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The Phenomenon of Platinum Print "Image Transfer" to Adjacent Papers

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People have been fascinated by all types of ghosts since stories have been told. The interest in "ghost images" that form on papers adjacent to certain types of photographs is no different. This phenomenon of a faint replica image created on papers stored in contact with platinum photographs and matte collodion silver prints toned with platinum is well documented and often used as an aid to identifying the process of the original photograph.[1] These mirror images, in a yellow or reddish-brown color,[2] are usually positives corresponding in density to the original print (fig. 1). In rare instances, examples exist as negatives with reverse image tones (fig. 2). Because these images are often such faithful representations of the photograph they mirror, there has been a recent trend to display these images as art in their own right, either with or without the accompanying parent photograph.[3]

While there has long been an interest in these ghost images, little research has been done to elucidate the phenomenon of the platinum mirror image–formation process. James Reilly described the process generally as an image transfer and refers to the catalytic abilities of platinum to speed up the formation of discolored products in paper that comes in contact with the platinum in the prints.[4] Similarly, Bertrand Lavédrine explained that the mirror-image formation can be a useful way to identify platinum prints, and he used the word "ghost" to describe the images formed where the natural cellulose degradation has been sped up by the platinum particles in the adjacent print.[5] This type of mirror-image formation is therefore not a true transfer process. However,

Figure 2. Peter Henry Emerson, *Gathering Water-Lilies*, 1886. Platinum print, 19.8 x 29.1 cm. Plate IX from P. H. Emerson and T. F. Goodall, *Life and Landscape on the Norfolk Broads* (London: Sampson Low, Marston, Searle and Rivington, 1886). National Gallery of Art, Gift of Harvey S. Shipley Miller and J. Randall Plummer, in Honor of the 50th Anniversary of the National Gallery of Art, 1995.63.1.i.

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2a. Detail of lower left corner.

2b. Negative ghost image on the interleaving tissue adjacent to the area shown in figure 2a.

Figure 1. Richard Keene, *Grindleford Bridge*, c. 1883. Platinotype, 8.2 × 14.5 cm, and corresponding positive ghost image on facing interleaving tissue. From Edward Bradbury, *All about Derbyshire* (London: Simpkin, Marshall, 1884), plate facing page 216. National Gallery of Art, Photograph Conservation Department Study Collection, Gift of Mike Ware.

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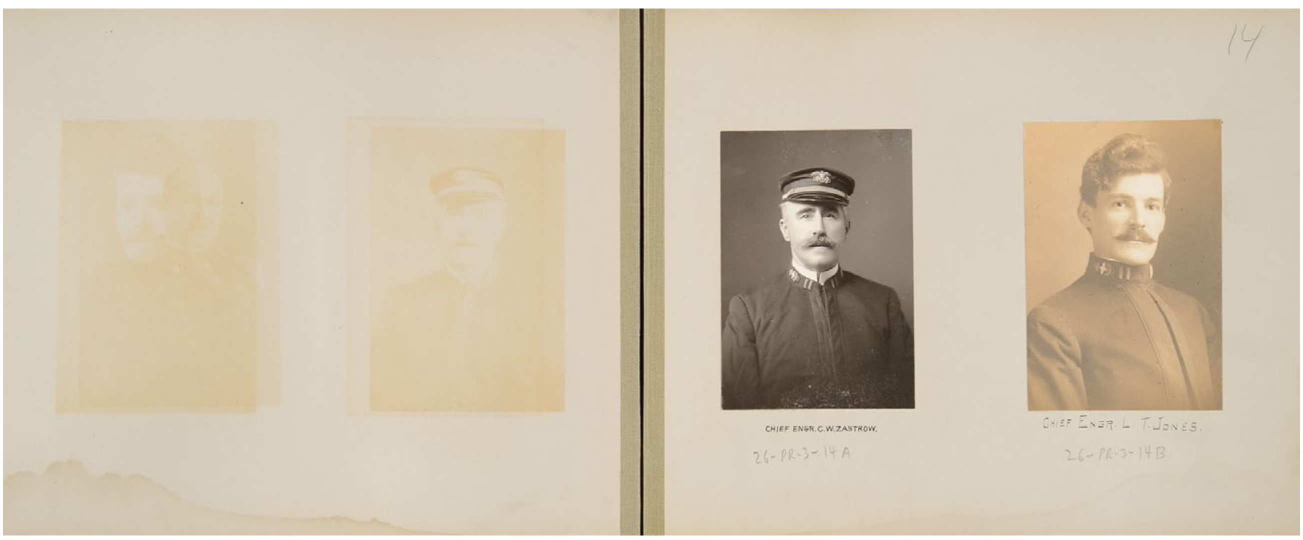
a 1998 National Park Service *Conserve O Gram*, may be the first to use the colorful term "ghost image."[6] Mike Ware has suggested the most illuminating and descriptive term, "autoplatinography," to express the idea that platinum is catalytically involved in creating these images on adjacent papers spontaneously over a lengthy period of time.[7] Lisa Duncan referred to a similar phenomenon with the general term "offset" when she analyzed some of Ansel Adams's gelatin silver photographs that did not contain platinum but did form ghost-like images.[8] Because there is no one name that has been given to describe this mirror-image formation process, for the purposes of this research and essay the term "ghost" or "ghost image" is used to describe this phenomenon that has captured people's imaginations and research interests.

Even though there is currently no explanation for the phenomenon, the field seems to support the hypothesis that platinum plays a catalytic role in the process, since the photographs themselves are well preserved even after creating ghost images. In fact, a reprographic process called "catatype," invented in 1903 by Wilhelm Ostwald, used a platinum print to repeatedly catalyze the formation of a red color in paper coated with an unstable combination of oxidant and reductant.[9]

The experiments for this research project were designed and analytical tests chosen to either support or disprove several different mechanisms of image formation, regardless of general acceptance. Testing many hypotheses was critical, as there are other examples of ghost-like occurrences in the graphic arts. Prints made with oily intaglio inks, for example, can transfer a stain to adjacent papers that appears as a mirror image to the ink. Some iron gall inks undergo interactions with adjacent papers similar to corrosion reactions,[10] which create a halo effect that can appear similar to the ghost phenomenon associated with platinum-containing photographs.

Theories that have been presented can be complementary or competing. One theory suggests that ghosts develop from the direct transfer of the platinum particles on the print to adjacent paper.[11] Other theories state that there could be direct catalytic reactions between platinum and cellulose or platinum and lignin.[12] Another suggested mechanism includes a reaction with airborne pollutants catalyzed by the platinum in the prints.[13] Other reaction types include Fenton reactions, in which residual iron reacts with oxygen and acids to form radicals that attack the cellulose backbone.[14] Oxidation or acid hydrolysis also could play a role in the mechanism of the mirror-image formation. The preliminary research presented in this essay addresses these different possible mechanisms and provides a starting point for future researchers who wish to study the process that occurs between cellulose and the metallic particles to create the images in platinum photographs or platinum-toned silver prints. For this essay, some of the ghost images have been very minimally enhanced to bring out the faint details.

