The Flexichrome: visual examination and scientific analysis of an overlooked color process.

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ABSTRACT

Flexichrome is the commercial name for a dye imbibition process where the color image is formed by hand coloring a gelatin relief with acid dyes, without the use of color separation negatives and with great creative freedom. Final prints resemble those made with other processes like carbro or hand-colored gelatin silver. The Flexichrome was first marketed by Jack Crawford as the 'Crawford Flexichrome' in the early 1940s. Kodak purchased the patent from Crawford and remarketed the product as the 'Kodak Flexichrome' from 1949 until 1961. This paper presents an overview of the Flexichrome process and, through the study of selected Flexichrome prints and historic dyes, investigates the technology and variations in the formulations available. Prints and dye samples were characterized using a complement of analytical techniques including visible and fluorescence light microscopy (VLM, FLM), Fourier transform infrared (FTIR) spectroscopy, and x-ray fluorescence (XRF) spectroscopy. A key goal of the study was to establish identification clues for Flexichromes, informed by results from invasive and non-invasive analytical techniques. Handheld XRF analysis showed both the absence of silver and chromium, supporting the ability to distinguish a hand colored gelatin silver print and carbro prints from the Flexichrome. Unaided visual examination and VLM provided the following visible characteristics specific to the Flexichrome: continuous tone with no misalignment or misregistration of superimposed color layers and the presence of fluid lines and visible brushstrokes depending on the skill of the colorist. A print can also exhibit differential gloss and fluorescence in the magenta colors when unobstructed by a finishing layer. FTIR analysis of multiple sets of dyes confirmed the nature of the dyes as being acid dyes as indicated in the literature. Color fading is therefore not uncommon in contrast to carbros which have a higher lightfastness.

KEYWORDS: Color photography, Photographic identification, Materials analysis, Flexichrome, Dye imbibition.

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1. Introduction

The Flexichrome (a dye imbibition process) is a photographic color process that has received limited attention in the historical and conservation literature (Sipley, 1951; Coe, 1978; Koshofer, 1981; Pénichon, 2013). It was however used by a wide range of photographers; from commercial, to artistic and novelty use. In the words of its inventor Jack Crawford, Flexichrome compared "favorably in quality with Wash-Off Relief, Chromatone, and Carbro," [1] and was "quite similar to the latter method in texture and physical appearance" (Crawford, c.1939).

Making a print with the Flexichrome was cheaper and faster than with other color processes available at the time; the process was praised for its color flexibility and high-quality color images hence its name 'FLEXI-chrome'. It clearly offered certain advantages, including the use of a regular black-and-white negative and the relative simplicity of the process. It takes, however, a significant number of steps and materials to create a Flexichrome. Although the process was widely distributed by Eastman Kodak when it relaunched it in 1949 (*Kodakery*, 1949; *Australasia Photo-Review*, 1949; *Austin American*, 1949), it was soon overshadowed by chromogenic processes and eventually taken off the market by Kodak.

Figure 1: Herbert Lyman Emerson, Untitled, 1950's, Flexichrome, 37.1 × 49.2 cm (image); 37.9 × 50.2 cm (paper), Photography and Media, 2012.282, The Art Institute of Chicago. Courtesy of the Art Institute of Chicago.

This paper will highlight the historical development of the process and visual characteristics of the Flexichrome based on a print by Herbert Lyman Emerson in the collection of the Art Institute of Chicago (Figure 1) and reference prints from the Image Permanence Institute (IPI) and private collections. Secondly, we will report on findings of analysis performed on prints and sets of Crawford and Kodak original dyes, including visible and fluorescence light microscopy (VLM, FLM), Fourier transform infrared (FTIR) spectroscopy, and x-ray fluorescence (XRF) spectroscopy.

2. History of the Flexichrome Process

2.1 *The Crawford Flexichrome (1940-1942)*

In 1938 Jack Crawford, a New York photographer, filed a patent application for a new method of producing multicolored relief pictures (Crawford, 1941b). The following year, he filed a second patent with minor chemical changes to the process (Crawford, 1943). The patents describe the act of coloring a gelatin relief by hand to create a color photograph, and contain limited material information. The receiving layer is described as a gelatin silver bromide film in the first patent, and a 'wash-off relief emulsion' in the second one. While Crawford did not invent a new color photographic process, he creatively used the existing materials and knowledge of dye imbibition photography to make his own color prints from black-and-white negatives. His method eliminated the need for separation negatives, which were the more complicated aspect of the carbro and Wash-Off Relief processes.

