardbird I-VII*. Images source: Gemini G.E.L. 1971.

The predominant visual imagery of the *Cardbird* series are photo-offset lithographs printed on paper.[5] Each crease, fold, and label present in the original found material was meticulously reproduced, achieving a trompe l'oeil effect. These prints are attached with an unknown adhesive to a double-wall corrugated cardboard with various screen-printed and rubber-stamped additions and attachments (refer to "Appendix I: Attached Elements and Fabrication Notes" for additional information). A clear material that resembles an acrylic gel medium coats the recto (Gemini G.E.L. 1971; Gemini G.E.L. Online Catalogue Raisonné).

It has previously been observed and noted by conservators and the Robert Rauschenberg Foundation that the lithographic printing found in the *Cardbird* series can shift from light brown to blue-gray (refer to "Appendix II. *Cardbird* Series Color Shift" for additional information). This change is suspected to be accelerated by exposure to UV and high light levels, typically found in non-museum display settings. This shift in color becomes increasingly more noticeable as elements of the *Cardbirds* gradually look less like cardboard and stand out against the actual cardboard component used. The inks used for the screen-printing and rubber stamps are understood to be more light-stable as they do not exhibit the same level of color shift. Currently, the Foundation is unable to answer specific questions from collectors and institutions regarding the light-stability of the *Cardbird* works. The goal of this research is to clarify at what rate, to what extent, and why the colorants of the lithographic-printed facsimile components change when exposed to light. Additionally, this comprehensive study will investigate whether the color changes correlate within the series and across impressions within the edition.[6]

2. METHODOLOGY

To measure the rate and extent of color changes, the following analytical techniques were performed: stereomicroscopy, digital microscopy, Raman spectroscopy, fiber optic reflectance spectroscopy (FORS), reflectance-Fourier transform infrared (r-FTIR) spectroscopy, ultraviolet fluorescence (UVF) imaging, x-ray fluorescence (XRF) spectroscopy, spectrophotometry, and microfade testing (MFT) (table 1). All analytical techniques were operated under standard conditions with the guidance of conservators and conservation scientists. Refer to "Appendix III. Methodology" for additional information, including the instruments, software, specifications, and contributors.

[5] Archival records indicate these prints were composed of five-color photo-offset lithographs, but examination with a stereomicroscope revealed only four colors in the halftone rosettes: cyan, magenta, yellow, and black also known as 'key," as is consistent with the CMYK color printing model (Gemini G.E.L. Online Catalogue Raisonné, Bruno, Romano, and Riordan 1974; 92).

[6] This research was conducted as the seventh installment of the collaborative partnership between RRF, VoCA, and WUDPAC. This partnership provides a unique educational model for contemporary art conservation, while addressing the specific needs of an artist's endowed foundation. Through the technical study of selected works, Research Fellows develop conservation guidance to support the long-term care of Rauschenberg's work (Robert Rauschenberg Foundation).

Table 1. Methodology overview, including object information.

Analytical technique	Purpose	*Cardbird*[7] works analyzed	Data[8]
X-ray fluorescence (XRF) spectroscopy	**Paper, printing ink, and coating characterization**: Identify additives in the paper and coating	*Cardbird IV* (72.1994.4)	Appendix IV: X-ray Fluorescence (XRF) Spectroscopy
Raman spectroscopy	**Printing ink characterization**: Investigate ink chemical composition and potential pigments and/or dyes.	*Cardbird I* (71.E004.AP1), *Cardbird IV* (71.E007.AP1)	Appendix V: Raman Spectroscopy
Fiber optic reflectance spectroscopy (FORS)	**Printing ink characterization**: Investigate ink classes more broadly.	*Cardbird I* (71.E004.AP1, 71.E004.AP3), *Cardbird IV* (71.E007.AP1)	Appendix VI. Fiber Optic Reflectance Spectroscopy (FORS)
Stereomicroscopy, digital microscopy	**Printing ink characterization**: Visually investigate printing inks.	*Cardbird I* (71.E004.AP3), *Cardbird II* (71.E005.AP3), *Cardbird IV* (71.E007.AP1)	N/A
Reflectance-Fourier transform infrared (r-FTIR) spectroscopy	**Coating characterization**: Evaluate coating composition and extent of UV protection.	*Cardbird I* (71.E004.AP1, 71.E004.AP2, 71.E004.AP3)	Appendix VII: Reflectance-Fourier Transform Infrared (r-FTIR) spectroscopy
Ultraviolet fluorescence (UVF) imaging	**Coating characterization**: Evaluate potential distribution and variance of the coating.	*Cardbird I* (71.E004.AP1, 71.E004.AP2, 71.E004.AP3)	Appendix VIII: Ultraviolet Fluorescence (UVF) Imaging
Spectrophotometry	**Printing ink light sensitivity**: Determine real-time color-change behavior before and after exhibition.	*Cardbird II* (71.E005.AP3, 72.1994.2), *Cardbird IV* (72.1994.4)	Appendix IX: Spectrophotometry
Microfade testing (MFT)	**Printing ink light sensitivity**: Determine relative light sensitivity of *Cardbird* printing inks.	*Cardbird I* (71.E004.AP1, 71.E004.AP2, and 71.E004.AP3), *Cardbird II* (71.E005.AP3^), *Cardbird III* (71.E006.AP1), *Cardbird IV* (71.E007.AP1), *Cardbird V* (71.E008.AP1), *Cardbird VI* (71.E009.AP1), and *Cardbird VII* (71.E010.AP1, 71.E010.AP2, and 71.E010.AP3)	Appendix X: Microfade Testing (MFT)

[7] 71.E00#.AP# indicates works from the RRF collection, 72.1994.# indicates works from the Solomon R. Guggenheim Museum collection. ^ indicates works with recorded exhibition history. It is possible that works with no specific recorded exhibition history may have had periods of display that were not recorded.
[8] Analysis locations, figures, tables, and references.

The investigation included comparisons of examples of each of the seven *Cardbird* works (*Cardbird I-VII*), with two additional *Cardbird I* impressions and two additional *Cardbird II* impressions, for a total of 11 works from the RRF collection. In addition, *Cardbird II* and *Cardbird IV* were selected for analysis from the Solomon R. Guggenheim Museum collection. These works were selected in order to compare material composition and light sensitivity within each edition and across impressions; as well as compare color shifts measured with accelerated aging tests to those initiated by exhibition conditions. Specific *Cardbird* works and analysis sites were collaboratively selected.

3. RESULTS AND DISCUSSION

3.1 Paper Characterization: XRF and Raman spectroscopy

The paper was further characterized with XRF and Raman spectroscopy (figs. IV-1, IV-2, V-1, V-2). With XRF, calcium, titanium, aluminum, and silicon were all detected in the paper substrate, likely as fillers typically found with coated papers (Banik and Bruckle 2011; Klein and Parraman 2014). The Raman shift at 142 cm^{-1} is seen in all Raman spectra. The identification is uncertain. This shift is possibly due to anatase; however, the primary anatase peaks are not detected. It is possible they may be buried by the fluorescence of the binding media and substrate.

3.2 Printing Ink Characterization: Raman Spectroscopy, FORS, and XRF

Standard CMYK printing models of the 1970s may have included Pigment Blue 15:3 or 15:4; Pigment Red 57:1, 184, or 185; and Pigment Yellow 13, 126, or 127 (Herbst and Hunger 2004, 147; Hutchinson 1999, 234; Kipphan 2001, 131 and 137). Raman spectroscopy, FORS, and XRF were used to confirm some overlap with these standard models, as well as overlap with more broad descriptions of colorants used for printing inks (table 2; figs. V-1, V-3 through V-5, VI-1 through VI-3) (Leach and Pierce 2007). The CMYK printing model for the *Cardbird* series may also contain mixtures of proposed and/or unknown colorants for each printing ink. The primary Raman shifts[9] produced from spot 1, 2, and 6 on *Cardbird I* (1529, 1341, and 1451 cm^{-1}) most closely match the copper phthalocyanine pigments, otherwise known as Pigment Blue 15 (P.B.15:1, P.B.15:2, P.B.15:3, P.B.15:4). P.B.15:1 and P.B.15:4 may be closer matches. Specific peak identification is difficult due to resolution of spectra collected with a portable instrument. Collected spectra do have some peaks that overlap with additional red, orange, and yellow synthetic organic pigments, in order of likelihood: P.R.4 (1341 and 1592 cm^{-1} peaks), P.R.224 (1594 cm^{-1} peak), P.Y.12 (1594 cm^{-1} peak), P.O. 34 (1594 cm^{-1} peak), P.R.208 (1594 cm^{-1} peak). However, the signal is not strong enough for conclusive identification. No black colorants were able to be identified. Due to the limitations of reference libraries for synthetic organic colorants, FORS spectra provided inconclusive information. In the visible range, FORS spectra emit a sharp reflectance at approximately 570 nm with a peak at approximately 585 nm. There is a lower reflectance peak at approximately 755 nm, and even lower reflectance peaks at around 490 and 540 nm. The CMYK colorants detected within the FORS instrument's spot size of at least 3mm result in spectral mixing, which can introduce a non-linear reflectance response. Additionally, sulfur-containing printing ink additives, such as sulfonated emulsifiers, dispersants, and/or driers, may be the source of the sulfur peak detected with XRF (Leach and Pierce 1993, 447; Apps 1958, 111).

[9] Although the analysis locations are predominantly red, the halftone rosette still retains a blue component, which exhibits significant Raman activity.

Table 2. Overview of possible printing ink characterization.

CMYK	Pigment	Pigment class	Context	Lightfastness[10]
Cyan[11]	Pigment Blue 15:1 (P.B.15:1)	α-modification of Copper Phthalocyanine Blue[12]	Possibly too red for four color printing (Herbst and Hunger 2004, 436-448).	BW 7-8 (Herbst and Hunger 2004, 443).
	Pigment Blue 15:4 (P.B.15:4)	β-modification of Copper Phthalocyanine Blue	Superior rheology, used in many printing methods (Herbst and Hunger 2004, 436-448).	N/A
Magenta[13, 14]	Pigment Red 4 (P.R.4)	β-naphthol chlorinated "Para Red"	Used in offset lithography (Herbst and Hunger 2004, 275-278).	Not commonly used commercially. Addition of TiO_2 reduces lightfastness considerably. BW 3-4 (Herbst and Hunger 2004, 278-279). Degrades and discolors in UV (Heaney, Unruh, and Rünčevski 2022, 5172).
	Pigment Red 224 (P.R.224)	Perylene tetracarboxylic dianhydride	Not common in offset lithography (Herbst and Hunger 2004, 482).	N/A
	Pigment Orange 34 (P.O.34)	Disazo Pyrazolone	Not common in offset lithography (Herbst and Hunger 2004, 267).	BW 4 (Herbst and Hunger 2004, 267).
	Pigment Red 208 (P.R.208)	Benzimidazolone	Used in many printing methods (Herbst and Hunger 2004, 365).	Noted to be very lightfast in print (Herbst and Hunger 2004, 365).
Yellow[15]	Pigment Yellow 12 (P.Y.12)	Diarylide Yellow	Used in offset lithography (Herbst and Hunger 2004, 244.	BW 2-3 (Herbst and Hunger 2004, 244).

[10] Modern reference information may not correspond to lightfastness information for prints made in the early 1970s. CMYK inks may combine colorants.
[11] The following colorants were eliminated as possible cyan candidates based on Raman Spectroscopy: P.B.13, P.B.16, P.B.36, P.B.75, and P.B.79.
[12] Copper was not detected with XRF, which would generally be expected for P.B.15:1 and P.B.15:4. This may be due to the challenges posed by the low pigment loading in the halftone distribution at the analysis locations, or it could reflect the use of a less common alternative phthalocyanine pigment, as over 40 metal-free or non-copper metal-complex variations have historically been used (Herbst and Hunger 2004, 436-448).
[13] The following were eliminated as possible magenta candidates based on Raman spectroscopy and FORS: P.R.2, P.R.8, P.R.12, P.R.48:3, P.R.49, P.R.53:1, P.R.81, P.R.88, P.R.122, P.R.144, P.R.170, P.R.176, P.R.184, P.R.185, P.R.210, and P.O. 36.
[14] Identification of the magenta printing colorant is less certain than that of the cyan printing ink, due to its weaker Raman spectral character.
[15] The following were eliminated as possible candidates based on Raman Spectroscopy: P.Y. 13, P.Y.17, P.Y. 83, and P.Y. 120.

3.3 Coating Characterization: r-FTIR, UVF, XRF

r-FTIR was performed to further investigate the coating on three impressions of *Cardbird I* (figs. VII-1 through 4, VIII-1, VIII-2). Results suggest that at least two synthetic acrylic coatings were applied to the series in variable locations, which will be referred to as "Coating A" and "Coating B." The offset lithograph background was coated with Coating A for AP1 and Coating B for AP2 and AP3. The screenprinted cardboard flap was coated with Coating A for all three editions of *Cardbird I*. Coating A has less spectral character than Coating B in the 1200-400 cm^{-1} range. Features around 3000 cm^{-1} can be attributed to C-H stretching bands, 1800 cm^{-1} can be attributed to C=O stretching backs, 1400 cm^{-1} can be attributed to C-H bending bands, and 1300-900 cm^{-1} can be attributed to C-O stretching bands (Derrick, Stulik, and Landry 1999, 191-192). Variations in spectra from expected characteristic IR absorption bands can be attributed to the collection and transformation methods performed in this study.[16] The r-FTIR spectra confirm this coating is a synthetic resin, with similar character to spectra of PVA, acrylic polymer emulsions, and Paraloid B-72. The sample locations have more similar chemical stretches to the acrylic polymer emulsion than the PVA and Paraloid B-72 reference spectra. Although there is slight variation in fluorescence behavior between the three impressions of *Cardbird I* when investigated with a UV flashlight, the two acrylic coatings are not distinguishable with ultraviolet fluorescence imaging (UVF). The coating was possibly further characterized with X-ray fluorescence (XRF) spectroscopy: detected sulfur may potentially be due to an additive present in the coating, such as surfactants and/or dispersants with sulfonated compounds (Schwartz, Perry, and Berch 1958, 891; Raffa et al. 2015, 8512).

3.4 Photostability: Spectrophotometry and Microfade Testing

The lightfastness of the offset lithograph printing inks is primarily determined by the specific photostability of pigments (refer to "table 2" final column); however, this parameter is a systems-related characteristic which cannot be determined solely in connection to pure pigments or generalized measurements. The pigment-vehicle system will also have an impact of photostability, depending upon the chemical nature of the surrounding vehicle, pigment volume concentration, layer thickness, additives, and substrate (Herbst and Hunger 2004, 87, 91). Spectrophotometry measurements were collected to determine real-time color-change behavior before and after exhibition, and MFT measurements were collected to determine the approximated light sensitivity of *Cardbird* printing inks (Beltran 2018).

Color measurements at six locations on the photo-offset lithograph of *Cardbird II*, from the Solomon R. Guggenheim Museum collection, were collected before and after five months of exhibition in 2024, during which the work was exposed to approximately 115,000 lux-hours (10,700 footcandles) (figs. IX-1 through 3; Table IX-1 through 3). After five months of exhibition, the ΔE*00 ranged from 0.21-0.47. This indicates a color shift occurred that would not be perceivable to the human eye. All locations became lighter (ΔL*); the mid-tones shifted greener (Δa*), bluer (Δb*), and duller (Δc*); and the black tones shifted redder (Δa*), yellower (Δb*), and brighter (Δc*) in the opposite direction (fig. 2). A collaged component of *Cardbird IV* with a hinged attachment allowed for direct comparison between a region exposed to light and a region protected from light, with identical manufacturing and environmental conditions aside from light exposure. This work has a known exhibition history of approximately 118,000 lux hours. The ΔE between these locations was 7.73, indicating a significant color shift

[16] While the findings represent a significant advancement in understanding the material behavior of the *Cardbird* series, certain conclusions, particularly regarding the coating materials, remain less definitive. This reflects broader limitations of the study, including a constrained analysis time frame, reliance on portable instrumentation, and the application of methods that, while informative, are not ideally suited to fully characterize all components.

that would be extremely noticeable to the human eye (table IX-3, fig. IX-2, fig. IX-3). The ΔL* value indicated a shift of 1.06 (lighter), Δa* value indicated a shift of -5.90 (greener), Δb* value indicated a shift of 4.88 (bluer), and ΔC* value indicated a shift of -5.42 (duller). Print uniformity between two different locations will inherently cause different measured values with a spectrophotometer and can indicate a limitation to this type of comparison. Further, it is not known how other environmental or inherent material qualities may have had a role in the change observed. However, the measured difference indicates a high sensitivity to light exposure over time, given the relatively low cumulative light exposure.

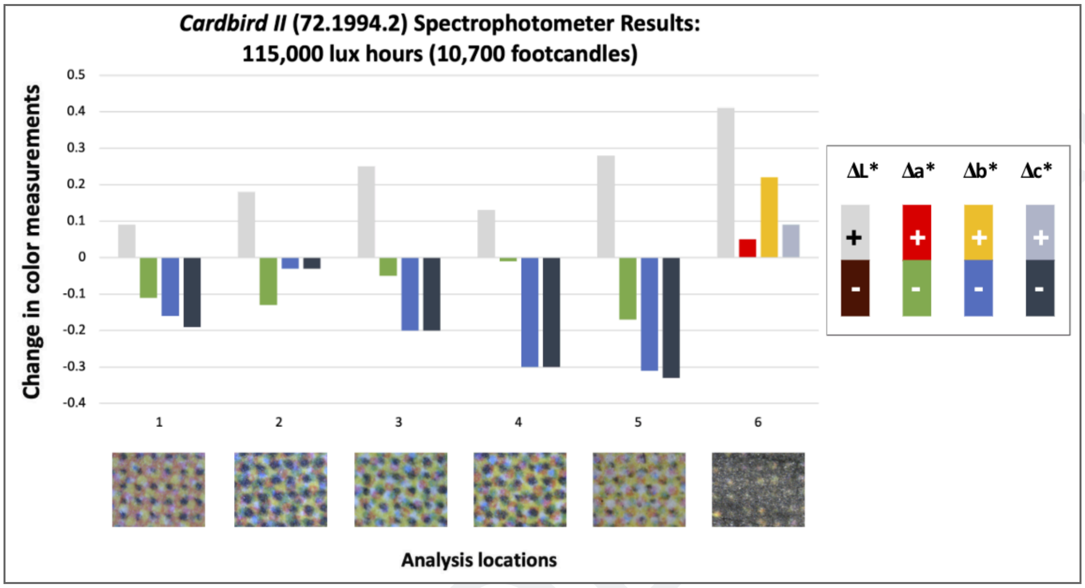


Figure 2. Results of *Cardbird II* (72.1994.2) spectrometric measurements. If a change in color measurements in > 1 or < -1, the change is considered perceivable to the human eye. Photomacrographs (2.76 × 1.55 mm field of view) depict analysis locations 1-6 on *Cardbird II* (71.E005.AP3).

With MFT, a total of 42 locations were tested across eleven impressions of *Cardbird I-VII* (2-7 locations per impression) for light sensitivity under controlled experimental exposure conditions (table X-1, figs. X-1 through X-22a). The offset lithograph printing inks experienced chroma loss at the red end of the spectrum, indicating that the magenta reacts more strongly with light than the yellow or cyan colorants. With MFT, the colors were shown to lighten in blue regions of the spectra, and darken in red regions (Hark 2025, 25-53).[17] Areas of the offset lithograph that are primarily red correspond in light sensitivity with a BW standard of approximately 1-2, closer to the BW1 range in the most sensitive areas (fig. 3). Areas of the offset lithograph with relatively evenly sized and spaced CMYK halftone rosettes, corresponding visually to standard cardboard, correlate in light sensitivity to a BW standard slightly below 2 (fig. 4-5) (Burge 2017, Hird 2000, 297). Variability was observed, with the three *Cardbird I* impressions experiencing a slightly higher average ΔE*ab (0.9) compared to the other objects. Although other components of the *Cardbird* series are light-sensitive, including the actual raw cardboard and black inks, the changes in the offset lithograph printed components have a greater impact on the overall visual interpretation of the series (fig. X-22a).

[17] "Due to extreme sensitivity, the [initial] test on the red area of *Cardbird IV* had to be stopped in under a minute. To allow further analysis, light intensity from the MFT setup was reduced from 600 to 150 mlm, and tests were repeated on BW 1, BW 2, and the red spot. Under reduced intensity, the rate of change decreased significantly, enabling an estimate that the red area's ΔE fell between BW 1 and BW 2. Subsequent testing at the standard 600 mlm again produced ΔE values of 1.2–1.3. The cause of the red area's initial extreme sensitivity remains unclear" (Hark 2025, 52).

