ABSTRACT

Conservators and scholars long have been interested in understanding the traditional color palette of Japanese woodblock prints. Some of the traditional organic colorants are very difficult to distinguish visually, particularly if faded or decolorized. For decades ultraviolet and infrared examination of colorants in oil paintings have served as powerfully revealing tools. Ultraviolet light has sometimes been used to examine Japanese woodblock prints as well. This research focuses on differentiating non-synthetic reds and the three main blues employed in traditional Japanese woodblock prints produced in Edo between 1740 and 1890, using combined observations of daylight-fluorescent, ultraviolet, and infrared examination.

The twenty-three prints under study belong to the Library of Congress, Prints and Photographs Division. As part of this research project, Sandra Connors and Paul Whitmore, of the Research Center on the Materials of the Artist and the Conservator at Carnegie Mellon University, measured the light fugitiveness of the print colors using a micro-fading tester. This instrument also produced reflectance spectra that were useful in identifying safflower red, vermilion, indigo blue, dayflower blue, and through a process of elimination, Prussian blue. The instrumental data for reds and blues in each print was correlated to visual examination of the prints in daylight-balanced fluorescent lighting, recorded using Munsell color chips, and examination under long wave ultraviolet light and with an infrared video camera.

The resulting characterization of these colorants using ultraviolet and infrared radiation, both "low-tech" resources, will enable scholars and conservators to more easily assess historic and artistic trends in the Japanese woodblock palette.

INTRODUCTION

One of the most engaging aspects of Japanese woodblock prints is their nuanced color. Fade testing of these colorants in the past two decades has shown that many are very fugitive to light. Identifying the most sensitive colorants can help custodians of collections better protect the prints when displayed. Some of the organic colorants are very difficult to distinguish visually, particularly if faded. Research by Connors and Whitmore suggests that well preserved and poorly preserved areas of the same colorants have similar fading rates. Therefore, it is likely that even a faded print will experience further colorant loss from extended display.

For decades, ultraviolet and infrared examinations of colorants in oil paintings have served as powerfully revealing tools. Ultraviolet light has sometimes been used to examine Japanese woodblock prints as well. Using these "low-tech" means of identifying colorants in what are referred to as Ukiyo-e prints (translated, "images of the floating world") can aid in the preservation and technical appreciation of this art form. Being able to reconstruct the true coloring of faded prints can assist in the interpretation of the imagery and artist’s intent.

This is a preliminary report on observations of traditional, full color, Japanese woodblock prints, from Edo (now Tokyo), using combined daylight-fluorescent, ultraviolet, and infrared examination techniques to differentiate reds and blues in various saturations and conditions. The ultraviolet and infrared examination results are correlated to color identifications using reflectance spectra gathered from a micro-fading tester. The prints examined date from between 1740 to 1890, a period representing all the traditional colors. Synthetic aniline dyes are excluded from the study.

The twenty-three prints under study were selected as representing an historical cross-section of the Library of Congress’s collection that exceeds 2300 in number. This small selection was drawn from a group of one hundred treasured works that were displayed in the exhibition, The Floating World of *Ukiyo-e*: Shadows, Dreams, and Substance, held at the Library in the Fall of 2001 (Kita et al. 2001).

The selection of prints includes the work of the seventeen Edo artists listed in table 1, and spans one hundred fifty years of evolution in the palette of woodblock prints. During this period the dominance of various reds and blues shifted, and the introduction of such foreign colorants as Prussian blue often replaced other commonly used blues.

As part of this research project, Sandra Connors and Paul Whitmore, of the Research Center on the Materials of the Artist and Conservator at Carnegie Mellon University, measured the light fugitiveness of the print colors using a micro-fading tester developed by Whitmore. The micro-fading tester is a device capable of performing non-destructive accelerated fading tests on a 0.4 mm diameter area of an object. The tests identified those colors having sensitivity to exposure in visible light. The instrument also produced reflectance and fading data useful in identifying safflower red, vermilion, indigo, dayflower blue, and through a process of elimination, Prussian blue (Connors et al. 2003; Connors 2003). Characteristic spectral curves for safflower and vermilion previously were identified in a 1995 study by Susumu Shimoyama and Yasuko Noda and in a 2001 study by Marco Leona and John Winter.