The Crawford Flexichrome was brought to the market in 1940 by the Defender Photo Supply Company, an early leader in the manufacture of photographic materials located in Rochester, New York (Potter, 1940)[2]. Photographers could purchase Crawford Flexichrome materials individually or as a kit through the Crawford Flexichrome Company, Defender or select dealers—$6 for the complete outfit (Deschin, 1941) (Figure 2). Crawford promoted his process in popular magazines such as *Photo Technique, Minicam, The Camera* and *The Complete Photographer* (Dudley, 1940; Crawford, 1941a, 1942b, 1942a), and organized public demonstrations at various locations around the United States (Nevada State Journal, 1941; New York Times, 1941e; New York Times, 1941d) [3]. For those who wanted to color their own pictures but did not care to make the black-and-white Flexichrome print (i.e. the gelatin relief), Crawford Flexichrome Laboratories in New York City offered a printing service. Customers supplied original negatives, prints, or transparencies and size desired; they received their prints in the mail, ready to be colored (Crawford, 1941c). By 1941, the Crawford Flexichrome Company was busy enough to be looking for more employees to help cover the demand (New York

Times, 1941a; New York Times, 1941b; New York Times, 1941c). Commercial success was however short-lived.

Defender Photo Supply Company ended its collaboration with Crawford in 1942, when the United States entered the Second World War and supply for commercial use was deprioritized over military needs (Defender Trade Bulletin, 1942; Coe, 1978; Nadeau, 1989). Between the years 1942 and 1949, the authors could not find ads or articles on the Flexichrome, suggesting the product was commercially unavailable until it was re-introduced by the Eastman Kodak Company in 1949 as the 'Kodak Flexichrome Process'. By 1943, Jack Crawford had sold his patents to Kodak; he eventually moved to Rochester, to direct the company's Flexichrome studio and improve the process (Crawford, 1943; *Kodakery*, 1949; Lipton, 1949).

Figure 2: A Crawford Flexichrome kit comprised of a set of 11 Flexichrome colors, a reducer and a modeling agent (or black dye), a jar of liquid paper backing, a bottle of Flexilene quick drying varnish, chromic acid, ammonium dichromate, two brushes, lint-less paper blotter and an instruction booklet. Film and processing chemicals were purchased separately (Crawford, 1940). Courtesy of the George Eastman Museum.

2.2 *The Kodak Flexichrome (1949-1961)*

It was common practice of the Eastman Kodak Company to acquire promising photographic patents and hire their inventors to continue their work under the Kodak brand. The company had the resources to support research and development of the Flexichrome and the ability to advertise and market the product globally. It developed an entire new line of Kodak Flexichrome products with simplified ready-to-use sets of chemicals and instructions, an improved convenience over Crawford's system where customers had to make the processing chemicals from scratch (Eastman Kodak Company, 1949).

In 1949, an extensive marketing campaign for the new Kodak Flexichrome began worldwide. Kodak emphasized the ease of making a color print using this process. The product was first introduced in New York City to commercial and professional photographers, dealers, artists, illustrators, and advertising agency representatives with an exhibit, a movie and demonstrations (Kodak, 1949) (Figure 3).

Figure 3: Jack Crawford at the launch event of the new Kodak Flexichrome (Kodakery, 1949).

The Flexichrome process was suitable to a myriad of uses, from studio portraiture to popular baseball cards, medical photography or artistic production. Commercial photographers such as Herbert Lyman Emerson likely used the process because it lent itself well to the production of originals that would be reproduced in magazines, while artists like Lyman Grey Fayman or Josep Masana created dramatic images of great artistic value (La Jolla Museum of Art, 1969; Galmes, 1984). In the industry, textile manufacturers, for example, favored the Flexichrome process for the illustration of their products because they could obtain closer matches to the colors of their original subjects than with other color processes available at the time (Varden, 1967).

Kodak discontinued the Kodak Flexichrome in 1961 but the dyes remained available until stock lasted (Nadeau, 1989). They were later marketed as Kodak Retouching Colors for color prints and transparencies and were especially well suited to retouch dye imbibition prints (Varden, 1967).