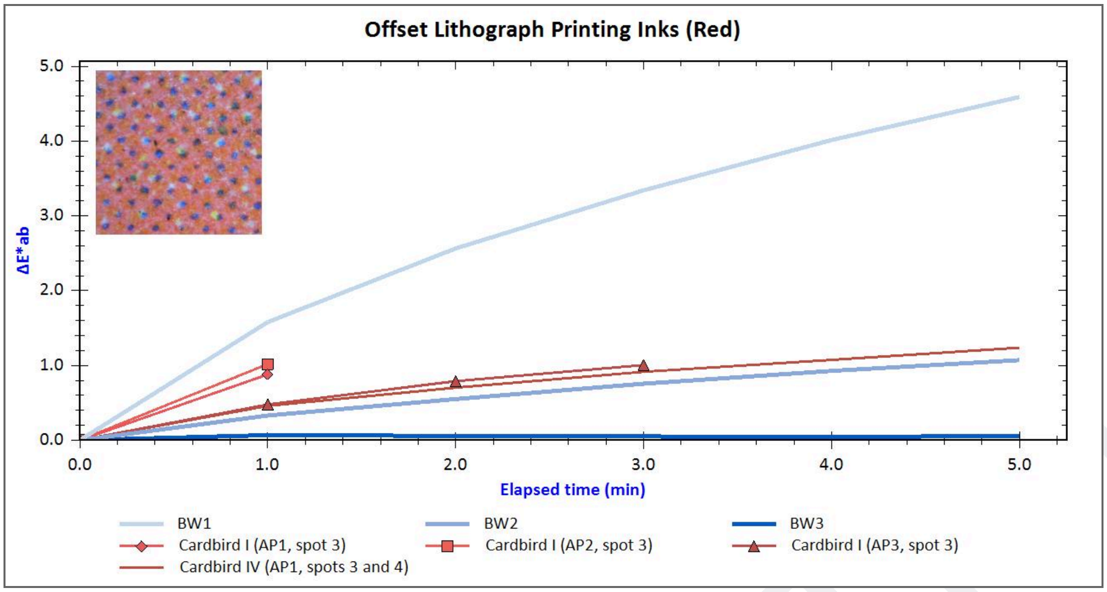


Figure 3. Comparison of MFT fading curves for four *Cardbird* works printed with primarily red offset lithograph printing ink (ΔE*ab).[18] A photomacrograph (2.76 × 1.55 mm field of view) is included as a representative CMYK distribution of these analysis locations (71.E004.AP3, spot 3).

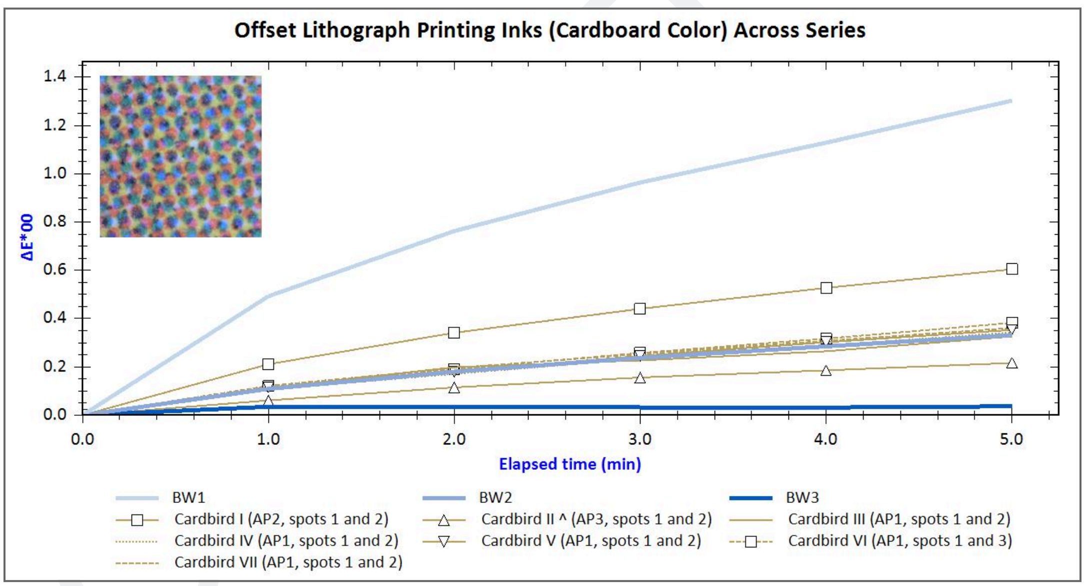


Figure 4. Comparison of MFT fading curves for seven *Cardbird* works across the series printed with more evenly distributed CMYK offset lithograph printing ink to imitate cardboard (ΔE*00). (^) indicates a work with a known exhibition history. A photomacrograph (2.76 × 1.55 mm field of view) is included as a representative CMYK distribution of these analysis locations (71.E007.AP1, spot 1). Curves for all spots besides *Cardbird I* and *Cardbird II* overlap significantly with the curve for BW2.

[18] The ΔE*ab metric was used as the on-site testing parameter, with testing terminated at ΔE*ab = 1. This is the only fading curve in the main report that plots ΔE*ab values on the y-axis; all other curves use ΔE*00, which applies corrections to the original CIELAB model. These include adjustments for chroma and hue differences, particularly in the blue region, improved accuracy in lightness (L*), and rescaled along the a* (red-green) axis to address nonuniformities in grey and neutral colors (Beltran et al. 2021, 21). Actual assessment of risk of fading is not impacted significantly by calculations. For reference, ΔE*00 curves for Figure 3 and ΔE*ab curves for Figure 4 and 5 are included in the appendix (figs. X-19 through X-21).

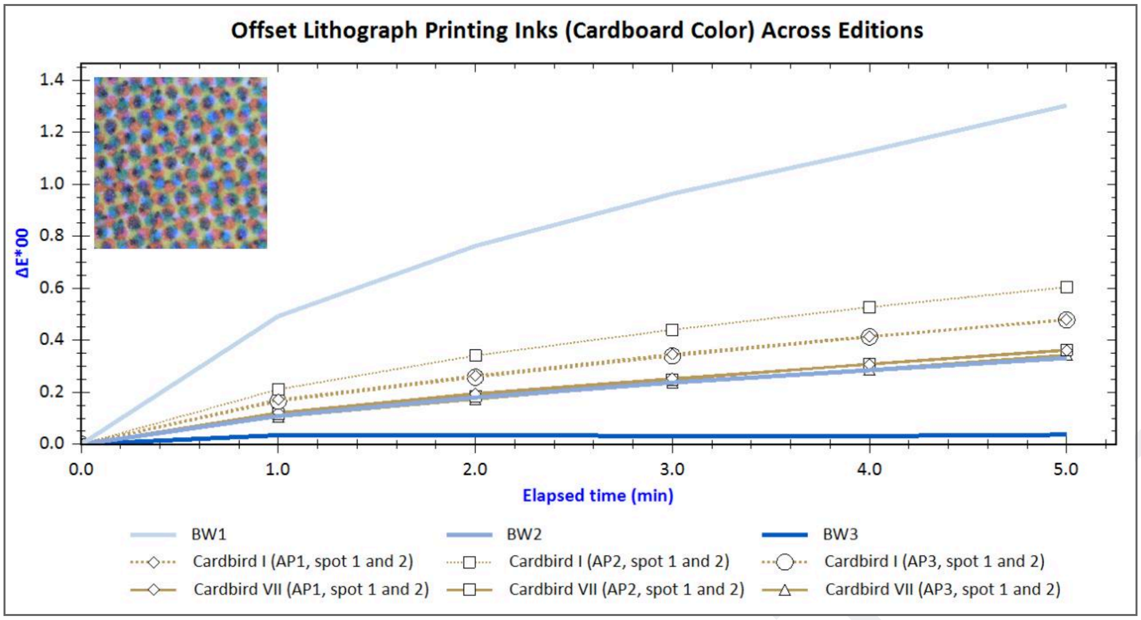


Figure 5. Comparison of MFT fading curves for two *Cardbird* works across three editions printed with more evenly distributed CMYK offset lithograph printing ink to imitate cardboard (ΔE*00). (^) indicates a work with a known exhibition history. A photomacrograph (2.76 × 1.55 mm field of view) is included as a representative CMYK distribution of these analysis locations (71.E007.AP1, spot 1). Curves for all *Cardbird VII* overlap significantly with BW2.

Although MFT showed lightening in blue regions and darkening in red regions of the spectra, spectrophotometric measurements before and after exhibition showed overall lightening (+ΔL*) and decrease in saturation/vividness (-Δc*), except for primarily black areas which showed an increase in saturation/vividness (+Δc*). Spectrophotometric measurements indicated there was slight variance in the extent of color changes that occurred depending upon analysis location, as confirmed by MFT predictions. In the absence of UV exposure, spectrophotometric measurements of color change in these areas aligned with Blue Wool (BW) standards 1–2,[19] consistent with MFT predictions. This confirms that, under controlled lighting conditions, these works can be safely exhibited while maintaining color change within ΔE < 1–1.6—the threshold for a just noticeable difference (Light Damage Calculator). Therefore, reciprocity does hold.[20] Based on relatively more stable fading curves collected with MFT on the only work with known exhibition history (fig. 4, *Cardbird II* AP3), initial exhibition likely causes the most dramatic fading rates. Color shifts are typically dramatic with early exposure and continue steadily at a slower rate.

3.5 Further Research

Further research into the photostability of the *Cardbird* series colorants could include investigation of the impact of UV in isolation or in combination with visible light with MFT, which would be of particular interest to private

[19] Theoretical calculation of BW fading rates after ~115,000 lux hours (50 lux, 8 hours/day, 0.79 years): BW1 ΔE ≈ 0.6, BW 3 ΔE ≈ 0.15, BW 3 ΔE ≈ 0.06 (Light Damage Calculator).

[20] The reciprocity principle states that the net exposure causing photochemical damage is represented by the product of the intensity of the illumination times the time, other factors being negligible. If the reciprocity principle holds, 100 lux of intensity x 1 hour causes the same amount of change as 1 lux of the same radiation x 100 hours (Feller 1994, 54).

collectors or other exhibition environments where UV radiation is not eliminated from light sources. Additionally, investigating the impact of relative humidity, temperature, or pollutants could corroborate the primary significance of light exposure while adding nuance to combined impact of environmental conditions. Clarifying the offset lithograph printing ink colorants in the *Cardbird* series would be furthered by conducting additional Raman spectroscopy and FORS to achieve a higher signal in addition to conducting data comparison with an expanded reference library. Comparison to references of the following synthetic organic pigments are of particular interest: pigment reds (P.R.3, P.R.9, P.R.101, P.R.102, P.R.112, P.R.149, P.R.153, P.R.155, P.R.157, P.R.163, P.R.164, P.R.165, P.R.166, P.R.167, P.R.169, P.R.327); potential extenders pigment whites (P.W.18 and P.W.24); and potential filler pigment white 6 (P.W.6) (Leach and Pierce 2007). Quantification of color mixtures in MFT analysis location photomicrographs using a processing program like ImageJ could enable more precise insights into the relative stability of individual CMYK colorants.

4. CONCLUSION

The composition of the offset lithographic printing inks used in the *Cardbird* series, as well as their resulting color shifts from light brown to blue-gray, can now be described in greater detail and more confidently attributed to light exposure. The materials were characterized more specifically. The paper contains calcium, titanium, aluminum, and silicon (detected with XRF), likely as fillers, and the titanium may be connected to anatase more specifically (detected with Raman). The CMYK colorants may include P.B.15:1, P.B.15:4; P.R.4, P.R.53:1, P.R.208, P.R.224, P.O.34, and P.Y.12 (detected with Raman and FORS). The coatings used on the series contain at least two distinct acrylic polymers potentially with sulfur additives that are applied on different materials and locations across impressions within the series, indicating more variance than previously known (detected with r-FTIR and XRF). These two coatings cannot be distinguished with UV fluorescence imaging. The color shift is confirmed to be light-induced, with the most sensitive color–the Magenta component of the CMYK offset lithograph– corresponding to a BW1-2 in both actual before/after exhibition color measurements and accelerated aging tests (detected with spectrophotometry and microfade testing).

5. ACKNOWLEDGEMENTS

This research is the result of the collaborative contributions of many brilliant scholars, thanks to the dynamic partnership of RRF, VoCA, and WUDPAC. The driving questions of this study were formalized and guided by the Foundation’s insight and facilitation, in particular: Julia Blaut, Kristen Clevenson, Sarah Moskowitz, Thomas Roach, and Francine Snyder. Support from VoCA provided exceptional guidance in advancing artist-centered perspectives on the preservation of contemporary art, with particular gratitude extended to Jeffrey Warda, Gwynne Ryan, and Lauren Shadford. Dr. Richard Hark, of the Yale University Institute for the Preservation of Cultural Heritage, provided instrumentation, led operation, and supported the interpretation of MFT. The development of research methodology and data collection was supported by WUDPAC-affiliated partnership participants, including Dr. Rosie Grayburn, William Donnelly, and Binh-An Nguyen. Data interpretation, particularly for FTIR and FORS, was guided by Catherine Matsen, Senior Scientist at the Winterthur Museum. Kate Schilling, Faculty at the School of Engineering and Applied Science at Yale University, and Katie Sanderson, Conservator of Photographs at the Metropolitan Museum of Art, were both consulted on the methodology and interpretation of color measurements. To each of these individuals and institutions, deepest gratitude is extended for their unwavering commitment to the shared stewardship of contemporary art, without which this work—and its future impact—would not have been possible.

REFERENCES

Apps, E.A. 1958. *Printing Ink Technology.* London: Leonard Hill Limited.

Banik, Gerhard, and Irene Bruckle. 2011. P*aper and Water: A Guide for Conservators*. London: Routledge.

Beltran, Vincent Laudato. 2018. *Advancing Microfading Tester Practice: A Report from an Experts Meeting Organized by the Getty Conservation Institute*. CA: The Getty Conservation Institute. https://hdl.handle.net/10020/gci_pubs/advancing_mft_practice.

Beltran, Vincent Laudato, Christel Pesme, Sarah K. Freeman, and Mark Benson. 2021. *Microfading Tester: Light Sensitivity Assessment and Role in Lighting Policy*. Los Angeles: Getty Conservation Institute. http://hdl.handle.net/10020/gci_pubs_microfading_tester.

Blaut, Julia. 1997. "Overview: Life and Art," "Early Works, 1948–54," and "Mid-Career, 1970s–1980s." Robert Rauschenberg Foundation (RRF). Last accessed November 10, 2024. https://www.rauschenbergfoundation.org/artist.

Bois, Yve-Alain and Clare Elliott. 2007. *Robert Rauschenberg: Cardboards and Related Pieces*. Houston, TX: Menil Collection.

Bruno, Michael, Frank Romano, and Michael Riordan. 1974. *Pocket Pal: A Graphic Arts Production Handbook.* 11th ed. New York, NY: International Paper Company.

Burge, Daniel. 2017. "IPI's Digital Print Workshop: Identification and Preservation of Digital Prints." PowerPoint. Winterthur/University of Delaware Program in Art Conservation. March 27-28, 2017.

Derrick, Michele, Dusan Stulik, and James Landry. 1999. *Infrared Spectroscopy in Conservation Science.* Los Angeles: Getty Conservation Institute.

Feller, Robert. 1994. *Accelerated Aging: Photochemical and Thermal Aspects*. Los Angeles: Getty Conservation Institute.

Gemini G.E.L.. 1971. "Cardbirds" brochure. Los Angeles, CA: Gemini G.E.L.

Gemini G.E.L.. *Online Catalogue Raisonné*, National Gallery of Art, Washington DC. Accessed November 10, 2024. https://www.nga.gov/gemini/home.htm.

Hark, Richard. 2025 "Microfade Tests on Cardbird I-VI by Robert Rauschenberg [71.E004.AP1, 71.E004.AP2, 71.E004.AP3, 71.E005.AP3, 71.E006.AP1, 71.E007.AP1, 71.E008.AP1, 71.E009.AP1, 71.E010.AP1, 71.E010.AP2, 71.E010.AP3]." Internal unpublished document. New York: Robert Rauschenberg Foundation.

Heaney, Matthew P., Daniel K. Unruh, and Tomče Runčevski. 2022. "Azo or Not: Continuing the Crystallographic Investigations of *β*- Naphthol Reds." *Crystal Growth & Design* 22, 9: 5168–75. https://doi.org/10.1021/acs.cgd.2c00079.

Herbst, Willy and Klaus Hunger. 2004. *Industrial Organic Pigments: Production, Properties, Applications*. Third Edition. Germany: Wiley-VCH

Hird, Kenneth. 2000. *Offset Printing*. Tinley Park, IL: Goodheart-Willcox Co.

Hunter, Sam, and Robert Rauschenberg. 2006. *Robert Rauschenberg : Works, Writings and Interviews*. Barcelona, Spain: Ediciones Polígrafa.

Hutchinson, GH. 1999. "A Half Century of Printing Inks," *Surface Coatings International* 82, no. 5 (May): 233–240, https://doi.org/10.1007/BF02720119.

Kipphan, Helmut. 2001. *Handbook of print media: technologies and production methods.* Berlin, Germany: Springer Science & Business Media.

Klein, Susanne and Carinna Parraman, *Printing Technologies and Applications: A Multidisciplinary Roadmap*. Briston, UK: IOP Publishing. https://doi.org/10.1088/978-0-7503-2568-4.

Leach, Robert and Ray Pierce. 2007. *The Printing Ink Manual*. Berlin: Springer Science & Business Media.

Raffa, Patrizio, Diego Armando Zakarias Wever, Francesco Picchioni, and Antonius A. Broekhuis. 2015. "Polymeric Surfactants: Synthesis, Properties, and Links to Applications." *Chemical Reviews* 115, (16): 8504–8563. https://doi.org/10.1021/cr500129h.

Rosenthal, Mark. 1993. *Artists at Gemini G.E.L. : Celebrating the 25th Year*. New York: Abrams.

Schwartz, Anthony M and James W. Perry. 1958. *Surface Active Agents, Their Chemistry and Technology*. New York: Interscience Publishers.

Tomkins, Calvin. 1980. *Off the Wall : Robert Rauschenberg and the Art World of Our Time*. First edition. Garden City, New York: Doubleday.

"Winterthur/University of Delaware Program in Art Conservation in conjunction with Voices in Contemporary Art: Conservation Fellowships, 2018-present." Robert Rauschenberg Foundation (RRF). Last accessed February 16, 2025. https://www.rauschenbergfoundation.org/collaborations/wudpac-and-voca-2018-present.

Appendix I: Attached Elements and Fabrication Notes

Table I-1. Attached elements and fabrication notes of the *Cardbird* series (National Gallery of Art Gemini G.E.L. Online Catalogue Raisonné).

Cardbird	# of one-color screen prints on cardboard	# of two-color screen prints on cardboard	Additional elements	Attachment methods
I	2 (collaged)	1 (hinged)	N/A	Reinforced sealing tape, Kraft tape
II	4 (two collaged, two hinged)	0	N/A	Reinforced sealing tape, Kraft tape, plated steel staples
III	2	2 (one collaged, one hinged)	1 colored screenprint on paper glued to the polyethylene bag (collaged)	Reinforced sealing tape, Kraft tape
IV	2 (one collaged, one hinged)	0	N/A	Tape (?)
V	3 (collaged)	0	1 cardboard insert (collaged)	Reinforced sealing tape, Kraft tape, steel staples
VI	1 (collaged)	0	1 rubber stamp on cardboard (hinged with tape)	Reinforced sealing tape
VII	0	0	1 cardboard insert	Reinforced sealing tape

Appendix II. *Cardbird* Series Color Shift[21]

Figure II-1. *Cardbird I.* The image on the left shows a museum piece displayed under controlled lighting conditions (source: Philbrook Museum, 2012.8), while the image on the right features a work from a private collection, where light exposure appears less regulated (Artnet past auction).

Figure II-2. *Cardbird IV*. The image on the left shows a museum piece displayed under controlled lighting conditions (source: Seattle Art Museum), while the image on the right features a work from a private collection, where light exposure appears less regulated (source: Bukowskis).

[21] Photo documentation conditions and post-processing are not consistent between these images. These comparisons provide an approximate reference of the primary condition concern.