Infrared examination has been employed in forensic ink analysis for much of the past century. The authoritative ink historian, Charles Ainsworth Mitchell, documented the appearance of pigments used for writing and printing inks with infrared photography in 1937. Of those inks relevant to Japanese printmaking, he found that Prussian blue appears dark (absorbs), but indigo appears transparent. He further noted that scarlet lake (cochineal), vermilion, and red lake appear transparent (Mitchell 1937).

As early as 1963, Charles Bridgman and Lou Gibson explored the photography of infrared emission, or luminescence, excited by blue-green light, as applied to the examination of oil paintings. Like Mitchell, Bridgman and Gibson observed that Prussian blue absorbs infrared radiation (Bridgman and Gibson 1963).

The idea of viewing Japanese prints under ultraviolet light is not a new one. A 1984 study of Japanese prints by Robert Feller and colleagues noted the ultraviolet fluorescence of safflower as well as Japanese madder, which was thought to be caused by their carthamin and purpurin and/or pseudopurpurin content respectively (Feller et al. 1984). In 1989, the Japanese print collector and historian, Rochelle Wexler Bickford, found that Prussian blue, under a “black light,” appears as a bright blue color, while the other blues do not (Bickford 1989).

In one further study of fluorescence induced by ultraviolet light, Rene de la Rie notes that Prussian blue lacks, or shows very weak, fluorescence. Additionally he observed that purpurin fluoresced when combined on a paper support, in an inorganic base such as aluminum hydroxide, or with a solvent such as ethanol, acetone, and ethyl ether (de la Rie 1982).

J. Rutherford Gettens and George Stout state that the presence of purpurin causes madder lake to fluoresce a fiery yellow-red in ultraviolet light (Gettens and Stout, 1966). Finally, in *Artists’ Pigments*, Feller mentions that in ultraviolet light purpurin-containing madder lake fluoresces a dull orange, cochinca fluoresces a vivid pink, lac lake does not fluoresce at all, and red lead absorbs strongly (Feller 1986–93).

### EXPERIMENTAL

Ultraviolet examination was performed with a Spectroline, hand-held, 365 nanometer, long wave ultraviolet lamp. A selected vocabulary was chosen to describe the color appearance observed in the prints, or the relative fluorescence versus absorption. The descriptors include

| Table 1. The seventeen Edo artists whose work was included in the twenty-three prints studied |
|---|---|
| Shunkō 1743–1812 | Katsuyori active 1794–1832 |
| Shigenobu 1739–1830 | Katsuoki 1798–1861 |
| Toyokuni 1749–1833 | Hishikawa active 1805–1825 |
| Utagawa active 1754–1815 | Kuniyoshi 1835–1900 |
| Korin active 1764–1788 | Kanetsu 1898–1973 |
| Tōhaku 1760–1849 | Sadahiro 1897–1873 |
| Eisen 1787–1867 | Yoshidō 1855–1904 |
| Hirosige 1797–1858 | Yoshiaki 1839–1892 |
| Kuniyoshi 1786–1865 | |
bright “day-glow” orange, orange, pale orange, dark orange, pale pink, bright pink, maroon, dark red, mauve, light brown, dark brown, gray, warm gray, blue gray, medium blue, and purple blue.

For infrared examination, a Doya Infrared Video Analyzer was used, comprised of a silicon-enhanced diode tube with six interchangeable barrier filters on its lens. The barrier filters have a total range from 690 to 1500 nanometers. For this experiment a number 10 filter was employed for a range of 690 to 740 nanometers. Two quartz lamps were used, one with a blue-green filter with excitation from 690 to 740 nanometers, and the other a yellow filter with excitation from 490 to 600 nanometers. Lamps comprised of light in the blue-green and yellow regions of the electromagnetic spectrum are found to induce emission of red, near red, and infrared in some subjects, which therefore are said to luminesce. The system includes a black and white monitor with a resolution of 800 lines per screen (fig. 1).

Luminescence encompasses both fluorescence and phosphorescence, which are differentiated simply by the duration of emission. Phosphorescence is an after-emission that persists after the excitation source has been turned off. Fluorescence refers to emission generated only while an excitation source is on. Because the duration of emission is difficult to measure, the phenomenon observed in this study is referred to by the more general term luminescence.