3. How to make a Flexichrome

The Flexichrome is a dye imbibition process. This means it uses the properties of a colloidal receiving layer to absorb or imbibe acid dyes and form a full color image. Making dye imbibition prints usually consists of successively transferring dyes from a yellow-, magenta- and cyan-dyed relief matrix onto a receiving sheet of paper coated with gelatin. With the Flexichrome, dyes are applied directly by hand onto a single positive gelatin relief image.

3.1 Making a gelatin relief

The making of a Flexichrome print started with a black-and-white negative, obtained directly in the camera or made from a color transparency. The negative was printed onto a sheet of Flexichrome film by projection or contact; exposure was performed through the film base (Dudley, 1940; Crawford, 1941a). Crawford Flexichrome Film, with a semi-matte surfaced celluloid base, was available in sizes from 5×7 inches to 20×24 inches (Crawford, 1941a; Lester, 1942; Deschin, 1941). Film in rolls 42 inches wide and 10 or 25 feet long was also available, for photomurals or commercial display (Crawford, 1941b; Crawford, 1942). Likewise, Kodak Flexichrome Stripping Film came in sizes from 5×7 to 20×24 inches and in rolls of 20 inches by 30 feet or 40 inches by 30 feet (Eastman Kodak Company, 1950).

Once exposed, the film was developed and then tanned in a dichromated solution to harden the gelatin surrounding the developed silver image. At that point, the film was immersed in warm water to wash away the unhardened or unexposed soft gelatin and create a relief where areas of thick gelatin correspond to the dark areas of the image. Next, the relief was bleached, fixed, and washed to eliminate its silver content [3]. The last step before coloring consisted in dying the relief in a black or 'modeling' dye bath. The gelatin relief absorbed the dye in proportion to its thickness resulting in a positive black-and-white image on a clear film base, which would be the outline to guide in the coloring of the image.

With Crawford Flexichrome, an opaque white paint or 'liquid paper' was applied to the back of the film to create a print. With Kodak Flexichrome, the dyed gelatin relief was stripped from its base and transferred onto a paper substrate [4].

3.2 Coloring the gelatin relief

The gelatin relief was then ready for coloring. During coloring, the dyes were absorbed by the gelatin proportionally to its thickness, i.e. the density of the image. Each new application of color displaced a portion of the black modeling dye. Dyes could be applied at will, until the desired color had been reached. Each print created was unique; multiple copies of an image required the printing and coloring of new reliefs (Figure 4).

Figure 4: The Process of hand coloring a Kodak Flexichrome (Eastman Kodak Company, 1950, pp. 20-21).

4. General visual characteristics of a Flexichrome

Examples of Flexichrome prints and transparencies are not easy to find per se, partly because in many cases they might have been misidentified as carbro or hand-tinted photographs (Maaruf, 2021). Key characteristics of Flexichrome prints are as follows: Firstly, the color is distributed in a continuous tone, this means there is no delineation between color areas, and the shading or color transition is smooth.

Secondly, because the colors of Flexichrome prints are applied by hand with a brush, there is no misregistration or misalignment of color layers, contrary to color prints made with assembly processes such as dye imbibition or carbro. Depending on the skill of the colorist, the edges of colored areas might not display crisp color delineations, but rather fluid lines that sometimes overlap or run into each other (Figure 5).

Fine brushstrokes are usually visible in areas such as the eyelashes or lips (Figure 6). These brushstrokes can be confused with retouching but upon close inspection, it should be clear that the color is part of the gelatin layer.

When examined in specular light, Flexichrome prints typically display a differential gloss between light and dark areas of the image. The high-density or dark areas—where the gelatin layer is thicker—are glossier than the low-density or light areas of the image—where the gelatin is thinner. The differential gloss might not be visible if the print has received a thick application of varnish.

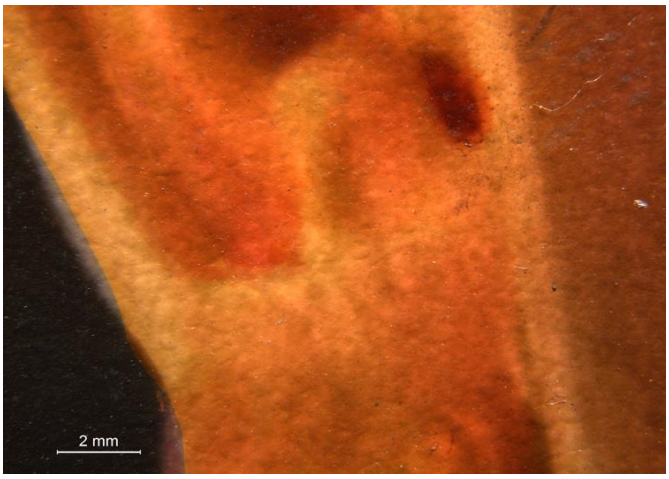

Figure 5: Detail of Emerson, Untitled, showing continuous tone and no delineation between color areas. Courtesy of the Art Institute of Chicago.