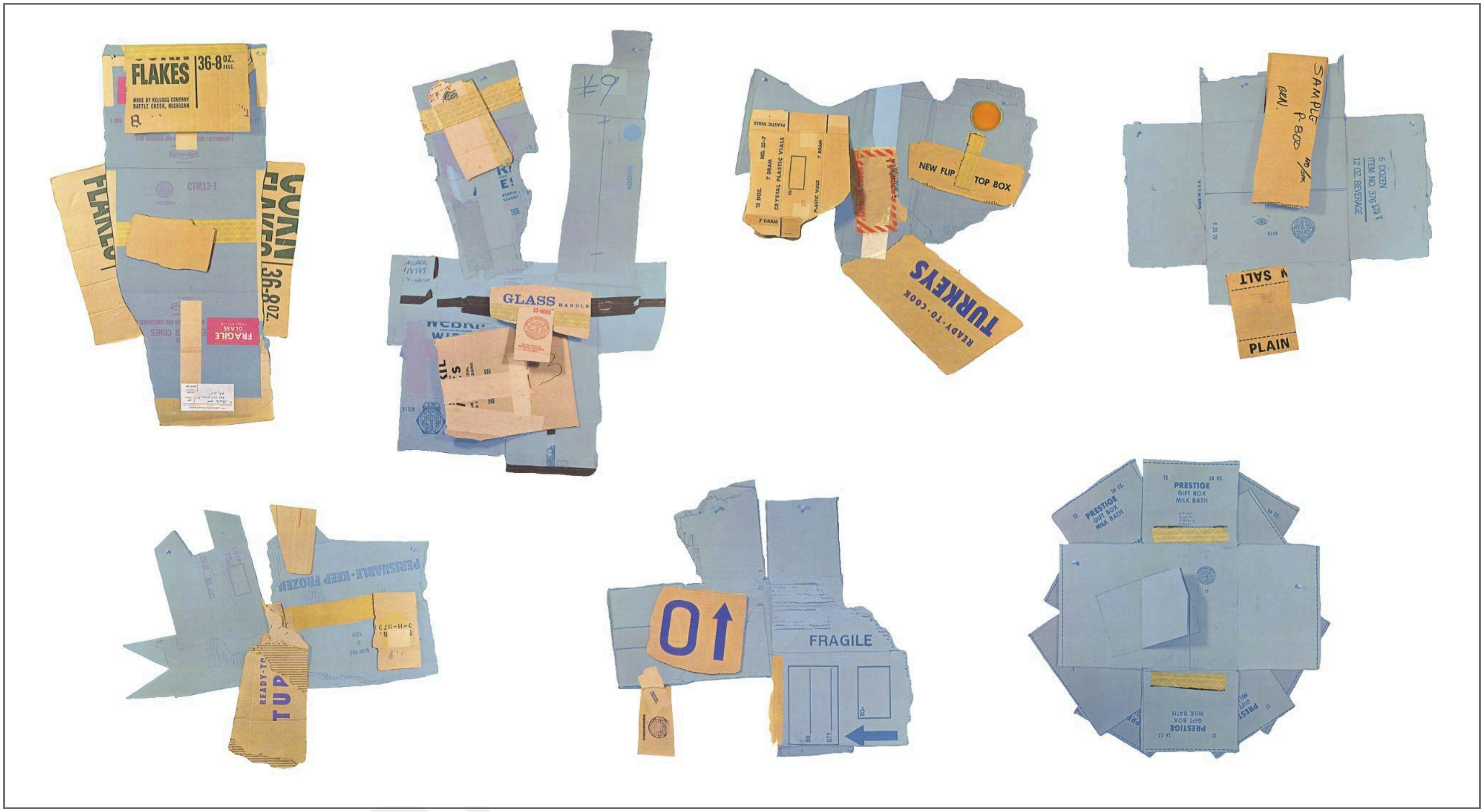


Figure II-3. False-color condition diagram to indicate the location of offset lithographs susceptible to a color shift (noted with blue-gray). Images source: Gemini G.E.L. (1971) with digitally altered color.

Appendix III: Methodology

Table III-1. Summary of analytical instruments, software, specifications, and contributors.

Analytical technique	Instrument	Specifications	Contributors[22]
XRF	Handheld Bruker Tracer 5g handheld XRF spectrometer	Analysis was performed with the Bruker Tracer 5G handheld XRF spectrometer using a rhodium tube (operating at 40kV high voltage, 9.6µA anode current, no filter and without helium purge) for 60 seconds, live time irradiation. The spot size was oblong in shape, approximately 1 × 0.5 cm. Spectra were interpreted using the ArTAX version 7.4 software.	Jeffrey Warda*, Daisy Diamond^, Dr. Rosie Grayburn^
Raman spectroscopy	BWTek iRaman (785 nm laser)	The sample locations were analyzed with the instrument in conjunction with integrated software with extended scan from 4000 - 400 cm-1, exposure time of 10 seconds/scan for 3 accumulations, and 10 % laser power. The two reference libraries used for comparison were the UCL Raman Spectroscopic Library and Winterthur database of select synthetic organic pigments. The software used to interpret the data is Omnic version 8.0.	Dr. Rosie Grayburn*, Daisy Diamond*^, Catherine Matsen^
FORS	FieldSpec 4 Hi-Res Spectroradiometer (ASD Inc., Panalytical)	FORS was performed on single points, operating from 350-2500 nm. The instrument was equipped with a 512 Silicon array (VNIR) and two TE cooled fast scan InGaAs photo-diodes (SWIRS). The bifurcated reflectance probe consists of a common end of six fibres (600 mm diameter) surrounding a single collection fibre (600 mm diameter). The sampled area was approximately 3 mm in diameter, at minimum. The acquisition time was <4 seconds. The spectrometer was calibrated with a white reference Spectralon® standard. The reference library used for comparison with the Cultural Heritage Science Open Source “Reflectance Spectroscopy FORS – GorgiasUV – Pigments-Checker Modern Art" database reference.	Dr. Rosie Grayburn*^, Daisy Diamond*^, Catherine Matsen^, William Donnely*
Digital microscopy	Dino-Lite Digital Microscope (EdgePLUS series)	Images were collected with DinoCapture 2.0 software (AnMo Electronics Corporation).	Daisy Diamond*^, William Donnely*^, Binh-An Nguyen*

[22] * indicates data collection, ^ indicates data interpretation

r-FTIR	Bruker ALPHA FTIR spectrometer	The portable FTIR instrument was used with the reflectance module. Data was acquired at 124 scans from 4000 to 400 cm^{-1} at a spectral resolution of 4 cm^{-1}. Multiple spectra were taken from different areas of the object. Spectra were collected with OPUS 8.7 software and analyzed in this program with various IRUG, commercial and academic reference spectral libraries. Data was collected in reflectance mode and transformed to transmission mode using a Kramers–Kronig Transformation (KKT). Paint outs were made as reference samples using neutral pH PVA adhesive (Lineco), acrylic polymer emulsion Gloss Medium & Varnish (Liquitex Professional), and colorless thermoplastic acrylic resin composed of a methyl methacrylate/butyl methacrylate copolymer Paraloid B-72 (Talas). Spectra for reference samples were collected and transformed in the same manner.	Dr. Rosie Grayburn*^, Daisy Diamond*^
UVF	Nikon D850 DSLR Camera	Images were collected with a Kodak Wratten 2E and Peca 918 filter, at f/8, 13s, with a Zeiss Makro-Planar T* 50 mm f/2 lens. Images include a UV Innovations target and were processed with the UV innovations recommended settings in Adobe Lightroom.	Jeffrey Warda*^, Daisy Diamond*^
Spectrophotometry	X-Rite Ci64 UV Spectrophotometer	The X-Rite Ci64 UV is an integrating sphere spectrophotometer that was used to measure color from 400 - 700 nm in 10 nm intervals. Calibration was completed prior to use with a white calibration tile and black trap. Measurements were taken with a mylar barrier template with square holes and arrows indicating instrument directional to ensure consistency. For each analysis site, measurements were collected with L*a*b* values five times, lifting the instrument and realigning it each time. These trials were averaged into standards for ΔE calculations for each analysis site. D65/10 Illuminant/observer, 6 mm aperture size, SPIN/SPEX specular, tungsten radiation source, and CIEDE 2000 ΔE formula. Serial Number: 022226 CMIT ID: 2013DJ8807 Latest calibration: March 2023. Color IQC software was used for data collection.	Jeffrey Warda*^, Daisy Diamond*^, Binh-An Nguyen*
MFT	Whitmore-design microfade tester	The MFT instrument consisted of a focused Ocean Optics HPX-200-UV xenon arc lamp source delivered with fiber optic cables maintained at a 0°/45° measurement apparatus with a custom rig, UV filter, and a spectrophotometer. Real-time color changes were recorded using an integrated spectrometer. Measurements were taken using standard illuminant D65, a 2° standard observer, and processed using Control Development Spec32 software. The	Dr. Richard Hark*^, Daisy Diamond*^, Binh-An Nguyen*

	duration of each measurement was five minutes or less, and the measurement was terminated if ΔE*ab reached ~ 1 during the interval at 600 millilumens (mlm). Overall color change values (ΔE) were calculated using the Commission Internationale de l’Eclairage (CIE) 1976 formula. The International Organization for Standardization’s (ISO) Blue Wool standards 1-3 were used for reference under the same test conditions. Data was interpreted with SpectralViewer V3rc1c (2024). 1-3 measurements were collected and averaged depending on the quality of the signal. Data is reported with both ΔE*ab and ΔE*00. ΔE*00, which applies critical corrections to the original CIELAB model. These include adjustments for chroma and hue differences, particularly in the blue region, improved accuracy in lightness (L*), and rescaled along the a* (red-green) axis to address nonuniformities in grey and neutral colors (Beltran et al. 2021, 21).

Appendix IV: X-ray Fluorescence (XRF) Spectroscopy

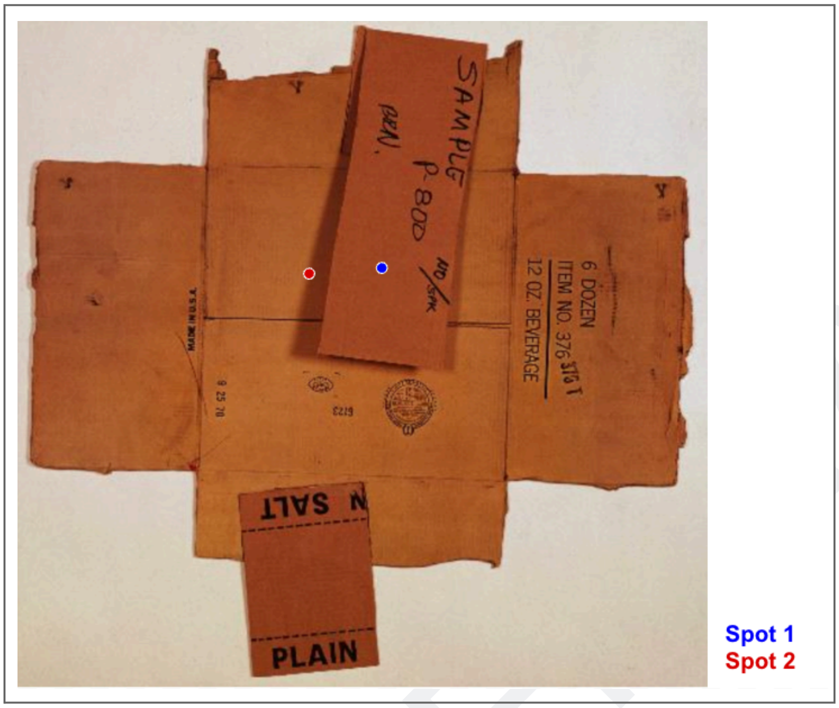


Figure IV-1. XRF analysis locations, *Cardbird IV* (Solomon R. Guggenheim Museum, NY). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.55).

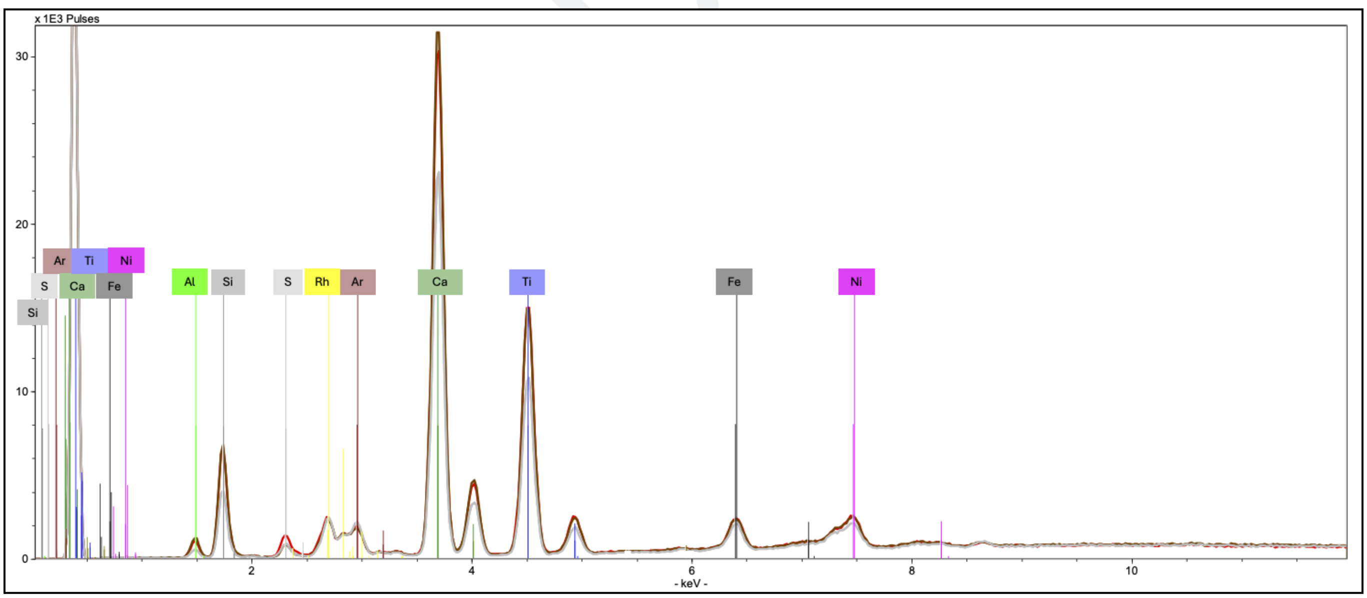


Figure IV-2. XRF representative spectrum.[23]

[23] Iron was detected in trace amounts, likely as a common contaminate. Nickel and rhodium are trace signals from the instrument, and argon is detected due to its presence in the air.

Appendix V: Raman Spectroscopy

Figure V-1. Raman spectroscopy analysis locations, *Cardbird IV* (Robert Rauschenberg Foundation). The following spectra (figs. V-2 through V-8) are presented in order of decreasing spectral match confidence, based on comparative reference data. Image source: Gemini G.E.L. Online Catalogue Raisonné (41.52).

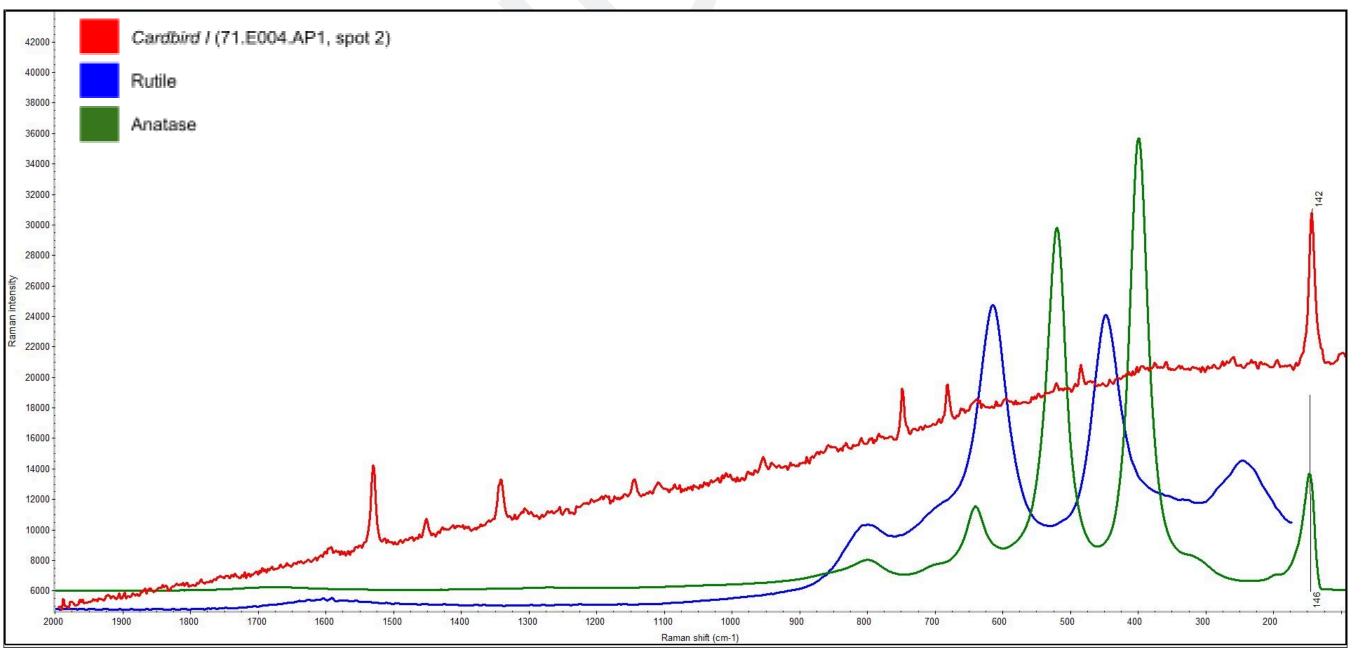
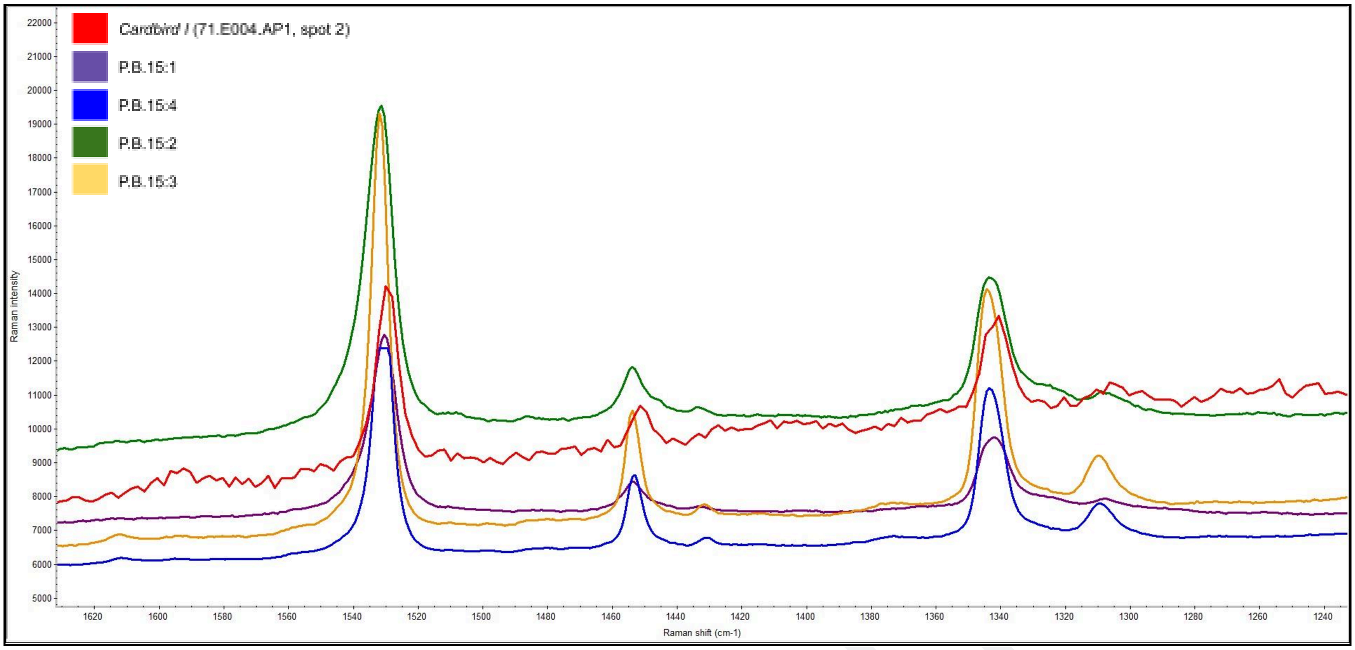


Figure V-2. Raman spectra for one representative sample location (71.E004.AP1, spot 2), with peaks corresponding to anatase reference spectrum. Rutile is included as a negative confirmation.