Figure 3. Open page spread from U.S. Revenue Cutter Album, early 1900s. National Archives and Records Administration (NARA), RG26-PR-3-14A and 14B, Still Pictures, Records of U.S. Coast Guard. Both the platinum print of Chief Engineer L. T. Jones and the matte collodion silver print toned with platinum of Chief Engineer C. W. Zastrow formed ghosts on the adjacent page. An earlier ghost can be seen at 3a, which formed during the time that the album had been bound in a different order. Rebinding occurred prior to the 1960s, so the ghost image of Chief Engineer L. T. Jones formed in the intervening fifty-five or so years.



3a. Double ghost image of Chief Engineer L. T. Jones and another U.S. Revenue Cutter officer.

3b. Single ghost image of Chief Engineer C. W. Zastrow.

3c. Photograph of Chief Engineer C. W. Zastrow. Matte collodion silver print toned with platinum, 14.1 × 9.8 cm.

3d. Photograph of Chief Engineer L. T. Jones. Platinum print, 14.5 × 9.8 cm.

Figure 4. Prints with ghosts, 1902, deaccessioned from the War Department Records and now in the NARA Conservation Study Collection. The print shown in figure 4a was found stored in direct contact with the mount shown in 4b. Careful examination of the mount (4b) revealed the presence of multiple ghost images, including the image shown in figure 4a and an image with a flag against the sky, most likely [*boat with flag*] shown in 4c, which was stored in close proximity to the two [*boat at dock*] prints, labeled 1 and 2 for the purpose of their use in experiments. These examples indicate that when different platinum-containing prints are stored in contact with each other multiple ghosts can form. In this case, the ghosts formed over the approximately one hundred years during which the stack of prints was shuffled and moved.

4a. Photographer unknown, [*boat at dock 2*], 1902. Matte collodion silver print toned with platinum, 11.3 × 16.2 cm.

4b. Mount with multiple ghosts. The ghosts on this mount mirror the images of the prints illustrated in 4a and 4c. This mount is the verso of the matte collodion silver print toned with platinum [*boat at dock 1*], the recto of which is identical to 4a and is illustrated in figure 9. The two prints were made from the same negative and were mounted similarly.

4c. Photographer unknown, [*boat with flag*], 1902. Matte collodion silver print toned with platinum, 11 × 19 cm. Note the flag at upper right.

4a.1. Detail of 4a.

4b.1. Detail of 4b.

4c.1. Detail of 4c.

Surveys and Analytical Examination

Initially approximately eighty platinum and platinum-toned matte collodion prints were examined to categorize the prints and associated historic mirror images, especially when they exist together as pairs. About half the prints had associated ghosts on the papers that were stored in direct contact with the prints. Several historic sets were found in the holdings of the National Archives and Records Administration (NARA), including those in a U.S. Revenue Cutter Album dating from the early 1900s (fig. 3). Additional samples were donated by the National Gallery of Art's Photograph Conservation Department and private collectors. The following information and physical characteristics were recorded: type of photograph, date, location, image tone, paper color, presence of mount and interleaving, presence of mount adhesive, condition, and housing. No specific trends were identified that pertained to photographs with ghost pairs as opposed to photographs without ghost pairs. Except for the negative ghost image found in the volume of platinum prints by P. H. Emerson and T. F. Goodall (see fig. 2), all others observed during the study were positive images, where image density correlates with that of the corresponding photograph (see figs. 1, 3–6). Several samples also had more than one ghost image due to changes in the binding order of an album, which caused two different ghosts to form on the same adjacent page (see fig. 3) or due to shifting and shuffling of photographs in a stack over the years (fig. 4). This

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Figure 5. Photograph of John La Farge's 1880 painting, *Visit of Nicodemus to Christ*, 1896. Platinum print, 30.5 × 24.8 cm. National Gallery of Art Photograph Conservation Study Collection.

5a. Verso of a mount that was stored against the platinum print in figure 5, showing a positive ghost image.

observation of two different ghosts facing the photograph of L. T. Jones (see fig. 3) demonstrates that these images can form in less than one hundred years. In the case of the NARA album, the rebinding and change in page sequence occurred fifty to sixty years ago, resulting in a clear, dark ghost corresponding to the current opposite photograph over the one generated by a different photograph from the previous binding order (see fig. 3a).

Selections of sample mirror-images with their corresponding photographs were analyzed by several techniques as part of the survey process. Instrumental methods included infrared (IR) and ultraviolet (UV) photography, microfade testing (MFT), UV-visible spectroscopy (UV-VIS), Fourier transform infrared spectroscopy (FTIR), x-ray fluorescence spectroscopy (XRF), x-ray photoelectron spectroscopy (XPS), time-of-flight secondary ion mass spectrometry (TOF-SIMS), solid-phase microextraction–gas chromatography–mass spectrometry (SPME-GC-MS), and scanning electron microscopy–energy dispersive spectroscopy (SEM-EDX). The analyses indicated that the same elements/molecules were present in both the light and dark areas of the historic ghost image as well as in the blank paper surrounding the ghost image. The UV-VIS spectroscopy of the dark area of the ghost shows a decrease in reflectance in the yellow and red wavelength of light when compared with reflectance of the clear paper or the light area of the ghost; this decrease corresponds to a decrease in the reddish-yellow or brown color visible with the human eye. However, this finding does not shed light on the mechanism of the phenomenon. The microfading experiments showed that the historic ghost was considered as lightfast as Blue Wool 3,[15] which is typically used as the standard for the safe display of records or art objects under low light levels in controlled exhibition conditions.

There were no new elements or molecules found that could distinguish between the ghost image and naturally aged paper. The XRF, XPS, and SEM-EDX results did not support the hypothesis that a metal was transferring from the photograph to the adjacent paper to create the ghost image. Nor did XRF support the hypothesis that the photographs that created ghosts contained more residual iron than photographs that had no known ghosts. FTIR, TOF-SIMS, and SPME-GC-MS detected similar organic peaks and patterns in the light and dark areas of the ghost image and surrounding paper. While FTIR and SPME-GC-MS did not show significant differences in peak

Figure 6. Photographer unknown, [*portrait of a woman*], date unknown. Platinum print, 16.2 × 9.4 cm. Private collection. This print is seen removed from its protective folder and interleaving tissue.

6a. Inside board of the protective folder, showing a ghost image of the platinum print.

6b. Tissue paper that was interleaved and in direct contact with the platinum print, showing a faint ghost image.

intensity, TOF-SIMS showed some intensity differences in peak height between the light and dark image areas of the one historic and one laboratory-created ghost samples, but no new peaks. The intensity difference suggests a potential difference in ion movement throughout the paper under the influence of the platinum in the adjacent photograph; however, it should be noted that without an internal marker added that is unrelated to compounds found in historic photographs, different peak ratio normalization procedures could produce different results. Therefore, the intensity difference may not be significant. These analyses still did not elucidate the responsible chemical mechanism but did suggest natural aging as well as differential ion migration under the influence of the platinum metal. See appendix for additional details.

Accelerated-Aging Studies

An accelerated-aging study was initiated to determine if ghost images could be created in a laboratory setting. It was expected that if laboratory-created ghosts could be formed, these images might prove easier to study because they would have known components and histories, without unknown historical contaminants that could complicate instrumental analysis. Seven historic platinum prints and matte collodion photographs were studied along with multiple modern step-tablet prints.