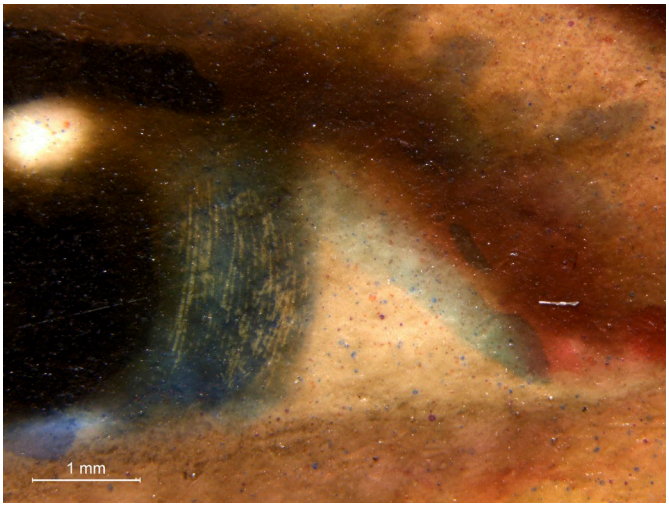

Figure 6: Detail of Emerson, Untitled, showing brushstroke color application visible in the detailed areas. Courtesy of the Art Institute of Chicago.

Under ultra-violet radiation, containers of magenta, red, and yellow reference dyes as well as the reducer fluoresced. Fluorescence in a print will however depend on the amount of dye present, the mixture of the dyes and the possible obstruction of a finishing varnish application.

In addition, the authors observed fading in several reference prints that had most likely been kept in frames and on view for an extended period of time. It would be worth investigating the light fastness of the Flexichrome dyes to inform display guidelines.

5. Analysis

5.1 *X-ray fluorescence (XRF) spectroscopy*

XRF analysis was performed on six Kodak Flexichromes: the Emerson print at the Art Institute, two reference prints from the IPI, and three prints from a private collection. Two carbro prints were also analyzed to provide comparative spectra.

No silver (Ag) was detected in the Flexichrome prints, which confirms that the Ag has been bleached out to the extent that it is not detectable with handheld XRF. This provides the ability to distinguish a hand-colored gelatin silver print from a Flexichrome [5].

Additionally, the elemental compositions of carbro and Flexichrome prints were compared, due to the visual similarities between these two types of print. Both processes make use of a dichromate to harden the gelatin and create a relief; however, chromium (Cr) was only detected by handheld XRF in the carbro prints but not in the Flexichromes (Figure 7).

Based on these analyses, the absence of both Ag and Cr appears to be an analytical marker for the Flexichrome, corroborating information derived from visual comparisons. Handheld XRF is limited in its ability to detect certain elements. The absence of both Ag and Cr in the XRF spectra does not mean they are not in any amount present in the prints, it only indicates that the amounts are non-detectable using this technique.

5.2 *Fourier transform infrared (FTIR) spectroscopy*

FTIR was used in the analysis of a set of Crawford Flexichrome dyes from the George Eastman Museum collection and three reference sets of Kodak Flexichrome dyes acquired for this project. The Crawford set contains a group of 12 dyes comprising blue, blue green, green, black, brown, flesh, lemon yellow, primary yellow, orange, red, scarlet, and violet. Two reference Kodak sets contain a slightly different group of 10 dyes (blue, cyan, brown, flesh basic, neutral, green, magenta, orange, purple, red, and yellow) and the third set contains 8 dyes (omitting the orange and purple).

According to contemporary sources, there were material differences between the iterations of the Flexichrome. Between the first and second patent by Crawford for example, there was a change in chemical processing of the prints, and meeting notes from the Kodak Research Laboratories made between 1947 and 1952 show a constant evolution in material composition to improve the tinting strength of dyes and lightfastness (Condax papers, 1947, 1950-1952).