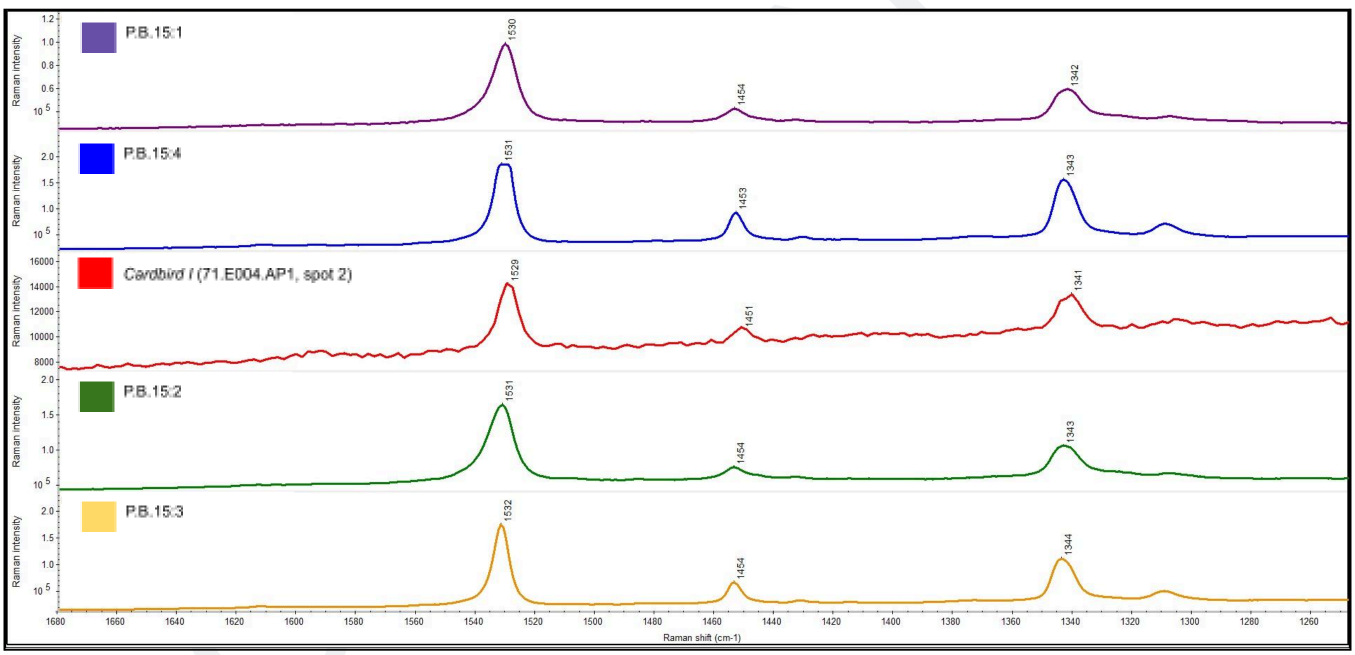


Figure V-3. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for cyan colorant identification, with peaks at 1529, 1341, and 1451 cm^{-1} corresponding to P.B.15:1, P.B.15:4, P.B.15:2, and P.B.15:3 reference spectra (in order of likelihood, from top to bottom).

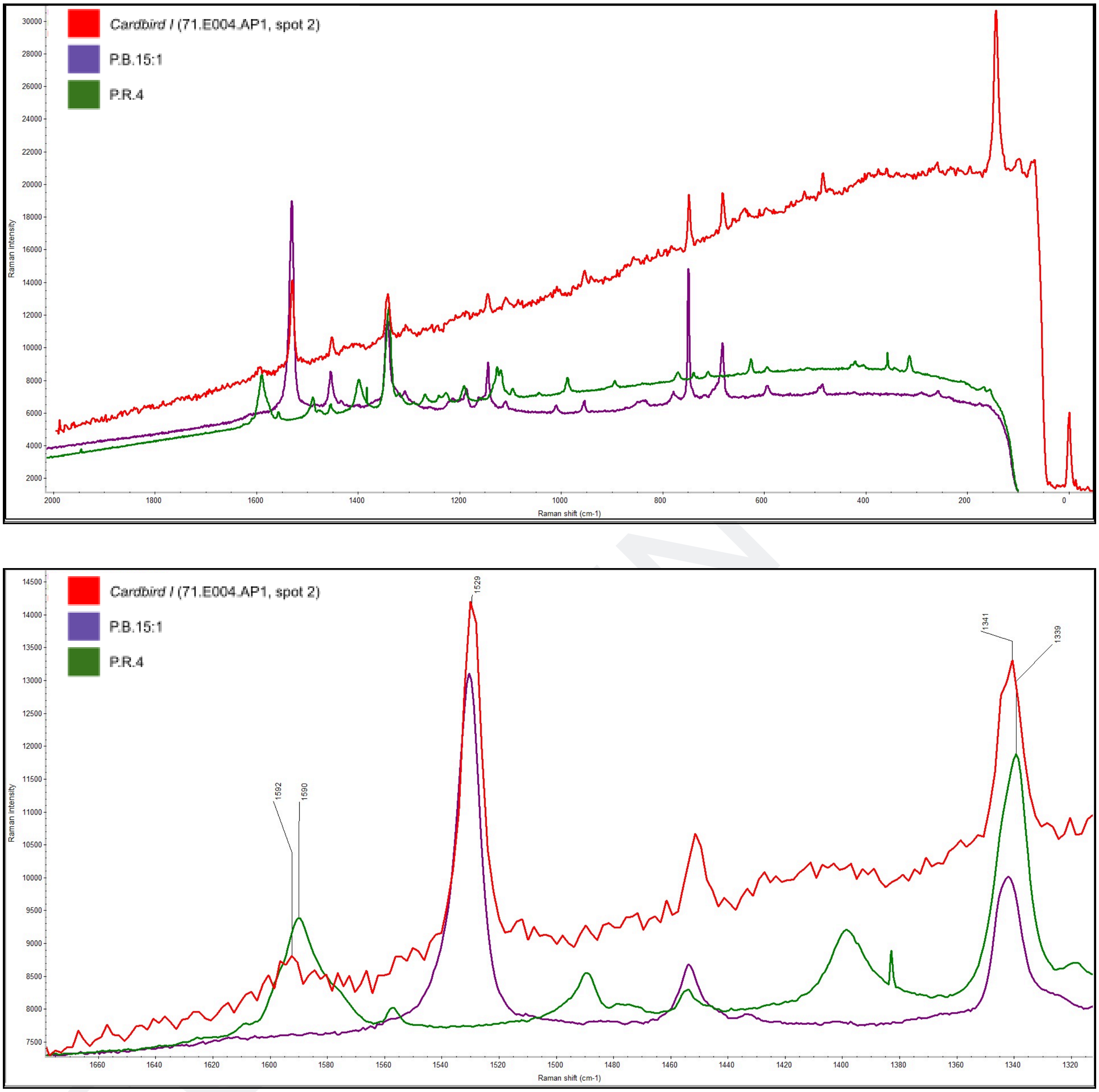


Figure V-4. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for magenta colorant identification, with peaks at 1341 and 1592 cm^{-1} corresponding to P.R.4 reference spectrum. The spectrum for P.B.15:1 is included because it is a likely component, and some observed peaks can be attributed to this pigment. One peak between 1460-1440 cm^{-1} overlaps for both P.B.15:1 and P.R.4.

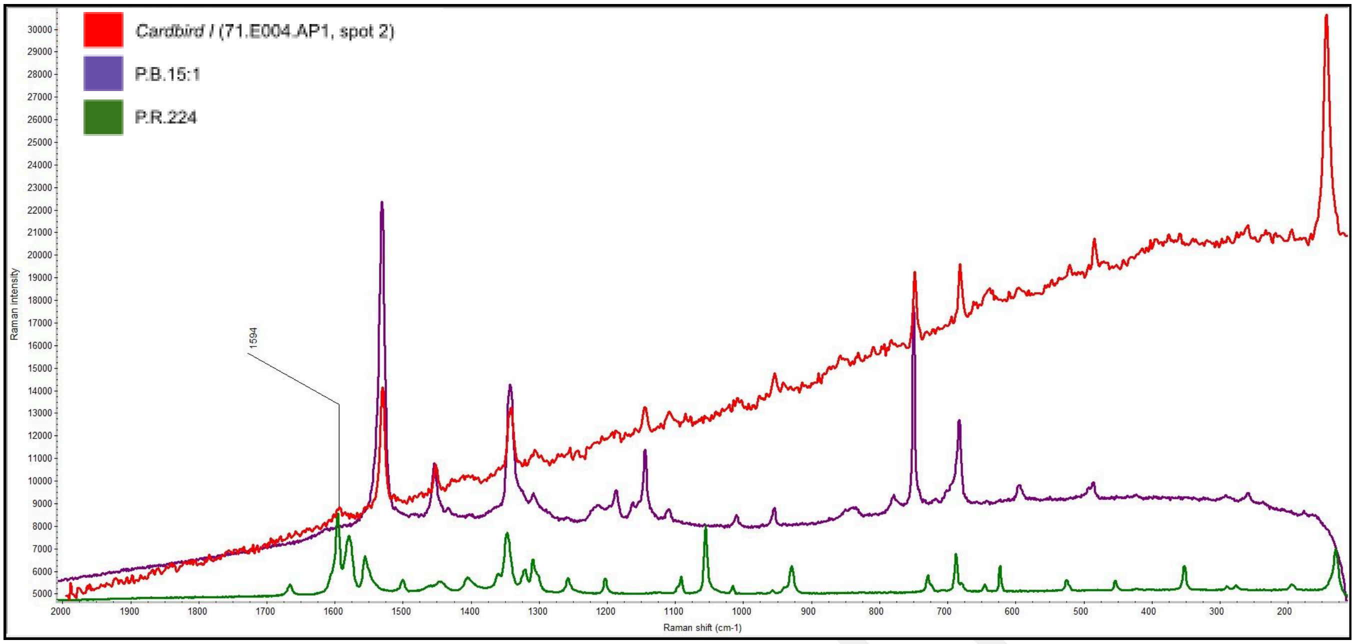


Figure V-5. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for magenta colorant identification, with peaks at 1594 cm^{-1} corresponding to P.R.224 reference spectrum. The spectrum for P.B.15:1 is included because it is a likely component, and some observed peaks can be attributed to this pigment. One of the strongest peaks for P.R.224 (between 1400-1400 cm^{-1}) overlaps with a peak for P.B.15:1. The third strongest peak for P.R.224 (between 1100-1000 cm^{-1}) may be hidden by fluorescence.

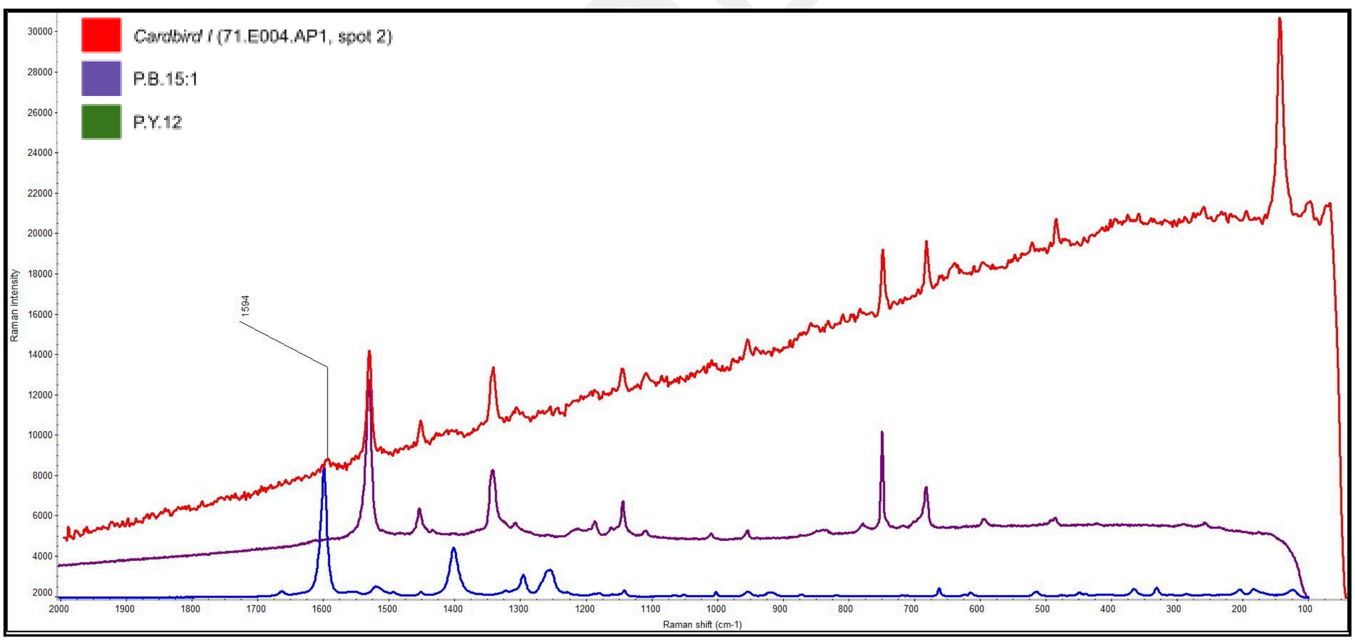


Figure V-6. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for yellow colorant identification, with peaks at 1594 cm^{-1} corresponding to P.Y.12 reference spectrum. The spectrum for P.B.15:1 is included because it is a likely component, and some observed peaks can be attributed to this pigment.

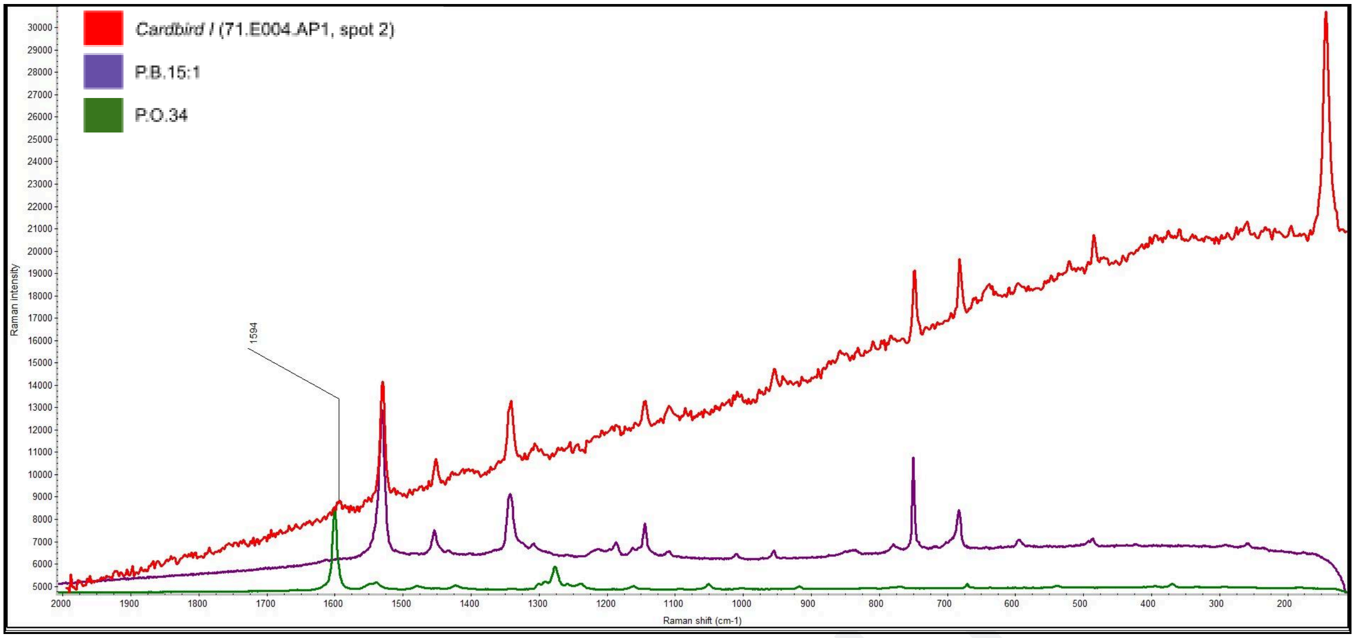


Figure V-7. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for magenta colorant identification, with peaks at 1594 cm^{-1} corresponding to P.O.34 reference spectrum. The spectrum for P.B.15:1 is included because it is a likely component, and some observed peaks can be attributed to this pigment. This colorant is much less likely than those investigated in the prior figures.

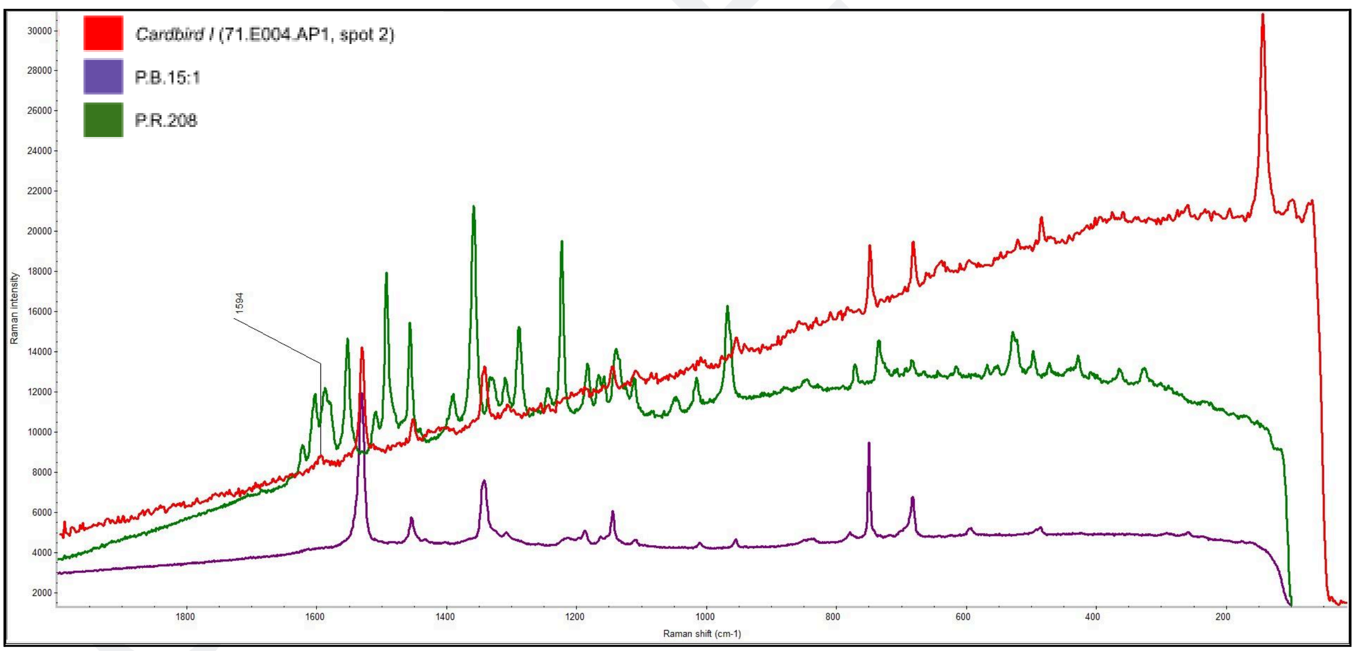


Figure V-8. Raman spectra for one representative sample location (71.E004.AP1, spot 2) for magenta colorant identification, with peaks at 1594 cm^{-1} corresponding to P.R.208 reference spectrum. The spectrum for P.B.15:1 is included because it is a likely component, and some observed peaks can be attributed to this pigment. This colorant is the least likely of the potential colorants in the prior figures.