Colors may have one of four appearances in infrared examination: they may appear dark (absorb), gray (reflect), transparent (transmit), or brighter than the paper support (luminesce). To simplify description of appearance that was observed on the black and white monitor, the following terms were used: dark gray for absorption, medium gray for reflectance, light gray or tone close to that of the paper for transmittance, and lighter than the paper tone for luminescence. While reds generally are transparent in infrared examination, in this study infrared luminescence was found to be key, especially in identifying safflower red.

The print colorants were examined in ambient laboratory light comprised of ultraviolet-filtered, daylight-balanced fluorescent illumination, to complement ultraviolet and infrared examination. The appearance in ambient light of the reds and blues was recorded using Munsell Matte Finish color chips. The Munsell color matching was undertaken to objectively record trends in the colorants employed for the twenty-three prints and was performed at 60 footcandles and 0.4 microwatts per lumen illumination. Characterization of the reds and blues resulting from daylight-fluorescent, ultraviolet, and infrared examination was compared with the spectral identification from the micro-fading tester (tables 2–3).

Dye swatches from a Japanese dye recipe book (Yoshioka 1982) were examined in the three methods as a form of comparison for the organic reds (safflower, sappanwood, madder, and cochineal) and indigo blue, of concern in the woodblock prints. The dye samples are on silk and employ various mordants, and therefore cannot be interpreted as equivalent to the same color on paper. Colorants mordanted with alum were selected as a more appropriate comparison to the colors as they would be printed on the Japanese paper used for woodblock prints, which is surface sized with animal glue and alum. While these dye samples on silk could not function as experimental controls, their appearance was consistent with our observations on safflower and indigo. These same dye samples also were analyzed by Jennifer Giaccai, at the Freer-Sackler Gallery of Art, using reflectance spectroscopy. Their reflectance spectra were found to be fairly consistent with Giaccai’s research on organic reds used in Japanese paintings of the Edo period.

RESULTS GATHERED FROM EXAMINATION OF WOODBLOCK PRINTS

Results gathered from the examination of the woodblock prints are presented in table 2.

Inorganic red lead and vermilion have been used since the advent of hand coloring on black and white woodblock prints starting around the 1690s. The colors continued to be used in limited amounts as full color prints came into production around 1765. Intentionally induced sulfiding of red lead to create a dark grey-brown patina on red in Japanese prints is discussed in a paper by Judy Walsh, Barbara Berrie, and Michael Palmer (Walsh et al. 1997). Especially when used for architectural elements, this effect mimics the weathering seen on red painted temples and shrines, an effect that hardly seems accidental.

Of the organic reds, safflower is by far the most commonly used from around 1700 to the mid-nineteenth century. The Feller study mentions madder, but other significant references on Japanese print production, such as...
Table 2. Fiske–Morenus chart comparing all analysis and observations for Eion.
those by Ishii Kendo, Chie Hirano, or T. Tokuno, do not include it (Feller et al. 1984; Kendo 1929; Hirano 1939; Morse 1982). Sappanwood is mentioned in all the above references. A color chronology by Roger and Keiko Keyes, used in their workshops on woodblock prints given at the Allen Art Museum in Oberlin during the late 1980s, shows sappanwood as a color introduced after 1825. Feller suggests that cochineal was imported from China and used in place of safflower in later prints (Feller et al. 1984). However, the extent of use of madder, sappanwood, and cochineal in woodblock prints needs to be confirmed by further analysis.

As noted from literature sources, vermilion is not expected to fluoresce, but rather to absorb in ultraviolet and to transmit, or be nearly transparent, under infrared examination. In a beautifully printed, privately commissioned surimono by Hidenobu (ca. 1820), there is an example of a scarlet color identified by Connors as not inconsistent with vermilion. In ultraviolet light it reads as dark red and in infrared examination it reads as a light gray tone, transmitting most infrared radiation (fig. 2). (While the color areas discussed in the prints are not obvious in black and white reproduction, the images are included as a point of reference.)

The important collector’s seals found on prints are hand stamped with the typical vermilion ink used in Japan. These stamps also appear as dark red in ultraviolet light. As noted by Mitchell, vermilion is barely visible with infrared

| Table 3. Sandra Connors report on micro-fading tester readings for Eizan |
examination, as was the case with the vermilion stamps observed in this study. In contrast, the orange-red inside the bowl, in the Hidenobu surimono mentioned earlier, is a safflower red which has a characteristic fluorescence in ultraviolet light, except where overprinted with black in the shadow of the bowl.