While production of dyes was curtailed in the United States during World War II, the dyestuff industry expanded rapidly in the postwar years and Kodak Research Laboratories continued their explorations and embraced advances in technology.

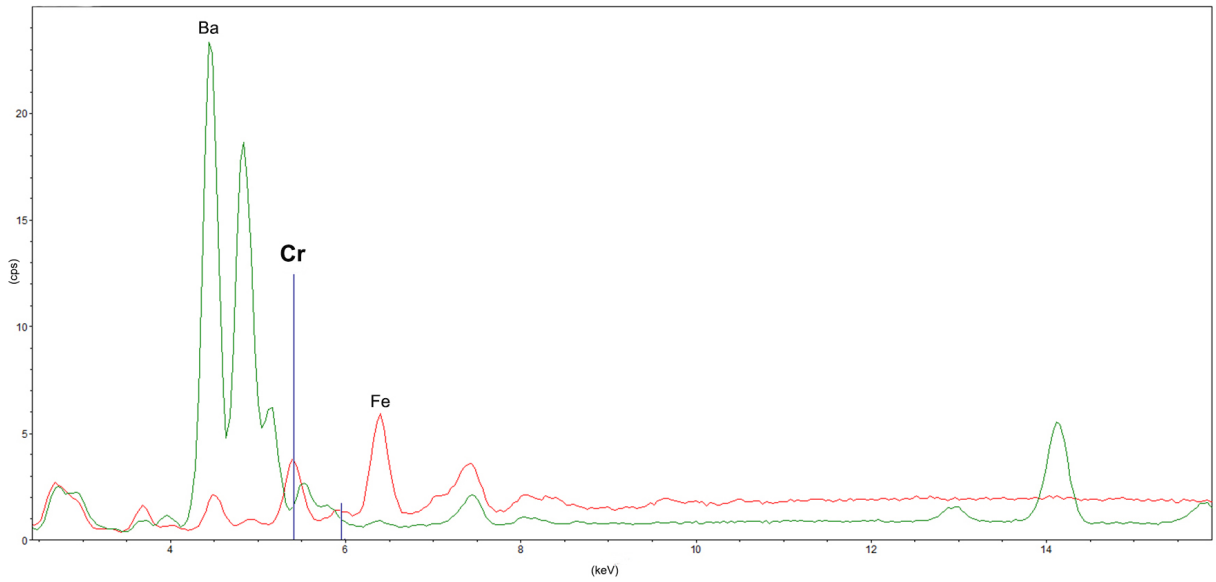

Figure 7: XRF spectra of a reference carbro (red) and a Kodak Flexichrome (green).

”Only 4 or 5 dyes will be necessary to cover all the range of colors needed,” wrote Kodak researcher Louis Condax in his meeting notes, ”However, Mr. Crawford feels that the mixtures should be incorporated in the set rather than to have the user mix them.” (Condax papers, 1947). The dyes used for dye imbibition processes fall under the family of acid dyes, which belong to the larger class of synthetic organic dyes (Colton and Thronson, 1940). The spectra collected from the Crawford dyes indicated the presence of acid- and azo-dyes. The spectra collected from the three Kodak sets showed close similarities to each other and, as suggested in the Condax papers, of the analyzed reference dyes there were only a few main types and the rest were mixtures of blue, magenta or red, and yellow dyes. Analysis indicated the presence of phthalocyanine blues, azo yellows, alizarin and anthraquinone reds (Figure 8 & Figure 9).

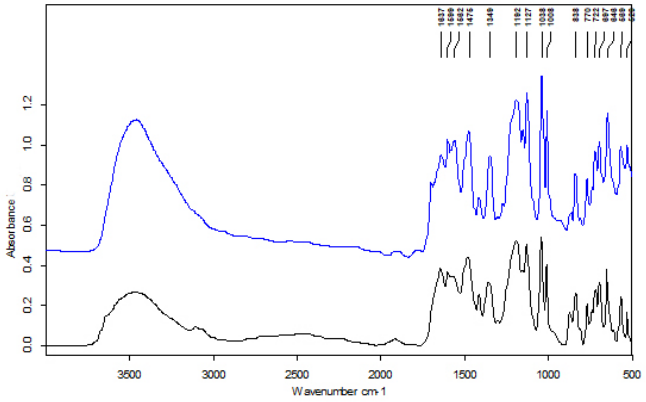

Figure 8: Infrared spectrum of Crawford Flexichrome primary yellow dye (blue) compared with the IRUG reference spectrum IOD00031 of Acid Yellow 23 (black).