Appendix VI: Fiber Optic Reflectance Spectroscopy (FORS)

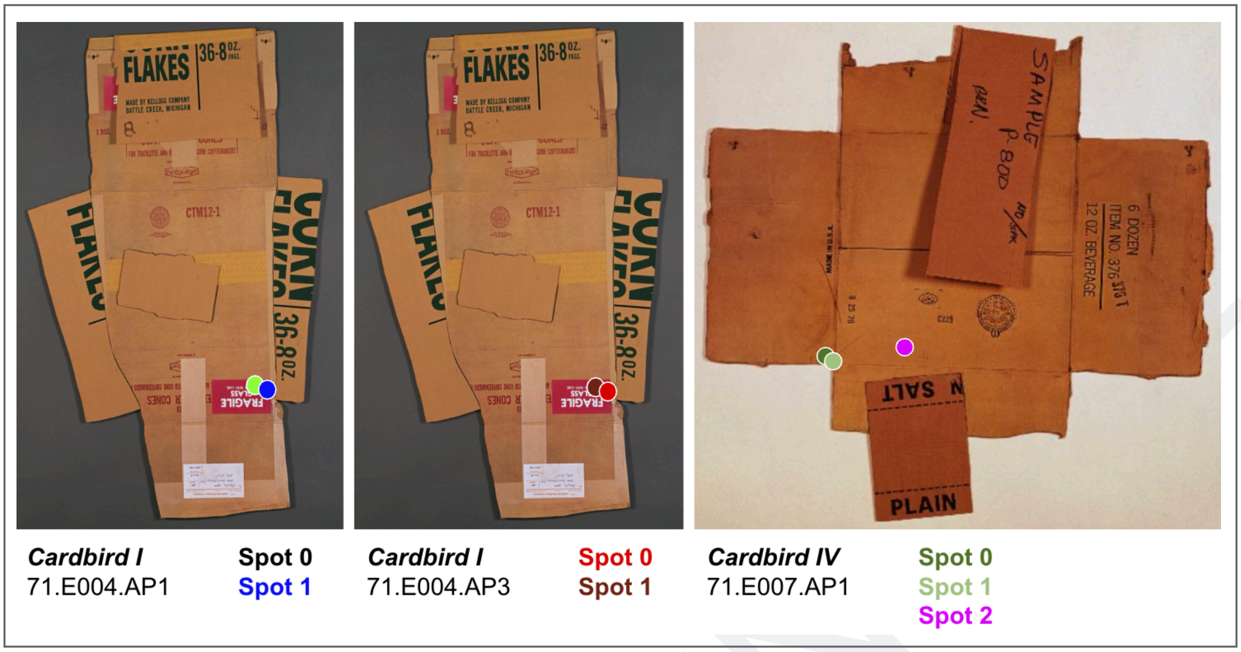


Figure VI-1. FORS analysis locations for two impressions of *Cardbird I* and one impression of *Cardbird IV* (Robert Rauschenberg Foundation). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.52 and 41.55).

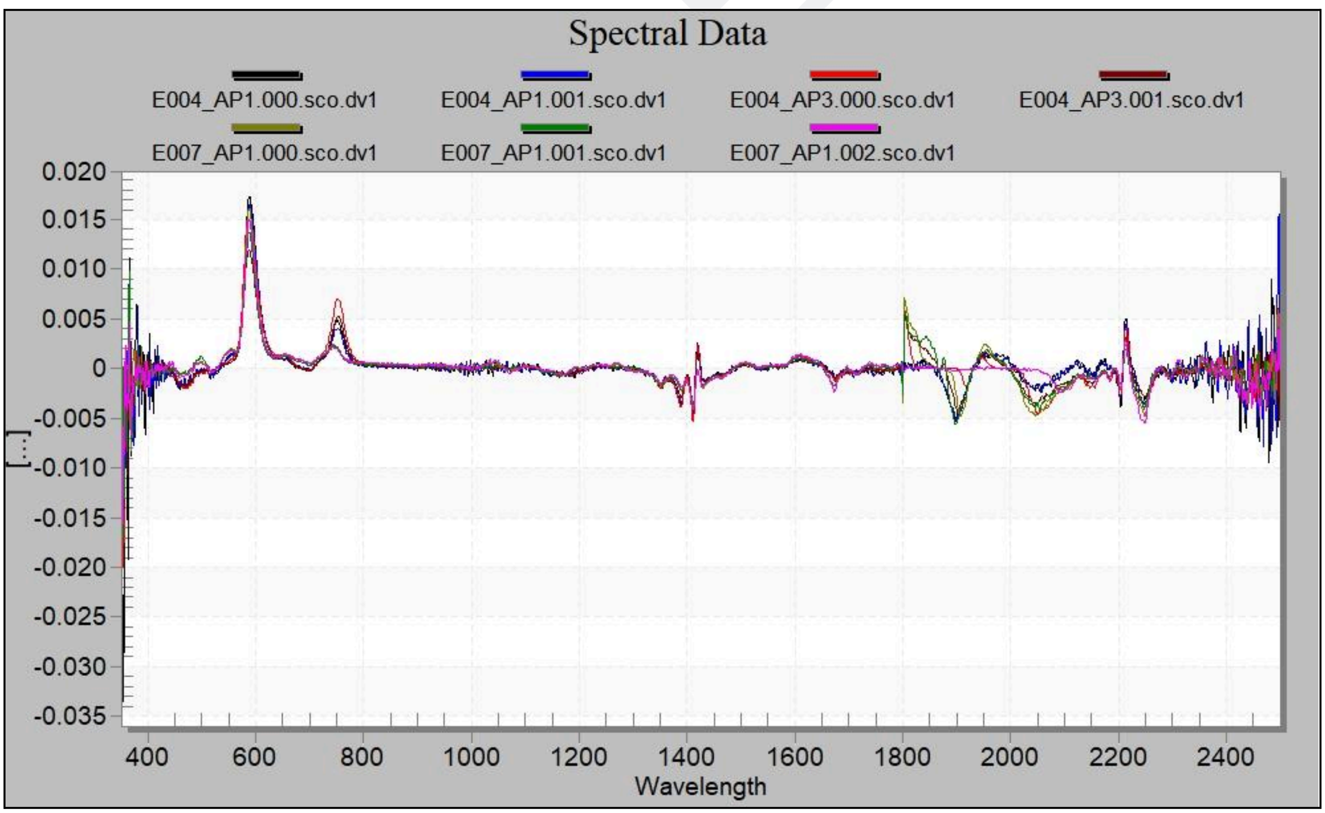


Figure VI-2. FORS spectra of primarily red printed areas (with the exception of the "cardboard" colored analysis location on *Cardbird IV*, spot 2) for two impressions of *Cardbird I* and one impression of *Cardbird IV*.

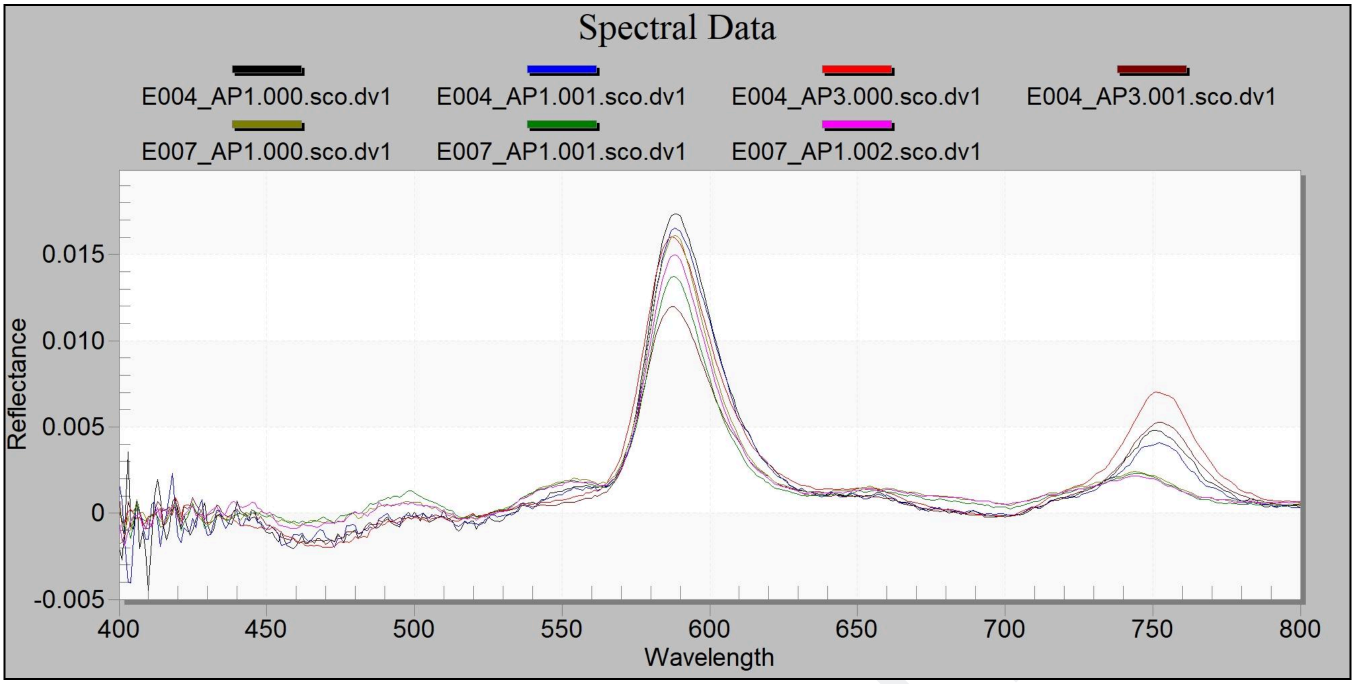


Figure VI-3. FORS spectra (400-800 nm) of primarily red printed areas (with the exception of the "cardboard" colored analysis location on *Cardbird IV*, spot 2) for two impressions of *Cardbird I* and one impression of *Cardbird IV*.

Appendix VII. Reflectance-Fourier Transform Infrared (r-FTIR) Spectroscopy

Figure VII-1. r-FTIR analysis locations, *Cardbird IV* (Robert Rauschenberg Foundation). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.52).

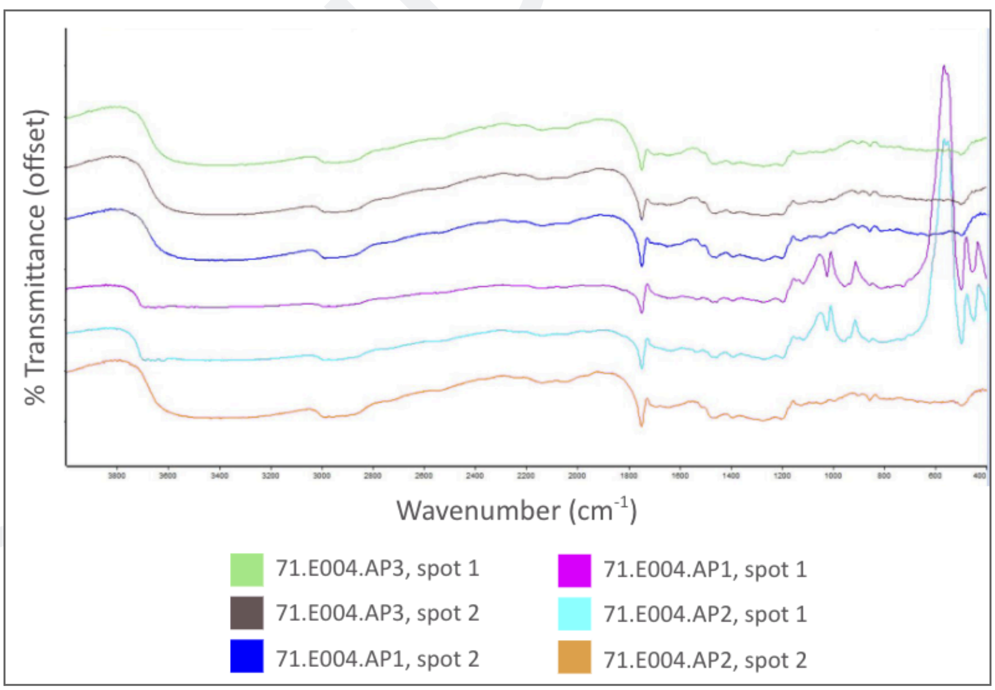


Figure VII-2. r-FTIR spectra for two spots on three editions of *Cardbird I.*

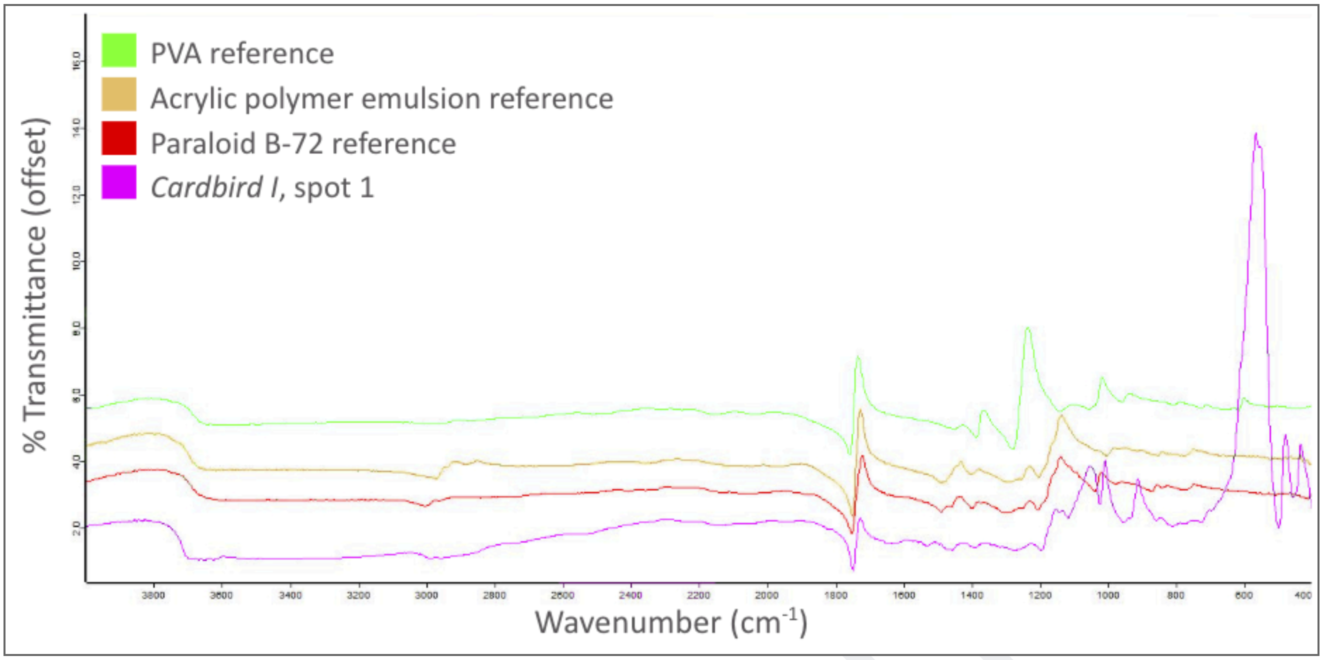


Figure VII-3. r-FTIR spectra comparing spot 1 on *Cardbird I* (71.E004.AP1, Robert Rauschenberg Foundation, NY) as a representative spectrum of "Coating A" compared with modern synthetic resin reference spectra collected.

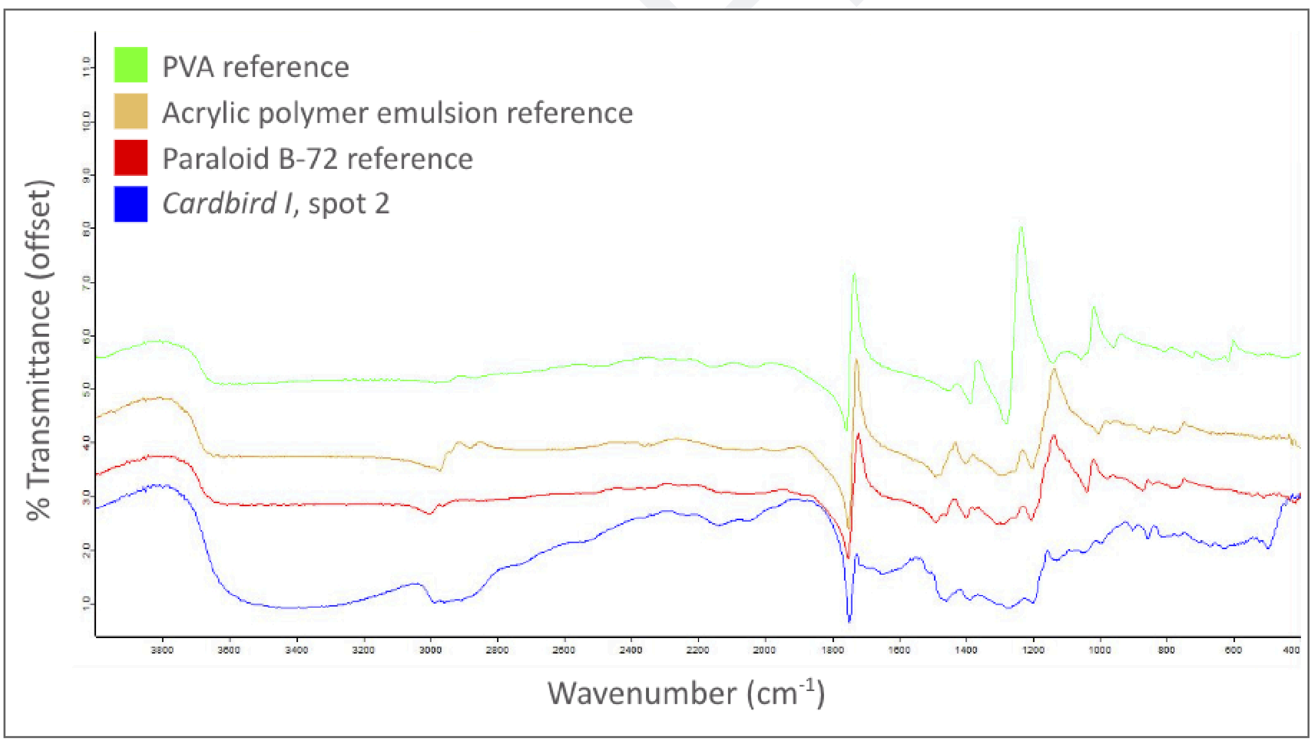


Figure VII-4. r-FTIR spectra comparing spot 2 on *Cardbird I* (71.E004.AP1, Robert Rauschenberg Foundation, NY) as a representative spectrum of "Coating B" compared with modern synthetic resin reference spectra collected.

Appendix VIII. Ultraviolet Fluorescence (UVF) Imaging

Figure VIII-1. Visible light reference image: three impressions of *Cardbird I* (Robert Rauschenberg Foundation, NY).

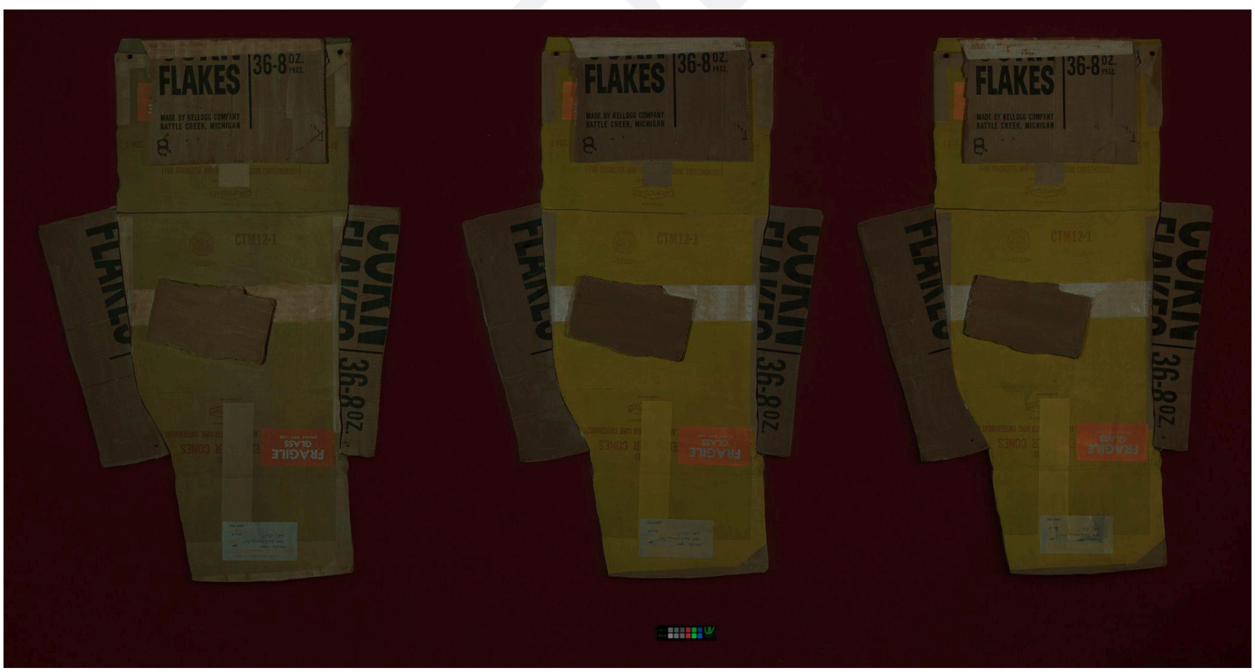


Figure VIII-2. UVF image: three impressions of *Cardbird I* (Robert Rauschenberg Foundation, NY).