Historic Platinum Prints with Ghost Images

Two mounted matte collodion silver prints toned with platinum referenced in figure 4 were selected for study. Both depict a boat at a dock, and they were printed from the same negative. The mount shown in figure 4b exhibits ghost images of the prints shown in figures 4a and 4c (an image of a boat with a flag), a consequence of its being stored in a stack with several copies of the same or similar photographs. Shifting movement and shuffling of the prints over the past one hundred years have caused multiple overlapping ghost images to form on the verso of each print. The shuffling is confirmed by the fact that the flag that appears in figure 4c is not found in the print it faced at the time of study (see fig. 4a).

To study a true platinum print, the National Gallery of Art donated an 1896 photograph of John La Farge's 1880 painting, *Visit of Nicodemus to Christ*, from its study collection (fig. 5). The verso of a mount stored in contact with the platinum print (fig. 5a) has a strong and clear ghost image formed over the past approximately 115 years. Samples of modern step-tablet platinum and palladium prints produced by the National Gallery of Art's Photograph Conservation Department using known historic recipes were also shared for the present study.[16] Because these prints were made very recently, these modern step-tablet prints have not yet produced ghosts.

Finally, four platinum prints were donated from private collections for inclusion in the present study. Three did not have any extant associated historic ghost images. The fourth print, however, had generated two historic ghost images: one appeared on the fine tissue paper in direct contact with the platinum print, and the second appeared on its protective historic folder (fig. 6).

Laboratory-Created Ghost Images

The two prints of a boat at a dock referenced in figure 4, both matte collodion silver prints toned with platinum, were the first studied. To address concerns that platinum-toned silver baryta prints and true platinum photographs might have different ghost-formation processes, the La Farge platinum print (see fig. 5) was used in additional accelerated-aging experiments. The aging experiments were all conducted in Espec Environmental Chambers and followed International Standards Organization (ISO) test methods for artificial aging[17] or a modification thereof.

In initial tests of the matte collodion print [*boat at dock 1*] the oven was set for ISO humid aging conditions (80°C and 65% relative humidity) and aged for 4 weeks. Because this was the first known attempt at creating a ghost image

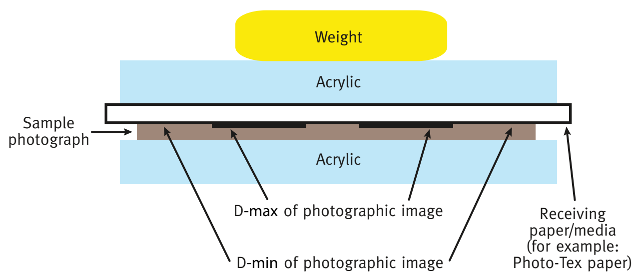

Figure 7. Schematic diagram of the accelerated aging experiment used to create ghosts. The recipient paper is placed over top of the sample photograph, and both are placed between two acrylic boards. Two 3-pound weights are placed on top of the sandwich, and the sandwich is then placed in the environmental chamber for accelerated aging shown in figure 8.

Figure 8. The environmental chamber used for accelerating-aging experiments. Initial aging conditions were 80°C and 65% RH for 4 weeks. Final aging conditions were 70°C and 65% RH for 6 weeks.

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through laboratory aging, several different paper types were placed in contact with the photograph, all of which were then sandwiched between two acrylic sheets. The sandwich was then weighted with two 3-pound weights as shown in the schematic (fig. 7) and aged in an environmental chamber (fig. 8).

The paper types were chosen for their different properties, including texture, pH/alkaline reserve, and grade of material. The six papers selected were Photo-Tex,[18] a fairly smooth, lightweight, alkaline-sized but unbuffered, lignin-free, 100% cotton, high-quality conservation interleaving paper; Whatman no. 1 filter paper, a neutral pH, slightly rough, heavyweight, pure alpha-cellulose paper typically chosen as a model for analytical studies; lens tissue, an open weave, very lightweight, unbuffered, lignin-free paper historically used for interleaving; glassine, a very smooth and glossy, lightweight unbuffered, lignin-free paper also historically used for interleaving; newsprint, a fairly smooth, lightweight, buffered paper with lignin; and file folder stock, a very smooth, heavyweight, slightly acidic, lignin-free paper. The newsprint and folder stock served as poorer-quality papers in contrast to the conservation-grade materials. For a complete list of the properties of the papers chosen for laboratory-created ghost images, see table 1.

After aging in the environmental chamber at 80°C and 65% RH for 4 weeks, the sandwich of the photograph shown in figure 9 was unpacked and findings assessed. Noticeable ghost images were visible on the Photo-Tex and Whatman no. 1 papers. A slight ghost was visible on the lens tissue and glassine, but none was observed on the newsprint or file folder stock. However, all six receiving papers accepted stain transfer from the board used to mount the print. This first experiment yielded several new pieces of information:

- The formation of a ghost image is independent of pH and alkalinity, because the alkaline-sized but unbuffered Photo-Tex (pH 9.4) and the near-neutral Whatman no. 1 paper (pH 5.6) both formed ghosts.
- Lignin degradation in the recipient paper was not a possible mechanism, because neither Whatman no. 1 nor Photo-Tex contains lignin but both clearly showed a ghost, and the lignin-containing newsprint did not show a ghost.
- The mechanism cannot be a simple stain transfer of degradation products associated only with the platinum-toned image, because all six receiving papers accepted stain transfer from the 100-year-old poor-quality mount board margins but only some of the recipient papers actually formed a ghost image from the

Table 1 | Materials Tested for Creating Ghost Images by Accelerated Aging

	Receiving Paper/ Material	Typical Use	Texture	Weight/ Thickness	Fiber Type	pH	Alkaline Reserve	Sizing	Lignin	Quality
Papers chosen for testing with matte collodion prints	Photo-Tex	Interleaving	Fairly smooth	Light	Cotton	pH 9.4*	None	Alkylketene dimer alkaline sized	None	Conservation-grade
	Whatman no. 1	Model paper	Slightly rough	Heavy	Alpha-cellulose	pH 5.6*	None	None	None	Conservation-grade
	Lens tissue	Interleaving	Open weave	Very light	100% hemp	pH 6–7	None	None	None	Conservation-grade
	Glassine	Interleaving	Very smooth	Light	Unknown	pH 6–7	None	None	None	Conservation-grade
	Newsprint	Model paper	Fairly smooth	Light	Recycled/ wood pulp	pH 8–10	Buffered	Unknown	Yes	Not conservation-grade
	File folder stock	Housing	Very smooth	Heavy	Recycled content	pH 5–6	None	Internal rosin	None	Office-grade
Additional materials used with platinum prints	PermaLife	Archival paper	Fairly smooth	Light	25% cotton	pH 9.7*	Buffered	Alkaline	None	Conservation-grade
	Hollytex	Interleaving	Open weave	Light	Polyester	N/A	N/A	N/A	None	Conservation-grade
	Aluminum oxide plate	Inert material	Very smooth	N/A	N/A	N/A	N/A	N/A	None	Analytical-grade material

* Tested in-house. Other pH values or ranges are based upon product specification and/or product advertising. For example, Whatman is marketed as neutral but in the laboratory the pH was found to be 5.6, just as Photo-Tex is marketed as unbuffered but had a laboratory-determined pH of 9.4.