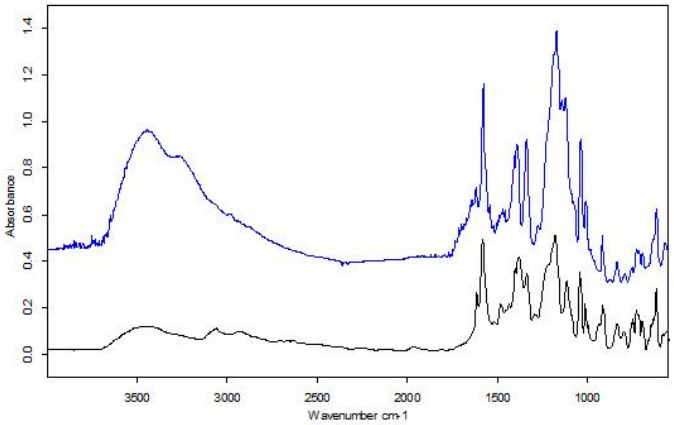

Figure 9: Infrared spectrum of Kodak Flexichrome green dye (blue) compared with the IRUG reference spectrum IOD00043 of Acid Green 6 (black).

FTIR was therefore useful for gaining information about the chemical classes of the Flexichrome dyes. There are often only minor chemical differences between individual colorants within the class, which, along with the presence of binders and extenders, complicates interpretation of the spectra (Lomax, Schilling and Learner, 2007). Therefore, complementary analytical techniques are required for a more definitive identification of these materials. This will also contribute to investigate further their lightfastness.

5.3 Cross-section

In collaboration with IPI, cross-sections were prepared to further understand the structure of Flexichrome prints. A sample from a Kodak print shows a paper substrate with a baryta layer and a gelatin coating on top, most likely a sheet of Kodak Dye Transfer paper, recommended by Kodak in the user manual. Above the gelatin layer of the

paper substrate is the gelatin relief with imbibed dyes. The cross section shows that the coloring dyes did not penetrate all the way through the relief layer and that a portion of the modeling black dye is still present. Finally, there is the surface varnish layer (Figure 10). This correlates with the cross-section diagram published in the Kodak material data series (Figure 11), although the varnish and baryta layers are absent in the diagram (Eastman Kodak Company, 1950).

Together with XRF analysis and a close visual assessment, cross-sections can provide additional information. However, taking a cross-section is a destructive method and is not advised on collection items. The paper base and baryta layer may not be present in the cross-section if the relief was transferred onto a different substrate.

The layering structure of a Crawford Flexichrome will consist of a bottom paint layer—unless it is a transparency—followed by a celluloid layer, the gelatin relief with imbibed dyes, and a final varnish.

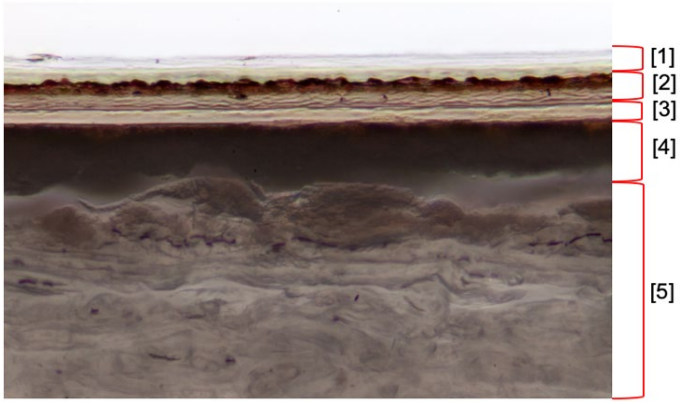

Figure 10: Cross-section of a Flexichrome in transmitted light. [1] varnish, [2] dyed gelatin relief, [3] gelatin coating, [4] baryta, [5] paper support. Courtesy of the Image Permanence Institute, Rochester Institute of Technology.