Appendix IX: Spectrophotometry

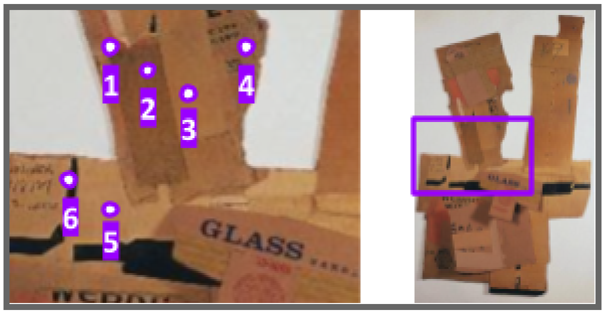


Figure IX-1. Spectrophotometry analysis locations, *Cardbird II* (Solomon R. Guggenheim Museum, NY). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.53).

Table IX-1. Spectrophotometry measurements: *Cardbird II* (Solomon R. Guggenheim Museum, NY) before and after five months of exhibition.

Analysis location	**Before Exhibition** (72.1994.2)			**After Exhibition** (72.1994.2)			**ΔE**
	L*	**a***	**b***	**L***	**a***	**b***	
1	56.636	23.946	35.295	56.73	23.84	35.14	**0.21**
2	52.629	0.086	25.451	52.81	-0.05	25.42	**0.23**
3	62.569	2.924	30.537	62.82	2.88	30.34	**0.32**
4	56.859	2.153	25.598	56.99	2.14	25.3	**0.32**
5	67.768	4.526	27.248	68.05	4.36	26.94	**0.45**
6	28.365	-0.939	0.602	28.77	-0.89	0.82	**0.47**

Table IX-2. Spectrophotometry measurements: *Cardbird II* (Robert Rauschenberg Foundation, NY) with no exhibition history.

Analysis location	**After Exhibition Color Measurement**		
	L*	**a***	**b***
1	55.944	23.525	34.252
2	51.541	0.924	24.606
3	61.029	3.637	29.76
4	56.004	2.571	25.089
5	67.472	5.245	26.75
6	28.944	-0.719	1.604

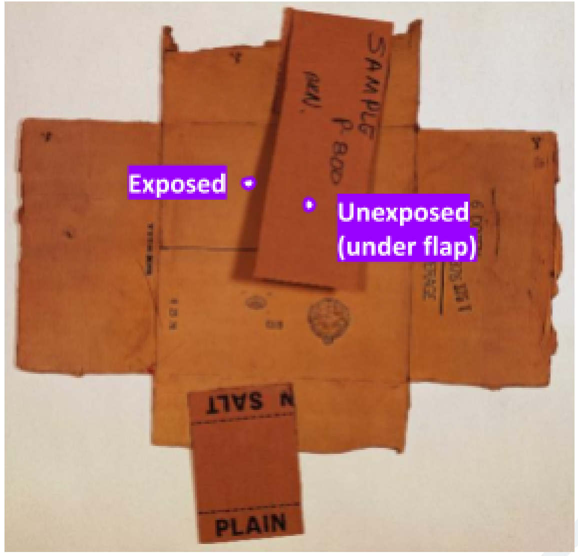


Figure IX-2. Spectrophotometry analysis locations, *Cardbird IV* (Solomon R. Guggenheim Museum, NY). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.55).

Table IX-3. Spectrophotometry measurements: *Cardbird IV* (Solomon R. Guggenheim Museum, NY) after ~11,000 footcandle hours of exhibition. As these are different sample locations, the data is somewhat compromised and does not provide conclusive information. However, the results are included in this report as a summary of analysis undertaken.

Analysis location	L*	a*	b*	ΔE
Unexposed (under flap)	56.636	23.946	35.295	**7.73**
Exposed	67.169	-0.115	25.255	

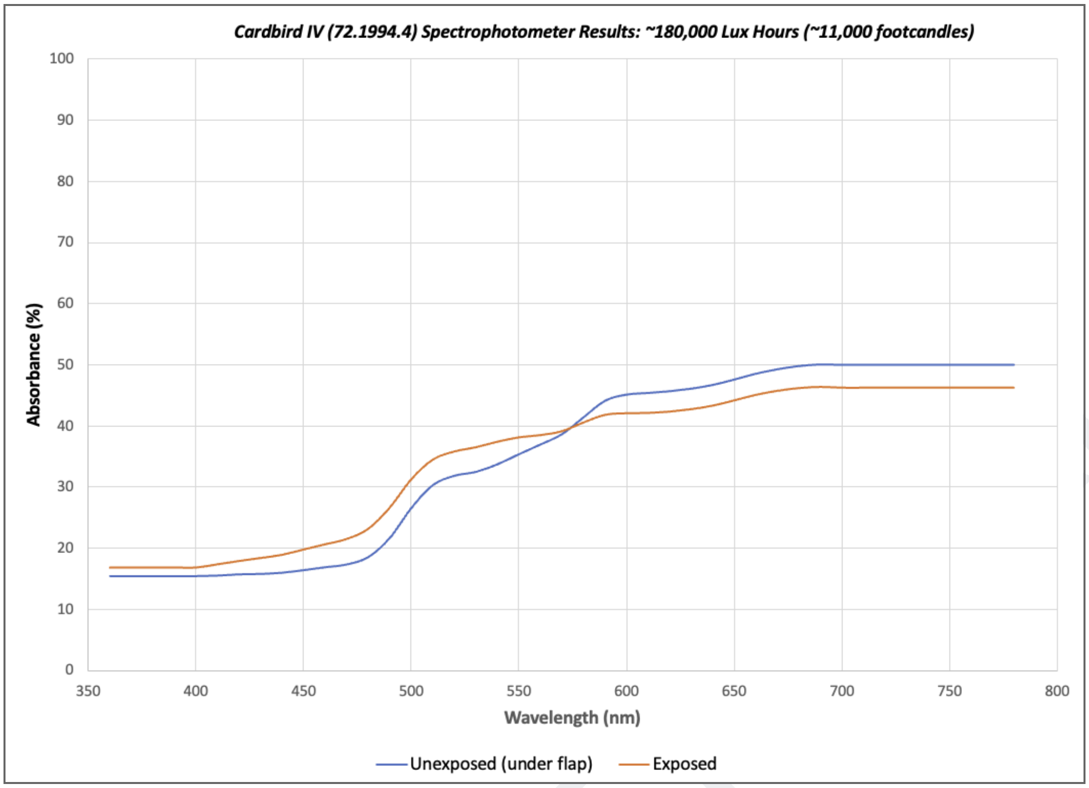


Figure IX-3. Spectrophotometry measurements of *Cardbird IV* (Solomon R. Guggenheim Museum, NY). As these are different sample locations, the data is somewhat compromised and does not provide conclusive information. However, the results are included in this report as a summary of analysis undertaken. The exposed analysis site is more blue than the analysis site with limited light exposure underneath the flap.

Appendix X: Microfade Testing (MFT)

Figure X-1. MFT analysis locations for *Cardbird I* (71.E004.AP1, 71.E004.AP2, 71.E004.AP3). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.52).

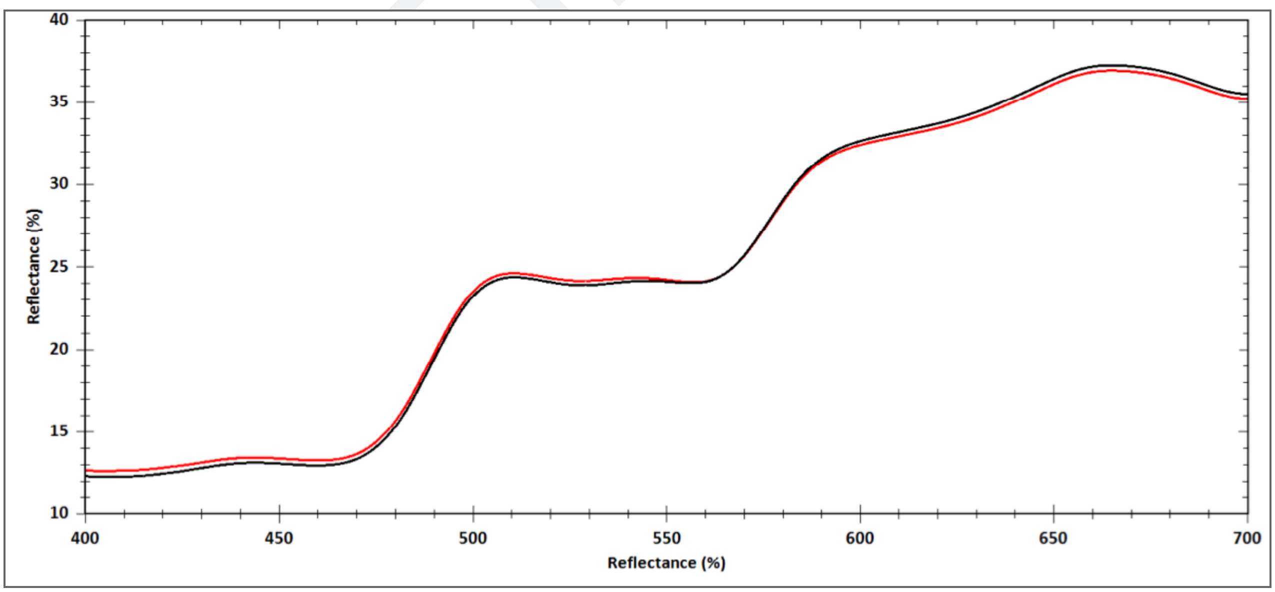


Figure X-2a. Individual reflectance fading curve (600 millilumens, mlm) for *Cardbird I* (71.E004.AP1) spot 1. Black = 0 minutes, Red = 5 minutes. Image courtesy Hark 2025, 28.

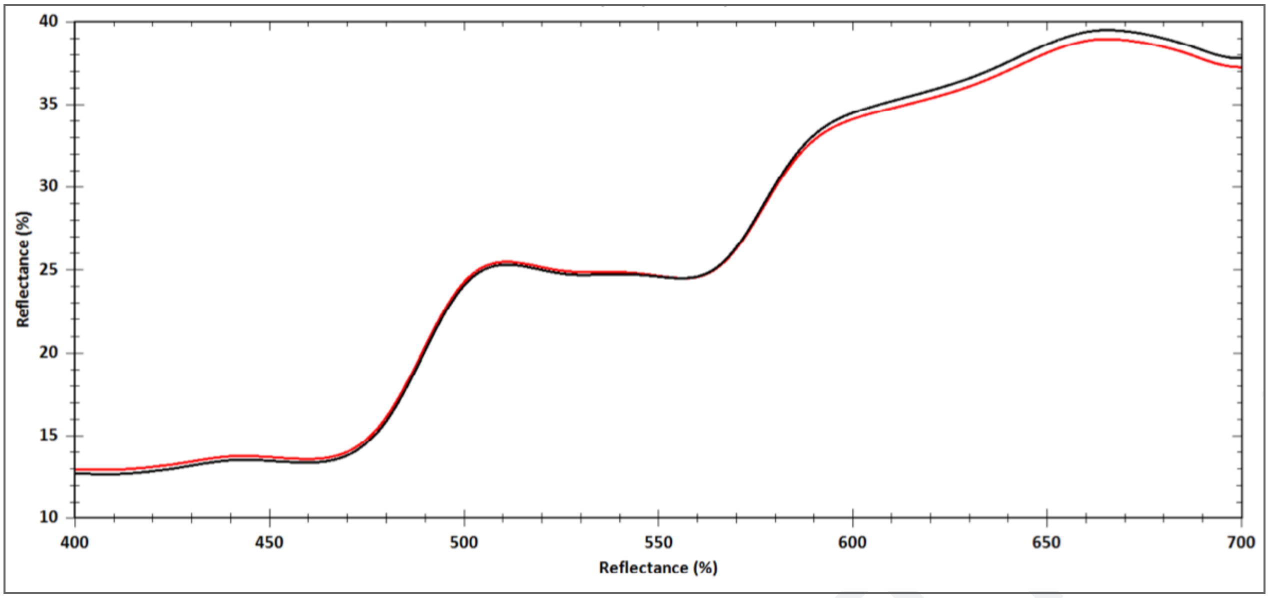


Figure X-2b. Individual reflectance fading curve (600 mlm) for *Cardbird I* (71.E004.AP1) spot 2. Black = 0 minutes, Red = 5 minutes. Image courtesy Hark 2025, 28.

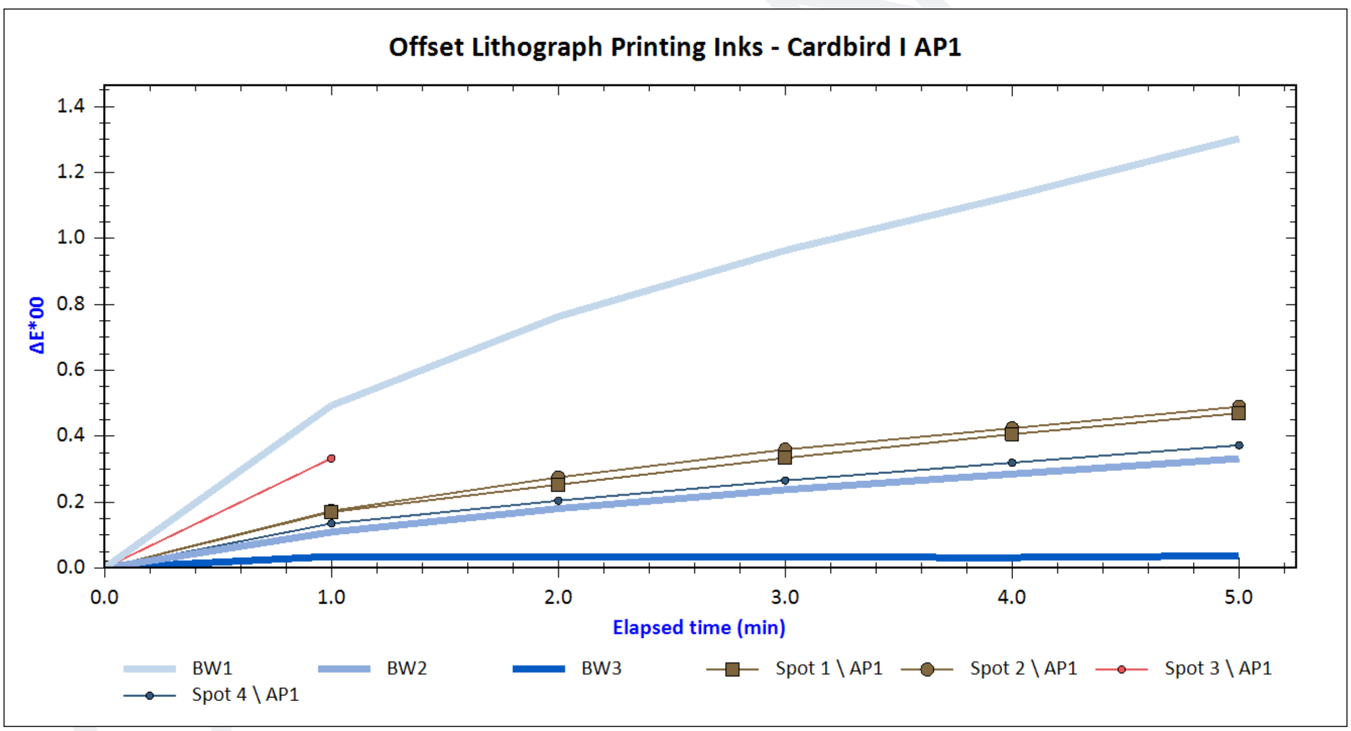


Figure X-3a. MFT fading curve (ΔE*00) for *Cardbird I* (71.E004.AP1).

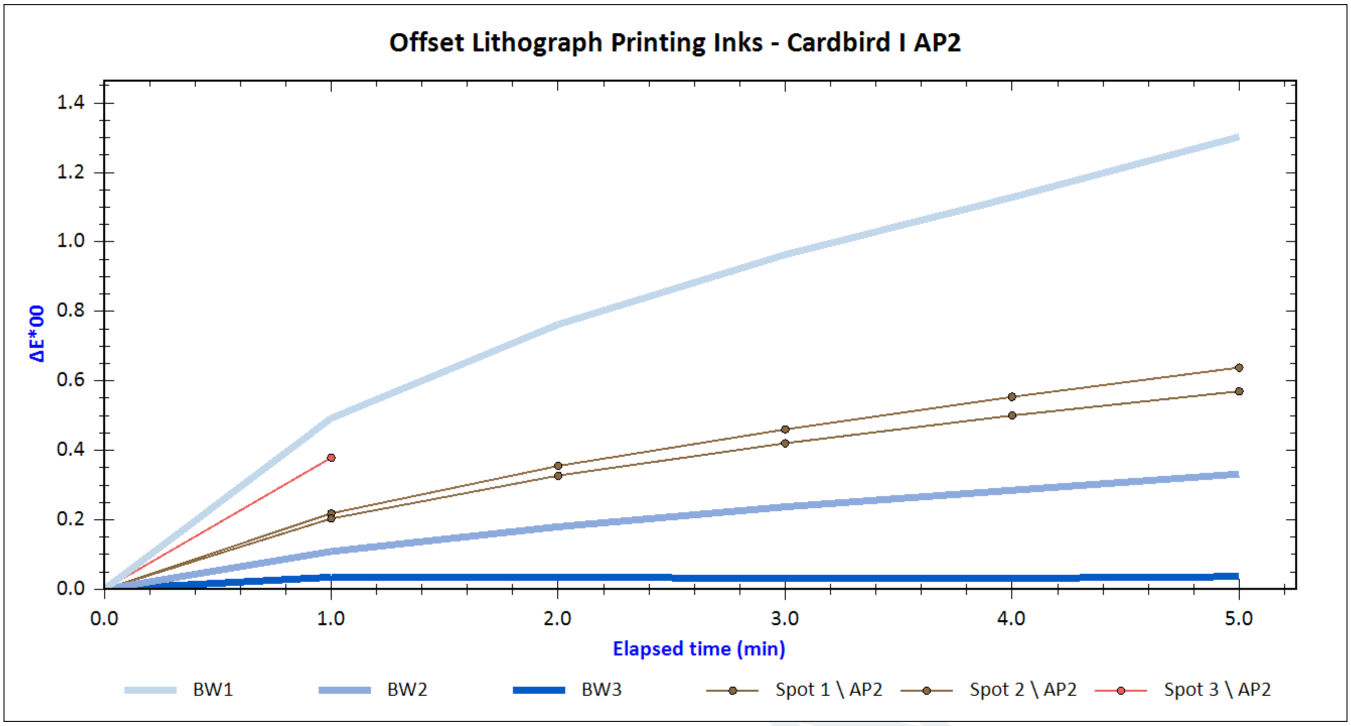


Figure X-3b. MFT fading curve (ΔE*00) for *Cardbird I* (71.E004.AP2). Note: there was an error recording spot 4.