9a. Whatman no. 1 | 9b. Glassine | 9c. Photo-Tex

9d. File folder stock | 9e. Newsprint | 9f. Lens tissue paper

9g

9h

Figure 9. Photographer unknown, [*boat at dock 1*], 1902. Matte collodion silver print toned with platinum, 11.3 × 16.2 cm. This is the recto of the image of the mount shown in figure 4b, and it is shown after the first aging experiment, with the six test papers (see table 1). Aging conditions were 80°C and 65% RH for 4 weeks.
9a. Whatman no. 1 paper. A clear, well-defined ghost is visible.
9b. Glassine. A slight ghost is visible.
9c. Photo-Tex paper. A clear, well-defined ghost is visible
9d. File folder stock. No ghost is visible, but the paper accepted stain transfer from the aged mount board.
9e. Newsprint. No ghost is visible, but the paper accepted stain transfer from the aged mount board.
9f. Lens tissue paper. A slight ghost is visible.
9g. Detail of [*boat at dock 1*].
9h. Detail, Photo-Tex paper shown in figure 9c. A ghost is visible.

photographic image. For example, the file folder stock received a dark stain transfer from the mount board but no image coloration indicative of a ghost from the print. In addition, the thin baryta layer of the matte collodion print may impede movement of cellulose degradation products from the photograph's underlying paper support.

- The ghost on the Photo-Tex is especially easy to see, and this result can be attributed at least in part to the smoothness of the Photo-Tex, which gave good contact between the recipient paper and the print. However, the quickly recognizable figures of the men standing on the dock in white shirts and dark hats are also easier to distinguish in a ghost than a less-easily recognized shape or pattern such as the waves in the water.

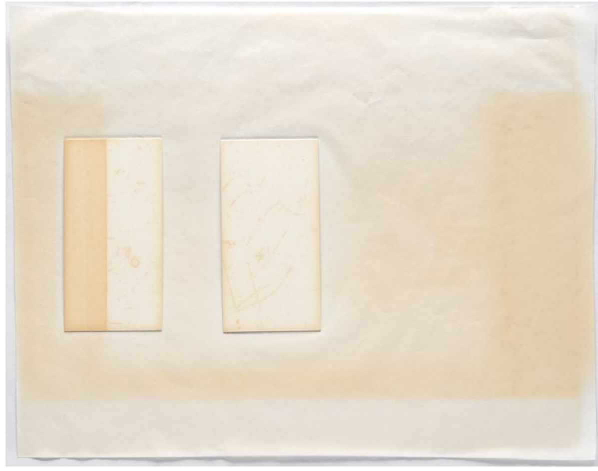
The experiment was repeated with [*boat at dock 1*] (see fig. 9) and the six papers, this time without weighting the acrylic sandwiches in order to test the effect of pressure and contact. Photo-Tex and Whatman no. 1 showed ghost images, but lighter than those produced in the first experiment. Lens tissue and glassine did not appear to form any

Table 2 | Ghost Image Formation Results [*boat at dock 1*] (fig. 9)

Aging Conditions: 80°C and 65% RH for 4 weeks

	Receiving Material	**Ghost**	**Mount Stain**
Heavy weight on samples	Photo-Tex	Yes	Yes
	Whatman no. 1	Yes	Yes
	Lens tissue	Slight	Yes
	Glassine	Slight	Yes
	Newsprint	None	Yes
	File folder stock	None	Yes
Lighter weight on samples	Photo-Tex	Yes	Yes
	Whatman no. 1	Yes	Yes
	Lens tissue	None	Yes
	Glassine	None	Yes
	Newsprint	None	Yes
	File folder stock	None	Yes

Figure 10. [*boat at dock 1*] (see fig. 9) after the experiment testing cellulosic and noncellulosic materials, with the Photo-Tex papers. Aging conditions were 70°C and 65% RH for 6 weeks.



10a. Photo-Tex paper with two aluminum oxide thin layer chromatography (TLC) plates resting on it. The ghost is visible on the Photo-Tex paper, but no ghost formed on the two TLC plates, although the TLC plate on the left was a strong accepter of stain transfer from the mount board.

Figure 11. Platinum print photograph of John La Farge's 1880 painting, *Visit of Nicodemus to Christ*, 1896 (fig. 5), after aging. Aging conditions were 70°C and 65% RH for 6 weeks.

11a. Photo-Tex paper, in contact with the top portion of the platinum print. The ghost is visible.

11b. PermaLife paper, in contact with the lower portion of the platinum print. The ghost is visible.

Table 3 | Ghost Image Formation Results

Aging Conditions: 70°C and 65% RH under weight for 6 weeks

	[*boat at dock 1*] Matte Collodion Print (fig. 9)		**[*boat at dock 2*] Matte Collodion Print (fig. 4a)**		**La Farge Platinum Print (fig. 5)**	
Receiving Material	**Ghost**	**Mount Stain**	**Ghost**	**Mount Stain**	**Ghost**	**Mount Stain**
Photo-Tex	Yes	Yes	Yes	Yes	Yes	Yes
Whatman no. 1	Yes	Yes	Yes	Yes	–	–
Hollytex	–	–	No	Yes	–	–
Aluminum oxide plate	No	Yes	–	–	–	–
PermaLife	–	–	–	–	Yes; blurred, not sharp	Yes; blurred, not sharp

– = not tested.

ghost images, but as they had such light ghosts in the first experiment and in the second experiment there was less weight and contact, this result was not surprising. The second experiment confirmed that better contact between the print and the adjacent paper gave stronger, clearer ghosts. See table 2 for a summary of the results of the two experiments.

Comparison of Cellulosic and Noncellulosic Materials

For the next experiments, conditions were modified with the goal of minimizing the yellowing of the paper caused by the aging of the substrate itself, thereby increasing the contrast between the paper and ghost to more easily distinguish the ghost image. To help achieve this goal, the temperature was lowered from 80°C to 70°C, while the relative humidity remained at 65%.

The matte collodion print [*boat at dock 2*] (see fig. 4a) was aged for 6 weeks at these new conditions in contact with Photo-Tex, Whatman no. 1, and Hollytex, a synthetic 100% open-weave polyester fabric support. Under the new conditions, the print [*boat at dock 2*] produced a ghost on the Photo-Tex and Whatman no. 1 paper that was more easily distinguished than the ghosts that formed on these papers in the first two experiments, with better overall contrast. Even though the Hollytex was in contact with the print containing recognizable images, it showed no obvious ghost image and accepted only a light stain along the edges where it was in contact with the mount board. Like the file folder stock, the Hollytex could absorb stain from cellulosic degradation products in the mount but did not form a ghost image (see table 3 for a summary of the results). The results suggest that another noncellulosic material should be tested for transfer to help determine if the mechanism of the ghost-image formation requires cellulose in the receiving layer as well as platinum in the print layer.