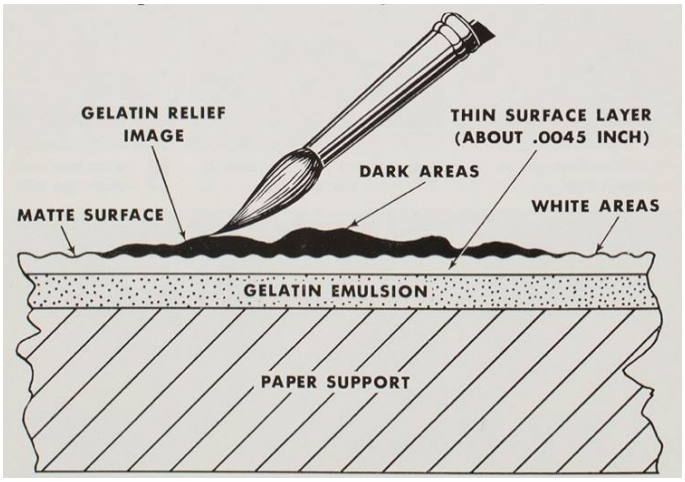

Figure 11: Cross-sectional diagram of a Flexichrome print, showing relief image greatly magnified (Eastman Kodak Company, 1950, pp. 22-23).

6. Conclusion

The Flexichrome process is a dye imbibition process that might be more prevalent in photographic collections than initially considered. Flexichrome prints share visual characteristics with carbro and hand-tinted gelatin silver prints, which has sometimes led to their misidentification. Due to misidentification and a lack of coverage in the historic and contemporary literature, the process is easily overlooked, even though it seems to have found commercial success under the Kodak branding, and was accessible and distributed worldwide.

Visual characteristics of a Flexichrome include a continuous tone, a lack of misregistration or misalignment of color layers, a brushed application of color, and non-delineated color transitions. There is the possibility of overall color fading and of UV-fluorescence of certain dyes. However, the mixing of colors and possible finishing layers may obstruct the fluorescence of the dyes. Lastly, because the final product is a gelatin relief, there is the possibility of differential gloss, which might not be detectable if a thick layer of varnish is present. A Crawford Flexichrome will be identifiable by its painted celluloid support.

XRF analysis indicated that silver and chromium were not present at detectable levels in a Flexichrome print. Elemental analysis complements the visual identification of the process, helping to distinguish it from a hand-colored gelatin silver print or a carbro.

FTIR supported the available literature by showing the dyes belong to the family of acid dyes. The dye sets were found to comprise of mixtures of a limited number of dyes. Due to the presence of additives and filler in the dye sets, complementary analysis is needed to further specify the individual dyes.

7. Conflict of interest declaration

The authors declare there is no conflict of interest concerning the research presented in this paper.

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Notes

[1] Wash-Off Relief was a dye imbibition process manufactured by the Eastman Kodak Company between 1935 and 1947. Chromatone was a silver toning process of the Defender Photo Supply Company, marketed from 1935 until 1942. The carbro process is a three-color pigment process where stacked layers of magenta-, yellow- and cyan-pigmented gelatin reliefs create a full color image.

[2] Defender and Crawford first exhibited the process in Chicago at the Combined Photographic Industry and Trade Show, August 19-23, 1940 (Defender Trade Bulletin, 1940, New York Times, 1941d).

[3] If a transparency was desired, the silver image was not bleached, to add density for the viewing in transmitted light or projection.

[4] Kodak recommended the use of Kodak dye transfer paper. However, the gelatin relief could be transferred to any type of paper or any other type of support desired.

[5] Does not apply to transparencies.

Experimental

1. *Visible and fluorescence light microscopy*

Print samples prepared as cross sections were examined using a Zeiss Axioplan 2 research microscope with reflected light and UV fluorescence illumination; images were captured using a Zeiss AxioCam MRc5 digital camera.

2. *X-ray fluorescence spectroscopy*

A Bruker/Keymaster TRACeR III-V handheld XRF spectrometer with Rhodium tube was used with voltage of 45kV and tunable beam current of 2-25μA.

3. *Fourier transform infrared spectroscopy*

A Bruker tensor 27 FTIR spectrophotometer coupled to Hyperion 2000 Automated FTIR microscope with nitrogen- cooled broadband MCT detector (covering the range 4000–450 cm^{-1}) was used. Samples were analyzed in transmission mode through the microscope after compression in a diamond cell; scans were acquired at a resolution of 4 cm^{-1}.

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