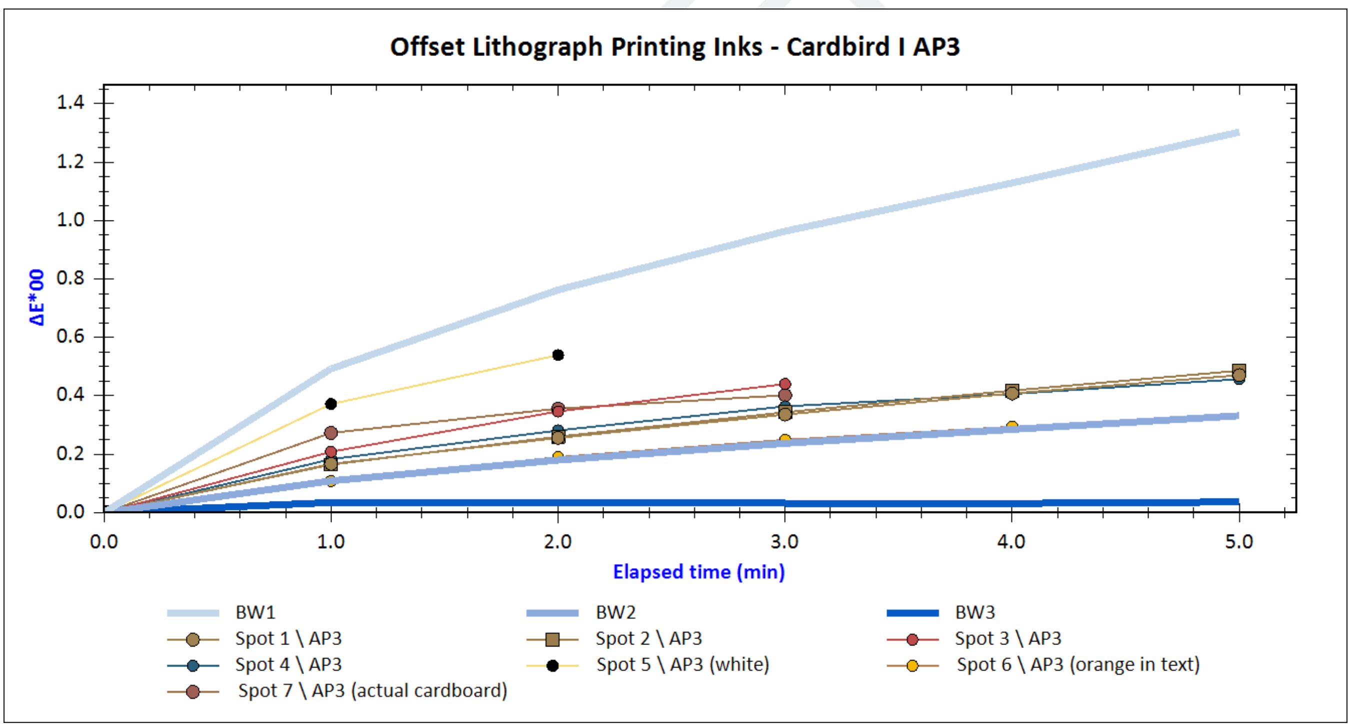


Figure X-3c. MFT fading curve (ΔE*00) for *Cardbird I* (71.E004.AP3).

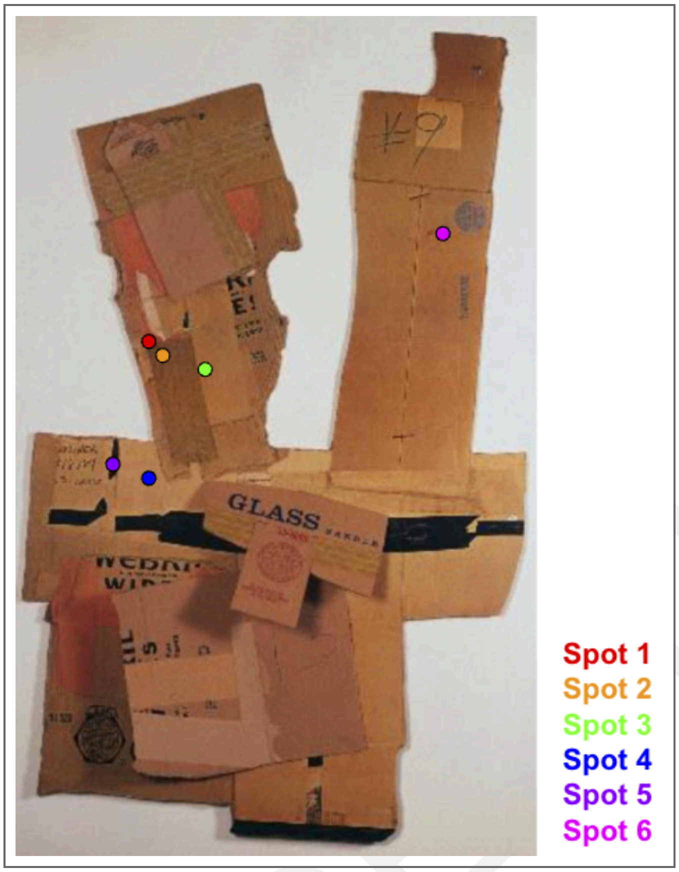


Figure X-5. MFT analysis locations for *Cardbird II* (71.E005.AP3). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.53).

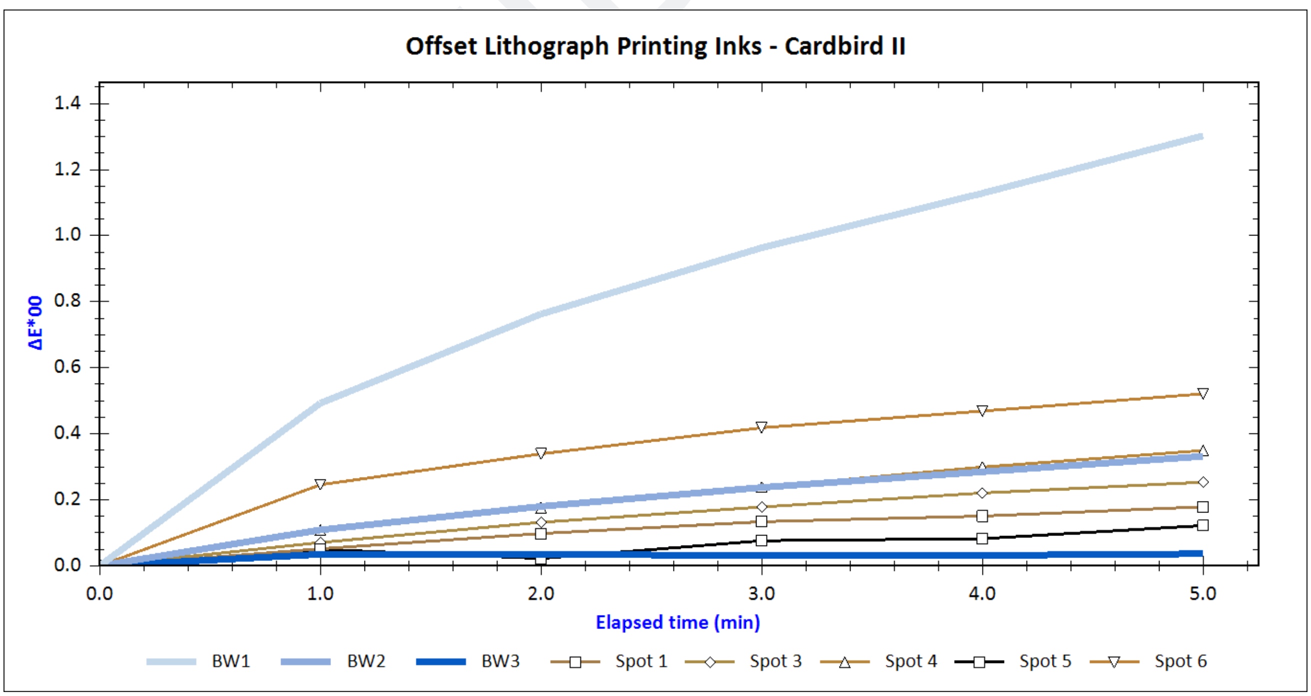


Figure X-6. MFT fading curve (ΔE*00) for *Cardbird II* (71.E005.AP3). Note: there was an error recording spot 2.

Figure X-7. MFT analysis locations for *Cardbird III* (71.E006.AP1). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.54).

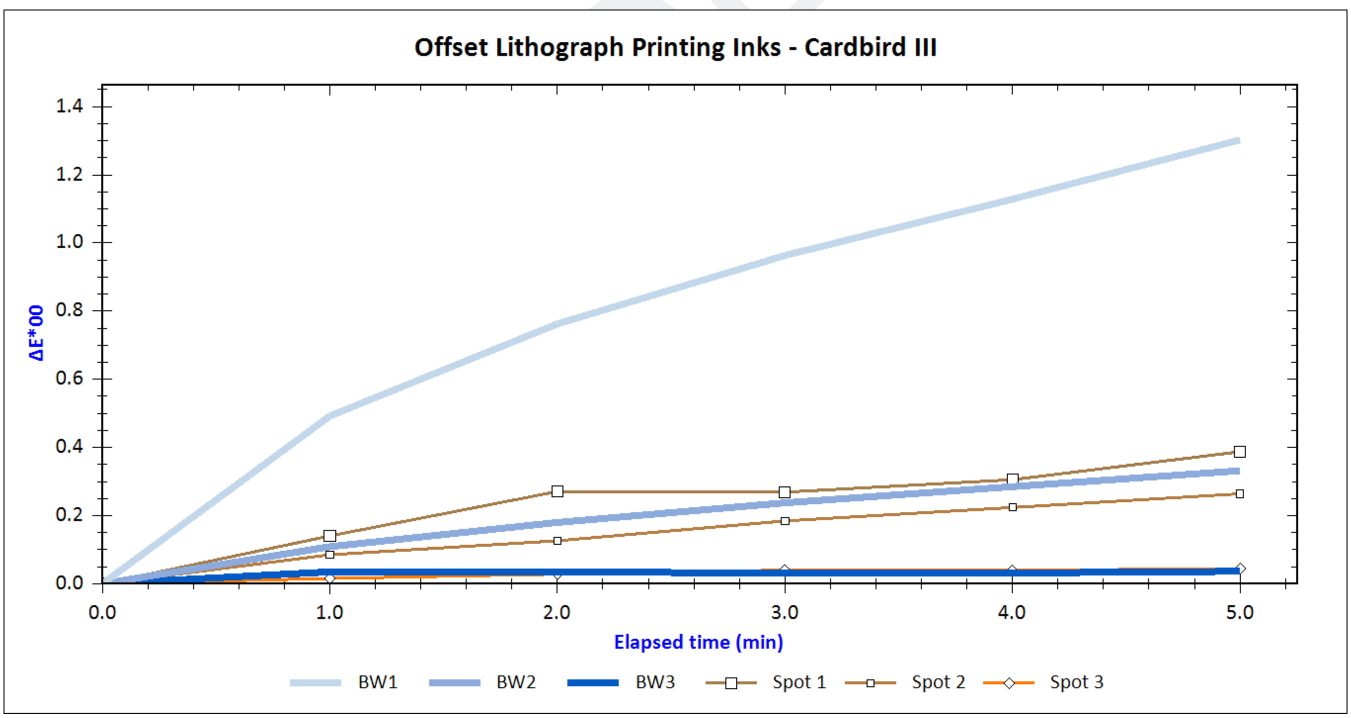


Figure X-8. MFT fading curve (ΔE^*00) for *Cardbird III* (71.E006.AP1).

Figure X-9. MFT analysis locations for *Cardbird IV* (71.E007.AP1). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.55).

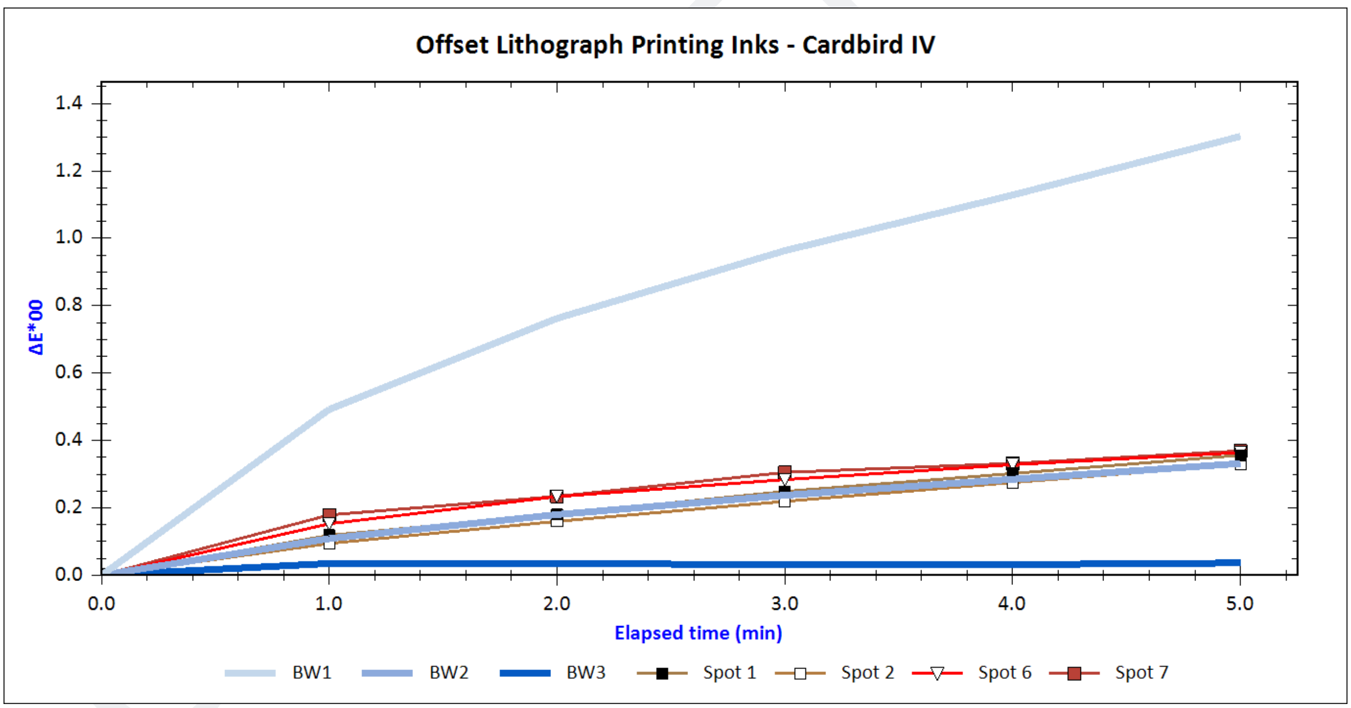


Figure X-10. MFT fading curve (ΔE*00) for *Cardbird IV* (71.E007.AP1).[24]

[24] "Due to extreme sensitivity, the test on the red area of Cardbird IV had to be stopped in under a minute. To allow further analysis, light intensity from the MFT setup was reduced from 600 to 150 mlm, and tests were repeated on BW 1, BW 2, and the red spot. Under reduced intensity, the rate of change decreased significantly, enabling an estimate that the red area's ΔE fell between BW 1 and BW 2. Subsequent testing at the standard 600 mlm again produced ΔE values of 1.2–1.3. The cause of the red area's initial extreme sensitivity remains unclear" (Hark 2025). Refer to the full report for reduced intensity tests and additional information.

Figure X-11. MFT analysis locations for *Cardbird V* (71.E008.AP1). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.56).

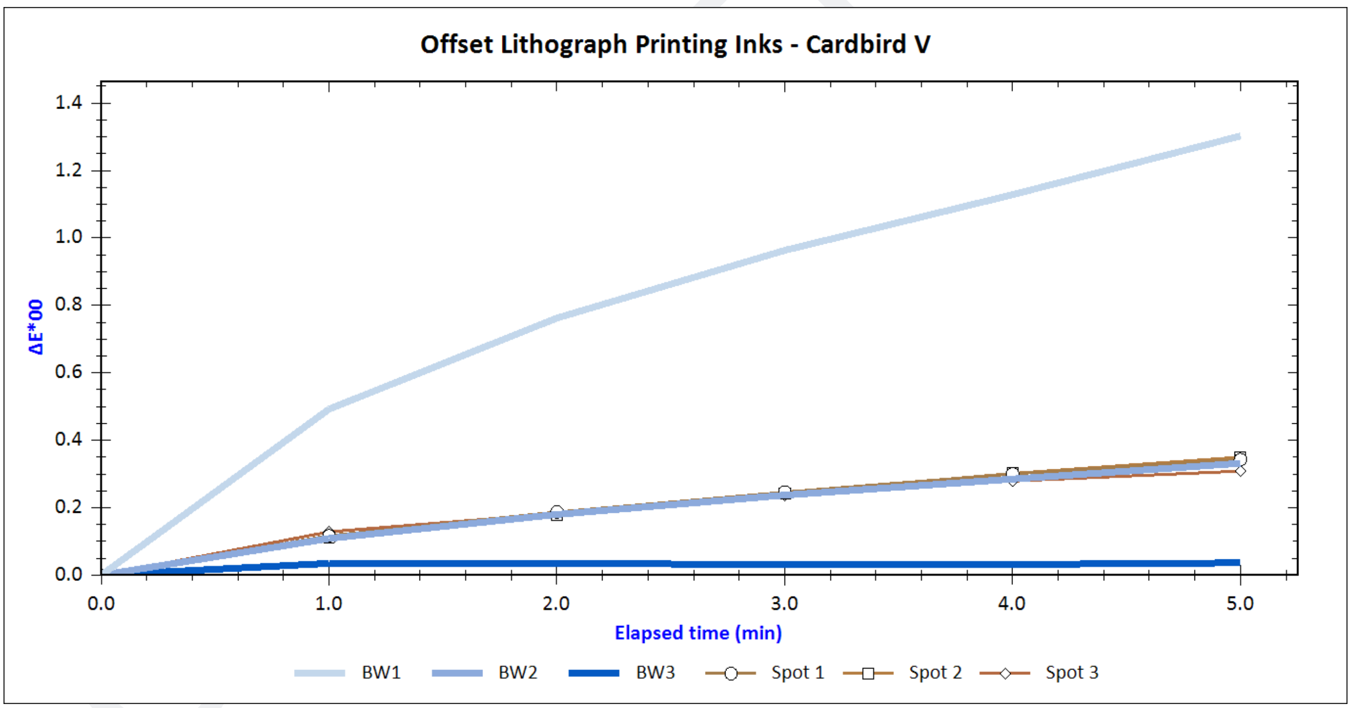


Figure X-12. MFT fading curve (ΔE*00) for *Cardbird V* (71.E008.AP1).

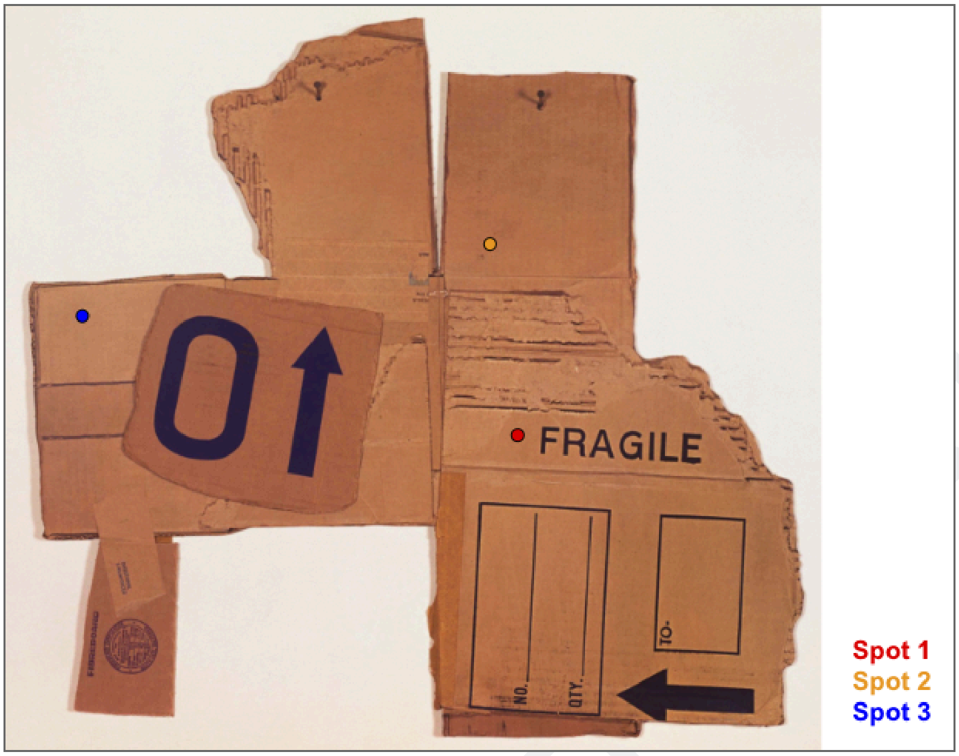


Figure X-13. MFT analysis locations for *Cardbird VI* (71.E009.AP1). Image source: Gemini G.E.L. Online Catalogue Raisonné (41.57).