The matte collodion print [*boat at dock 1*] (see fig. 9) was tested against an aluminum oxide thin-layer chromatography plate as a second noncellulose material. The weighted test sandwich also contained Photo-Tex as a control to make sure that the print was still capable of producing ghosts even though it had already produced laboratory-created ghosts in different experiments as well as several historic ghosts. That a print could no longer create ghosts under the same experimental conditions would indicate that a reactant in the mechanism was being exhausted and that the process was not catalytic in nature. However, this matte collodion print continued to produce ghosts, including five strong laboratory-created ghosts in addition to the multiple historic ghosts, without any noticeable decrease in the intensity of the ghosts produced. The aluminum oxide plate was a strong accepter of the paper-aging stains from the mount board but did not produce a ghost in this experiment (fig. 10; see also table 3). This finding supports the hypothesis that cellulose and platinum are both required for the mirror-image formation process and that the ghost-formation process is not a stain transfer mechanism.

Platinum Prints, Transfer Images, and Stability

After testing the matte collodion prints, the aging experiments continued with a true platinum print. The photograph of John La Farge's 1880 painting, *Visit of Nicodemus to Christ* (see fig. 5) was tested in contact with a sheet of Photo-Tex and a strip of PermaLife, a fairly smooth, lightweight, buffered (3% calcium carbonate), lignin-free, 25% cotton, high-quality conservation-grade paper (see table 1) along the lower portion of the print to determine if an alkaline reserve might have any effect on the formation of a ghost image. The La Farge print created a clear, detailed ghost on the Photo-Tex paper similar to the ghosts formed on the Photo-Tex in contact with both matte collodion prints of the boat at a dock. The PermaLife paper also showed a ghost that was equally dark but not as sharp as the ghost on the Photo-Tex (fig. 11; see also table 3).

A second experiment using Photo-Tex and PermaLife aged with the La Farge print confirmed these findings. While the two paper types abutted in the first experiment, the weighted sandwich was set up in the repeat experiment so that approximately 5 centimeters of the Photo-Tex were between the PermaLife paper and the print. This experiment also served to reproduce the historically observed phenomenon of a ghost appearing on an interleaving as well as "passing through" the interleaving to form on the accompanying folder (see fig. 6, for example). Results showed that a ghost did appear on the Photo-Tex but also penetrated the Photo-Tex to appear on the PermaLife behind the Photo-Tex. The fact that the ghost appears on the paper behind the contact paper does not support the hypothesis that the second mirror image is formed through direct catalysis with the platinum. It could suggest, however, that a stain is transferred from the paper in direct contact with the print to a paper behind it or that a reactant, such as a free radical, transfers via gas phase diffusion. It is interesting to note that the ghost formed on the PermaLife both in direct contact and

Figure 12. Photographer unknown, [*portrait of a couple*], date unknown. Platinum print, 14.3 × 9.4 cm. Private collection. Aging conditions were 70°C and 65% RH for 6 weeks.

12a. Photo-Tex paper in contact with the front of the print. No ghost formed but overall paper-aging stain was transferred.

12b. Photo-Tex paper placed between back of print and mount. No ghost formed but overall paper-aging stain was transferred.

behind the Photo-Tex was slightly blurred, in contrast to the clear ghosts always observed on the Photo-Tex and Whatman no. 1 papers in other experiments. Experiments were unable to explain why the edges of the PermaLife ghost were blurred when all other ghosts, both historic and laboratory-created on smooth or rough paper, were always sharp and clear. It is possible that the alkaline reserve may affect the ghost-formation process to cause the blurring, but as PermaLife was the only test paper with a true alkaline reserve, these results would need to be repeated with a different alkaline paper to test the validity of this hypothesis. However, the experiment does support the conclusion that the ghost-image formation is independent of pH/alkalinity.

A corner of the LaFarge laboratory-created ghost image was removed and washed for 20 minutes in deionized water to determine if the image would be lost or changed through washing. This laboratory-created ghost image was previously used for the microfading test and had proven to be light stable for display under low-light-level exhibition conditions. Upon washing, the overall paper lightened as expected, but the ghost image remained clear and detailed. Stain had transferred to the adjacent paper from the mount board, and the lightening is the result of the stain being washed away during this conservation treatment. This result suggests that the normal organic breakdown products formed during paper aging and transferred to the adjacent paper remained water soluble, but the ghost image itself is not water soluble, perhaps indicating a chromophoric change to the cellulose through an oxidative and/or hydrolytic mechanism.

Aging Photographs with No Historic Ghosts

Laboratory accelerated-aging of three historic photographs without any known historic ghost images did not generate any mirror images, even when in contact with Photo-Tex, which consistently produced good mirror images when tested with photographs with known historic ghosts. In each case, the mount board stain transferred, but no ghost could be distinguished in the receiving sheets (fig. 12). The experiment was repeated with the same results. It is likely that not all platinum photographs are prone to forming mirror images, as then this phenomenon would be more prevalent.

Ghost formation from the step-tablet photographs, produced through known historic recipes, was considered inconclusive because it was difficult to distinguish discoloration related to the aging of its paper substrate from that caused by the formation of a possible mirror image. Because only a modern step-tablet was tested, there was no recognizable image to make detecting a ghost easier. In a few places on well-processed modern step-tablets trials, a darker line and faint coloring suggesting a possible ghost could be seen on the receiving paper, especially along the edge of the rectangle corresponding to the edge of the maximum-density step. In another example, the stain along the edge of a deliberately poorly processed modern step-tablet suggested a reverse ghost. However, due to the difficulty of determining whether a faint ghost or nothing at all had appeared, the results for this experiment were deemed inconclusive. In the future, it may prove useful to make prints for the purpose of forming ghost images using a standard resolution target.

Aging Platinum Black Nano-Particles and Platinum Metal

In the course of aging experiments platinum metal and platinum black were also aged against adjacent paper to attempt ghost formation of the metal or metallic particles themselves. Platinum black is a nanoparticle form of platinum with a size similar to the particles found in photographic images. The platinum metal was aged in a weighted sandwich between two sheets of Photo-Tex at 70°C and 65% RH, but no changes in the paper were observed. This result was expected, however, as most catalytic applications use platinum black. Therefore, two forms of platinum black were obtained. The first, platinum black deposited on carbon cloth, was produced by the firm Fuel Cells Etc. The second was 50 nanometer platinum nanopowder from Sigma Aldrich, which was then deposited in-house on a thin layer of methylcellulose applied to a piece of Photo-Tex. The methylcellulose was used because it is compositionally similar to paper. Both the commercial and in-house samples were aged against Photo-Tex in the sandwich-aging method.

After aging, the platinum powder on both the carbon cloth and on the Photo-Tex gave the same inconclusive results. No ghost could be distinguished on the adjacent paper because the platinum black nanopowder had rubbed off and created an overall smudgy black appearance on the adjacent paper. The carbon cloth also contributed to the "smudge" when the commercial paper was tested, as a sample of carbon cloth run as a control gave a dirty appearance similar to that of the adjacent paper. The "smudge" from the platinum black hid any potential ghost formation reaction. The attempt was made to very gently brush or blow (with nitrogen gas) the platinum black off of the adjacent paper, but this action only increased the "smudge," as the nanoparticles of platinum were forced into the weave of the paper.

The Effect of Applied Voltage

Discussions of the results of the study thus far, and specifically the TOF-SIMS results that suggested differential ion mobilities in the darker and lighter ghost areas, led to the hypothesis that the electrical charge, an electrostatic potential similar to a zeta potential existing on the nanometallic platinum particles in the cellulose fibers of the photograph, could be influencing the ghost-formation process. Cellulose fibers have associated water molecules, which could contribute to creating a quasi-zeta potential on the nanoparticles of platinum in the image and influence surrounding ion migration. To test the influence of charge on the platinum nanoparticles, a voltage was applied across the platinum portrait shown in figure 6 and adjacent Photo-Tex by modifying the accelerated-aging sandwich method to form a capacitor-type arrangement as diagrammed in figure 13. By placing copper metal strips under the print and on top of the adjacent papers between the acrylic plates, opposite polarities could be induced. The capacitor was attached to a power supply and placed in the environmental chamber at 70°C and 65% RH for aging (fig. 14). To date, the prints with known historic ghosts (see figs. 4, 5) had also generated laboratory-created ghosts upon accelerated aging. However, after a voltage of either positive or negative potential was placed across the

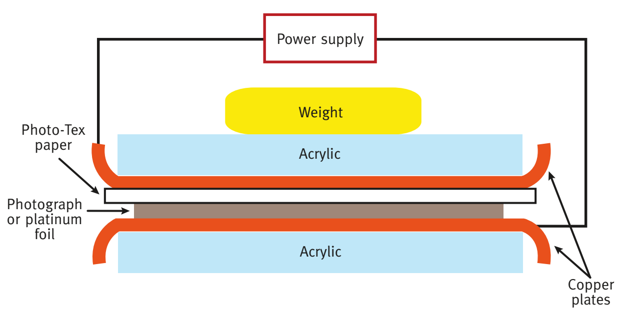


Figure 13. Schematic diagram of the accelerated-aging experiment shown in figure 7, modified with voltage difference across the sandwich. Copper plates are placed behind the recipient paper and photograph, and everything is placed between two weighted acrylic boards. The copper plates are attached to a power supply.

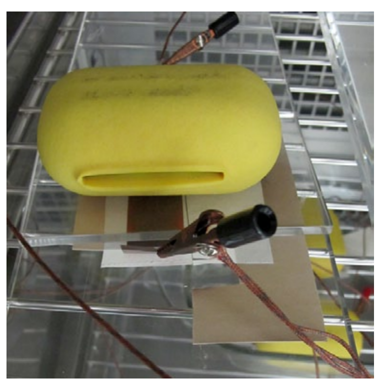


Figure 14. The capacitor-type assembly placed in the environmental chamber for aging. Final aging conditions were 70°C and 65% RH for 6 weeks.

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Figure 15. Detail of [*portrait of a woman*] (fig. 6) after aging in a capacitor-type assembly. The darkened spots that formed in the photograph were a result of aging; these exact areas had previously been analyzed by XPS.

15a. Photo-Tex paper in contact with this detail. No ghost has formed.

and used here for accelerated aging. It is likely that the mechanism or mechanisms for mirror-image formation are the same for the natural- and accelerated-aging samples (see appendix).

pH Study

Finally, to try to determine if acid transfer could play a role in the ghost-formation mechanism, a bulk cold extraction pH study was conducted on a mirror image created from the almost completely dark corner of the La Farge print (see fig. 5) and compared with an adjacent paper from a historic print that did not form a ghost image. The print that did not form a ghost had only stain transfer from the aged paper. Photo-Tex that was aged at the same conditions but with no historic material had only a slight drop in pH, from pH 9.4 to pH 9.3, but in both cases where the Photo-Tex was aged in contact with historic platinum prints, the pH was lower by almost 2 pH units regardless of whether a ghost-image formed. This finding supports the hypothesis that acids, formed in the print during aging or remaining from processing the print, transfer to the adjacent paper during contact-aging. However, because this transfer occurs for both a ghost-image adjacent paper and an adjacent paper with no ghost image, it does not elucidate the ghost-image mechanism.

platinum print, no mirror image was created even though this print had previously produced ghosts historically (fig. 15). The photograph was re-aged without a voltage potential, and still no ghost was created. Based upon the understanding that applied voltage influences how ions migrate and the TOF-SIMS data suggesting that ion migration has a potential role in the ghost-image mechanism, it is hypothesized that the voltage may have played a role in disrupting the formation of a mirror image, especially as the print had previously produced ghost images.

Analytical Examination of Laboratory-Created Ghosts

The conservation field questions whether accelerated aging accurately represents natural aging or changes the conditions so significantly that the results of an accelerated-aging test cannot be extrapolated back to natural conditions. To address this concern in relation to the historic versus the laboratory-created ghosts, the analytical techniques chosen during the research to study the historic ghost images were also used to study the laboratory-created ghosts. The analytical results from both the historic ghosts and laboratory-created ghosts produced comparable findings. The only difference was that the laboratory-created ghosts showed less environmental contamination compared with ghosts created during natural aging. For example, the laboratory-created ghosts had lower levels of iron and silicon in the XRF data. However, the overall analytical results for the historic and laboratory-created ghosts were the same, a result that supports the laboratory methodology designed

Conclusions

This project was designed to consider and test as many mechanisms and theories as possible to try to determine how ghost images are formed. The following conclusions were reached:

- Since platinum was not detected on adjacent papers, metallic species, including platinum, do not transfer from the photograph. XRF, XPS, SEM, and TOF-SIMS have shown there is no transfer, within the limits of detection of these techniques.[19]
- These techniques did not find a higher concentration of iron or sulfur in the ghost-image areas as compared with the non-ghost-image areas of the paper, so iron enrichment or pollutant effects do not seem likely as mechanisms. There was no source of gaseous pollutants in the laboratory-aging study that produced ghost images.
- Stain material hidden in the platinum image of the photograph that is transferred to the recipient paper was not likely the cause of the ghost image because: (1) stain was not detected on the image area of the

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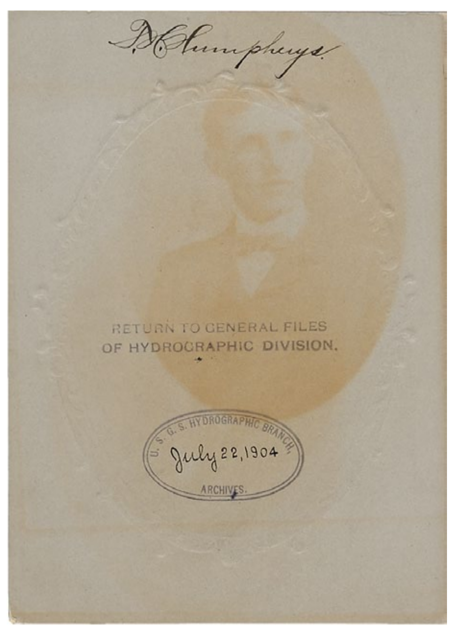
well-preserved prints used to create the ghost images; (2) all the materials tested accepted stain from the aged mount board, but not all of the materials showed a ghost image; (3) except when PermaLife was the recipient paper, the ghost image was very clear and sharp, while typical staining is diffuse and less directionally specific; (4) the pH of the paper in contact with the historic print was lower after aging regardless of whether a ghost formed; and (5) the ghost image remained sharp and clear even after water soluble discoloration due to typical aging had been removed from the paper during washing.