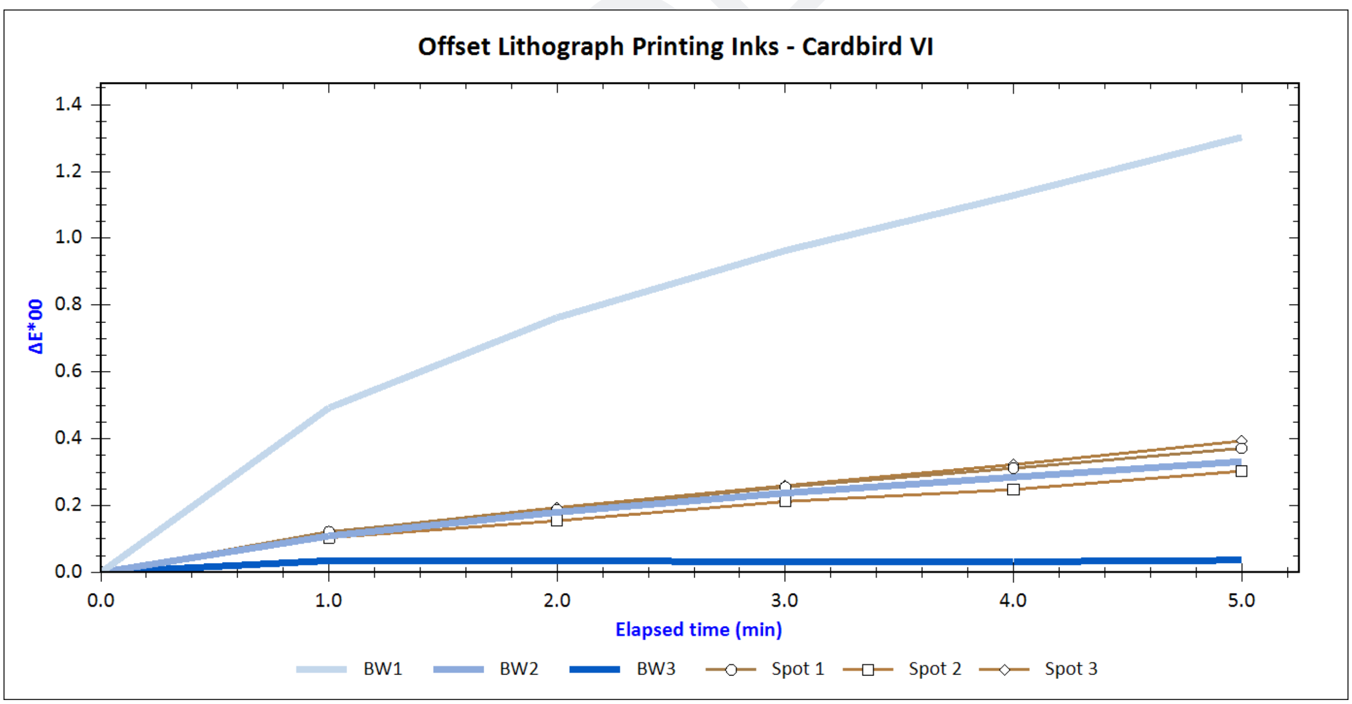


Figure X-14. MFT fading curve (ΔE*00) for *Cardbird VI* (71.E009.AP1).

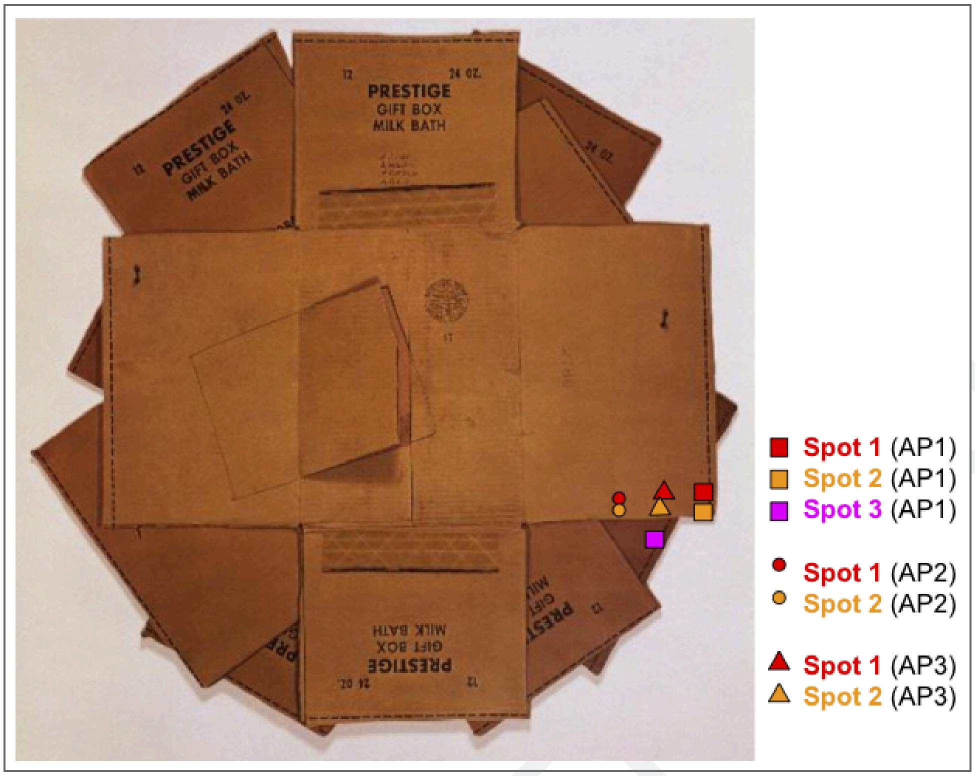


Figure X-15. MFT analysis locations for *Cardbird VII* (71.E010.AP1, 71.E010.AP2, 71.E010.AP3).Image source: Gemini G.E.L. Online Catalogue Raisonné (41.58).

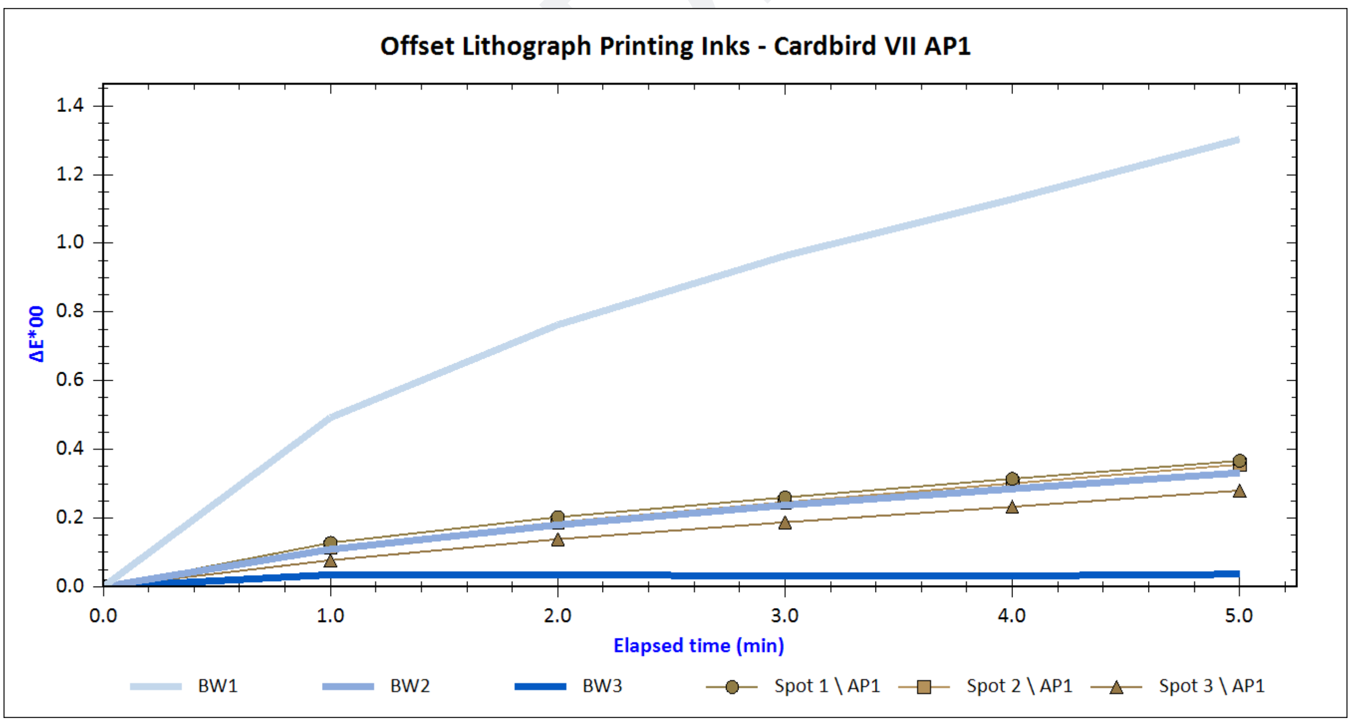


Figure X-16. MFT fading curve (ΔE*00) for *Cardbird VII* (71.E010.AP1).

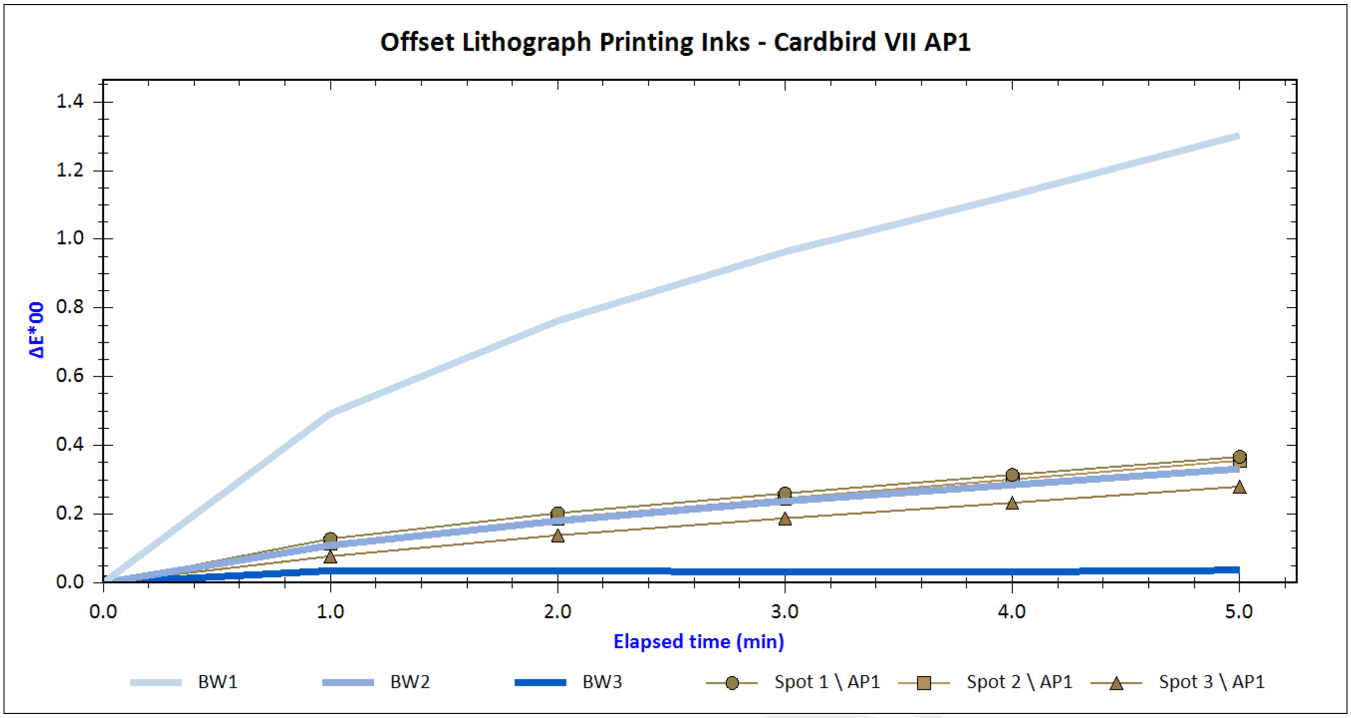


Figure X-17. MFT fading curve for *Cardbird VII* (71.E010.AP2).

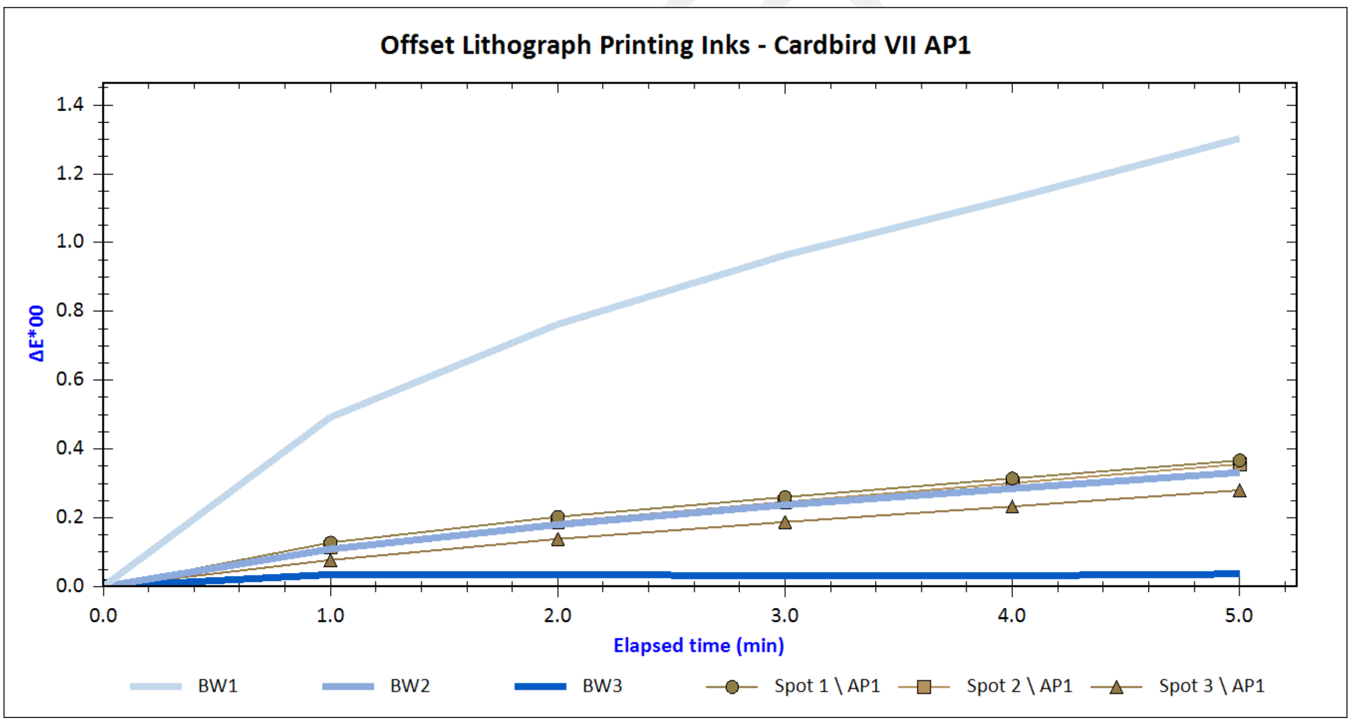


Figure X-18. MFT fading curve (ΔE*00) for *Cardbird VII* (71.E010.AP3).

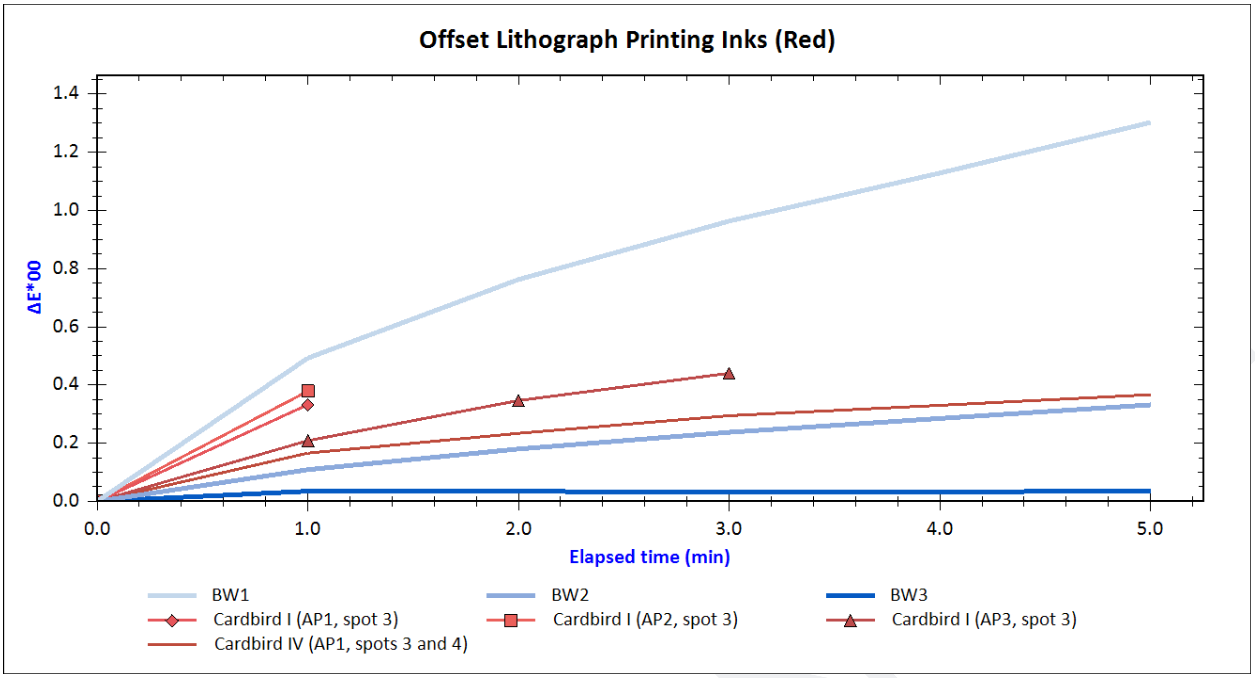


Figure X-19. Comparison of MFT fading curves (ΔE*00) for four *Cardbird* works printed with primarily red offset lithograph printing ink. This is the same chart as Figure 3 (interpreted in section "3.4 Photostability: Spectrophotometry and Microfade Testing"), but with Δ*E00 as the y-axis instead of ΔE*ab.

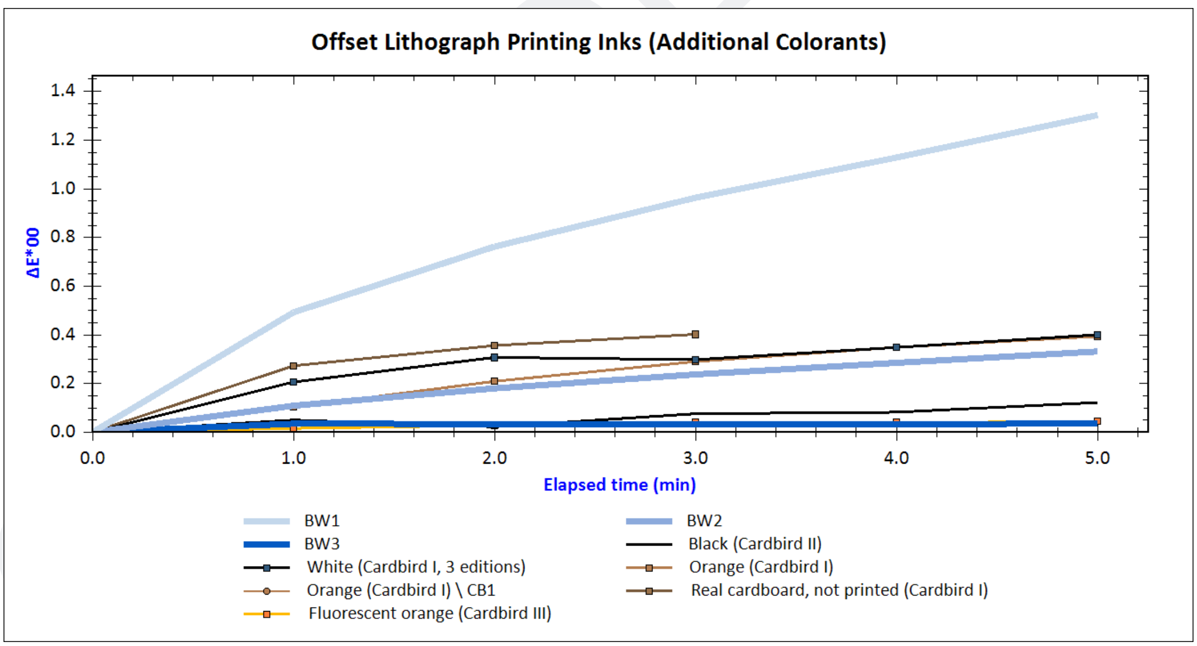


Figure X-20. Comparison of MFT fading curves (ΔE*00) for additional components of *Cardbird I-III*. This fading curve depicts multiple colored components beyond the offset lithograph that were briefly investigated. Light sensitivity is variable: the white paper corresponded to BW 1.5-2, the orange section of *Cardbird I* (area of orange in the "H" in Hardware in California Hardware Company) corresponded to a BW 2 and BW 3 on two different editions; the actual cardboard corresponded to BW 1.5-2, and the bright orange paint in the circle of *Cardbird III* corresponded to BW 3.