- Multiple ghosts were created from a single print, and the intensity and sharpness of the ghosts were consistent in later aging rounds, a result that suggests a catalysis mechanism is involved because the reaction appears to continue without being depleted over time.
- Papers of very different characteristics were able to form ghosts, including papers of different smoothness and texture, density, gloss, and pH/alkaline reserve. These characteristics, as well as the amount of contact pressure, may influence the darkness of the ghost, but not whether the ghost actually forms.
- Not all cellulosic materials formed ghosts; for example, no ghost formed on the file folder stock. However, the majority of the experiments seem to support that cellulose and platinum were both required to form the ghost image, especially as the two noncellulosic materials tested did not form ghosts.

Platinum-catalyzed reactions of cellulose or cellulose degradation products cannot be ruled out. Additionally, an electrochemical theory or ion migration theory is still valid based upon the influence of nanoparticle platinum as a cause for ghost formation. This theory would also support the observation that ghost images have also formed with prints containing only silver nanoparticles. However, based on the above findings, these experiments have eliminated some previously proposed hypotheses.

Even though the ghost-image formation mechanism is still unknown, the information discovered can be used to preserve, exhibit, and access platinum photograph holdings. Current preservation storage and housing guidelines, including those practiced at NARA to preserve its platinum print holdings (fig. 16), were confirmed for historic platinum photographic records. Conservators and other cultural heritage professionals and family historians concerned with housing and storing platinum photographs may want to use noncellulosic interleaving sheets, such as polyester, to prevent the formation of ghost images on materials in contact with photographs.[20] The presence of a ghost should not significantly influence decisions regarding exhibition, and ghosts may be safely exhibited under low-light-level museum conditions.

16



16a

Figure 16. Photograph of L. M. Holt, 1905. Matte collodion silver print toned with platinum, oval 12.7 × 8.8 cm. NARA, RG 115-RDP, Records of the Bureau of Reclamation, Prints: Portraits of the U.S. Geological Survey, Hydrographic Division Personnel, 1903–6.

16a. Adjacent mount showing ghost image.

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Both the historic and laboratory-created ghosts gave similar analytical results, a finding that suggests the mechanism or mechanisms for the historic and laboratory-created ghosts are likely the same. This finding is significant because the laboratory-created ghosts are therefore a good model for studying the ghost-formation phenomenon that occurs naturally. The authors hope that future research will find the accelerated-aging method described in this essay helpful for creating ghosts in the laboratory and that the observations and analytical results presented here will aid understanding and advances in knowledge about the mechanisms behind the ghost image–formation process in platinum photographs and platinum-toned matte collodion silver prints.

Acknowledgments

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Notes

1. For information on toning with platinum, see Ronel Namde and Joan M. Walker, “Platinum Toning of Silver Prints,” in this volume. It is of note that palladium prints by Alfred Stieglitz in the National Gallery of Art’s collection have mirror images on the facing window mats, but this essay and study focus only on platinum photographs and platinum-toned matte collodion prints.

2. Reilly 1986, 24.

3. Bray 2013, 103.

4. Reilly 1986, 24.

5. Lavédrine 2009, 159.

6. Vogt-O’Connor 1998.

7. Mike Ware, “The Technical History and Chemistry of Platinum and Palladium Printing,” in this volume.

8. Lisa Duncan, “A Photographic Offset: The Technical Study of Ansel Adams’s 1927 Portfolio, *Parmelian Prints of the High Sierras*” (MA thesis, Winterthur/University of Delaware Program in Art Conservation, 2009), online at lisaduncanllc.com.

9. Ware, “Technical History and Chemistry of Platinum and Palladium Printing,” in this volume.

10. These are seen on iron gall ink records in National Archives and Records Administration holdings.

11. Whitney 2010.

12. Mike Ware, personal communication, 2015; Whitney 2010; Boeringa 2010.

13. Ware, communication.

14. Boeringa 2010.

15. Section 1.4.1, “Standards, Guidelines, and Recommendations for Light Levels during Exhibition,” in Photographic Materials Specialty Group 2004.

16. For more information on historic recipes using modern materials, see Matthew L. Clarke, “Characterization, Degradation, and Analysis of Platinum and Palladium Prints,” in this volume.

17. ISO 5630-3:1996 “Paper and Board—Accelerated Ageing—Part 3: Moist Heat Treatment at 80°C and 65% Relative Humidity,” www.iso.org.

18. Photo-Tex is internally sized with alkylketene dimer. This sizing is accomplished in an alkaline process, but no true alkaline reserve is imparted so the paper is unbuffered even though it has a higher than neutral pH.

19. It was noted that mercury could transfer from a modern palladium print to either another palladium print or to an adjacent paper. However, the transfer of mercury did not produce any image or visually change the adjacent paper, so it appears to be unrelated to the ghost image–formation process. It was also noted only when analyzing modern palladium prints, not when analyzing historic or modern platinum prints or matte collodion prints toned with platinum.

20. The St. Louis facility of the National Archives and Records Administration holds an especially significant ghost image that formed from a photograph on the adjacent page of the associated record. Had this ghost image not formed, the likeness of serviceman Hugh Edmiston Jr., would have been lost completely because the photograph was destroyed by the water used to put out the fire in 1973, while the paper with the ghost image was saved from the fire by the water. Thus Edmiston’s image was preserved through the ghost phenomenon!

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Appendix

Instrumental Analysis Summary for the Phenomenon of Platinum Print "Image Transfer" to Adjacent Papers

While the results of analyses to elucidate the mechanism of ghost-image formation are inconclusive, the following descriptions of instrumental conditions and summaries of results are presented as a starting point for future analysis of the phenomenon.

Paper produces numerous volatile organic compounds as it ages, and analysis of these emissions may provide insight about degradation pathways.[1] Volatiles from ghost and nonghost areas of a Photo-Tex specimen were studied using contact solid-phase microextraction.[2] A divinylbenzene/Carboxen/polydimethylsiloxane fiber (Supelco) was placed in direct contact with samples for 5 days. Gas chromatography–mass spectrometry (GC-MS) analysis was performed on an Agilent 5973 Inert system with a 30-meter HP-INNOWAX column (Agilent). Although a range of compounds was detected, the differences in concentration between ghost and nonghost areas were not significant.

X-ray fluorescence (XRF) and Fourier transform infrared spectroscopy (FTIR) have been widely used to study cultural heritage materials, since both are nondestructive techniques[3] and therefore compatible with analyzing photographs.[4] They are complementary techniques as well, because XRF provides information on the inorganic elemental composition and FTIR analysis elucidates the molecular and organic composition. A Thermo Nicolet FTIR 6700 with a Harrick Scientific Video Meridian Attenuated Total Reflectance accessory with OMNIC software was used to collect the FTIR spectra. FTIR also was not able to distinguish between the light and dark areas of the ghost because the spectra of the light and dark areas of both historic and laboratory-created ghosts matched that of cellulose and could not be differentiated.

XRF spectra were collected with the Bruker ARTAX 400 XRF instrument with a helium flush and the rhodium tube operated at 50 kV and 700 μA for 180 seconds. A focus of 0.65 mm with an air pocket behind the sample was used to compare the light and dark areas of the ghost with the surrounding paper as well as with the same areas on the photograph. XRF demonstrated that no transfer of metallic elements from the photographic surface was causing the ghost image; the light and dark areas of the ghost image gave the same elemental peaks as the surrounding paper. Iron, calcium, potassium, silicon, and aluminum were found in the historic ghosts, some of which are possibly from environmental contamination, while only iron and calcium were found in the laboratory-created ghosts. The XRF results were confirmed by scanning electron microscopy with energy dispersive spectroscopy (SEM-EDX) run on the Hitachi S-3500N operated in variable pressure mode at 15 kV accelerating potential with an Oxford Aztec EDS system. The SEM imaging also did not detect any differences between the light and dark area. The relative amounts of iron, calcium, and sulfur found by XRF in three platinum photographs did not correlate to the production of a ghost image: images were formed by only one of two prints with a high iron concentration, but an image was formed by the third print with a low iron concentration. Therefore, the relative amounts of iron could not be used to predict if a ghost would form.

XPS analysis of [*portrait of a woman*] (see fig. 6) was performed on a Kratos Axis 165 x-ray photoelectron spectrometer operating in hybrid mode using monochromatic Al Kα x-rays (1486.7 eV). The pressure of the instrument was 5×10^{-8} Torr or lower throughout data collection. Charge neutralization was required to minimize sample charging. Survey spectra and high resolution spectra were collected at pass energies of 160 eV and 20 eV respectively. XPS data were collected from the surface of the platinum photograph from both light and dark areas as well as two control areas near the edges where there was no visible image. Data were taken from equivalent areas on the ghost image and also the interleaving tissue paper.

The XPS results clearly showed platinum signal from the photograph, as would be expected, while the data taken from the ghost image showed no evidence of platinum within the detection limits of XPS (~0.05 elemental %). Data taken from the surface of the platinum photograph also revealed the presence of calcium (~0.1%), nitrogen (~6.0%), silicon (~0.5%), and sulfur (0.4%); however, there were no significant concentration differences between the four spots measured on or off the platinum photograph. The equivalent spots on the ghost image sample also showed calcium (~0.1%), nitrogen (~0.5%), silicon (~1.2%), and sulfur (~0.3%). In addition aluminum (~1.9%) and chlorine (0.04%) were detected, and there were no significant differences between the four spots probed. The same elements detected in the ghost image were also detected in the interleaving tissue paper.

As well as giving quantifiable elemental information about the top 10 nm of a surface, XPS also gives chemical state information. The C 1s high-resolution region was looked at more carefully to reveal any differences between chemical bonding from spot to spot and sample to sample.

Each C 1s spectrum was peak fit to four peaks corresponding to C-C/C-H, C-O-R, C=O and COOR functionality. XPS would be expected to reveal any significant oxidative decomposition (i.e., oxidation of OH groups to aldehydes, ketones, or carboxylic acid/ester type functional groups) of the cellulose. Ratios of the different functional groups were compared to reveal any changes in relative concentrations of aldehyde, ketones, and carboxylic acid versus hydroxide functionality at each of the different spots on the sample. There was no significant change from spot to spot on the platinum print or the ghost image analyzed.

It should be noted that while XPS is considered to be nondestructive in many cases, x-rays have been shown to degrade some materials, particularly some classes of organic polymers, and are known to degrade cellulose[5] after long exposure times. We did notice some yellowing of the areas that had been exposed to the x-ray beam for longer periods. The C 1s spectra were collected relatively quickly, so we anticipate the functional group analysis to be reflective of undamaged cellulose. However, the longer collection times required for the low-concentration elements did lead to some degradation evident upon aging (see fig. 15).

Time-of-flight secondary ion mass spectrometry (TOF-SIMS) analysis was carried out in an IONTOF TOF-SIMS5-300, using a 30 keV Bix+ analysis beam. The base pressure of the instrument was 1×10^{-8} Torr or lower throughout data collection. Both the ghost image from figure 6 and a laboratory-created ghost image were studied. The mass spectrum from the ghost image area revealed Na+, Mg+, Al+, AlxOy+/-, Si+, K+, Ca+, Cr+, Fe+, aliphatic and aromatic hydrocarbons, N-containing hydrocarbons, O-containing hydrocarbons, Cl-, CN-, CNO-, and sulfate. It should be realized that secondary ion intensities are not quantifiable; however, after suitable normalization, relative differences between similar samples can be realized. Based upon this chosen normalization, relative to the clear paper area, the ghost image area did not show evidence of oxidation (e.g., COOH) but did appear to have higher intensity of Na+, Mg+, Al+, Si+, K+, Ca+, Cr+, NH4+, Cl-, CN-, CNO-, and sulfate.

Similar relative differences were found in an aged laboratory-created ghost. The spectrum acquired from the ghost image was characterized by Na+, Mg+, Al+, AlxOy-, Si+, K+, Ca+, Fe+, aliphatic and aromatic hydrocarbons, N-containing hydrocarbons, O-containing hydrocarbons, Cl-, CN-, CNO-, sulfates, and dodecyl benzene sulfonate (DBS).[6] Relative to the aged paper, the ghost image was found to have higher intensities of Mg+, Al+, Ca+, Fe+, Cl-, CN-, CNO-, sulfate, and dodecyl benzene sulfonate. These results indicating the enrichment of particularly the small metallic ions in the area of the ghost led to the idea that platinum nanoparticles might exert an electrostatic charge that could contribute to the migration of these species to the surface.

A few photographs and ghosts were examined under IR and UV light. The camera used was a Fujifilm Finepix IS Pro. The examination of the ghosts under different lighting conditions did not help explain the ghost image–formation process. One ghost did fluoresce strongly under UV light, but this was an exception and could not be explained. UV-VIS spectroscopy was run on a Thermo Nicolet Lambda 950 in diffuse reflectance mode scanning from 190 through 2200 nm. While the UV-VIS spectroscopy could not elucidate the mechanism of the ghost-image formation, it did confirm the reddish-yellow-brown color of the dark area of the ghost that is visible to the human eye, since the ghost showed a decrease in reflectance especially in the yellow and red wavelength of light compared with a light area of the ghost or paper. Microfading tests[7] were also run on both historic and laboratory-created ghosts. The microfading curves of the historic and the laboratory-created ghosts were most similar to that of Blue Wool 3, which is a standard used in the textile industry and is the conservation standard used to designate stability under low-light settings used in museum exhibits.

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Notes

1. Lattuati-Derieux et al. 2006, 123–33.

2. Lattuati-Derieux et al. 2004, 9–18.

3. Cattaneo et al. 2008, 277–84.

4. McCabe and Glinsman 1995, 71–84; Lisa Duncan, "A Photographic Offset: The Technical Study of Ansel Adams's 1927 Portfolio, *Parmelian Prints of the High Sierras*" (MA thesis, Winterthur/University of Delaware Program in Art Conservation, 2009), 1–12, online at lisaduncanllc.com.

5. Brown et al. 1992, 199–209.

6. This is a common surfactant added to modern papers.

7. Whitmore et al. 1999, 395–409.

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