In the large figure of the left panel of a Kuniyoshi triptych (1850), the absorption of a red lead in ultraviolet light is evident. Under infrared examination the red lead reads as a medium gray tone. Again, as a contrast, the pale pink flesh color in the right figure of the middle panel is safflower that faintly fluoresces in ultraviolet, and luminesces brightly when viewed with the infrared video camera (figs. 3–4).

We can speculate that the light-sensitive colors in a large number of Ukiyo-e prints have faded to some degree over their 250 to 300-year life. It can sometimes seem shocking then to see the bright, saturated colors in prints that have been relatively protected. Particularly reds and purples can seem almost garish. However, visually the overall palette comes into harmony when all colors are fully saturated, rather than the imbalance that occurs when unfaded colors overwhelm those that are faded. Often the most intense colors can be seen in shunga, the erotic prints that probably have seen little display.

The print by Kuniteru (1867) is a good example of the tell-tale fluorescence of safflower in ultraviolet and its luminescence when examined with the infrared video camera. In this print, both the darker and lighter reds, and the
orange made of red mixed with yellow, have the characteristics of safflower when examined with these methods (fig. 5).

Compared to the previous print by Kuniteru, the Eizan (1800–1867) color palette is slightly less saturated. Yet the red, spectrally identified as safflower, fluoresces under ultraviolet, and the orange, which is a mixture of safflower and yellow, has some fluorescence as well. In infrared examination the luminescence of safflower clearly can be seen, making the paper tone appear darker than the area printed with red safflower (fig. 6).

Compared to the Eizan, the two colors in the kimono and cap of a print by Enkyo (1796) appear more faded. Examined with the infrared video camera, the pink luminesces and the purple appears slightly brighter than the paper tone. As with the orange in the last example, we see that the purple, a mix of red and blue, still exhibits the characteristics of the safflower component (fig. 7).

The Shunko (1760) exhibits even more fading, yet the safflower does fluoresce in ultraviolet light. It also presents the infrared luminescence seen in the previous examples of more saturated safflower, reading as slightly brighter than the paper tone (fig. 8).

These examples illustrate the potential for this method to help scholars interpret the original appearance of Ukiyo-e print colors, and to assist a collection custodian in identifying sensitive colors in order to better assess the risk to the print of further exposure to light.
For centuries dayflower blue has been used in Japan to make an under-drawing on silk as a guide for painting or for applying stop-out for resist dyeing. It is a colorant that will completely wash out in water, and because of its solubility in water, dayflower is not generally used as a textile dye. Woodblock printers were surely aware of this sensitivity to moisture, particularly as they printed on dampened paper. Also, dayflower does not make an intense blue but rather a translucent cool or grayish-blue.

The use of dayflower blue seems to occur more in the early years of color printing, being largely replaced by indigo in the late eighteenth century. A study by Shiho Sasaki and Pauline Weber explores the manufacture and properties of this color thoroughly (Sasaki and Weber 2002).

Indigo is a staple of Japanese textile dyeing and is grown in southern Japan. It has been used in prints from the beginning of color printing through the nineteenth century.

Prussian blue, first available in Europe in 1704, was known to have been imported into Nagasaki in the 1820s, and was used extensively by Hokusai in his print series Thirty-six Views of Mount Fuji. Recent study by Roger Keyes and Elizabeth Coombs suggests that Prussian blue was used in the late eighteenth century (Keyes and Coombs 2002).

In a delicately printed surinomo by Kuniyasu (ca. 1810–20), dayflower blue is used in the robe and mixed with yellow to make a pale green in the hat. This is the only example of dayflower spectrally identified by Connors. Dayflower, appropriate to its sensitivity to moisture, makes
a translucent, sometimes watery-looking blue. In ultraviolet it is a warm, light to medium gray. Examined with the infrared video camera it appears as a light gray tone or almost the same as paper tone (figs. 9–10). Although not evident in this undamaged print, dayflower sometimes has a drippy, mottled appearance where humidity or contact with moisture has caused the color to move or dissipate. This form of damage generally is not seen in indigo or Prussian blue.

In ambient light, indigo can have a cool greenish or bluish-gray appearance. It also can be applied thinly and vary greatly in saturation. Indigo is usually the color used to mix with or overprint yellow to create green.

In consulting a triptych by Yoshiku (1860), using both ultraviolet and infrared examination, the area of the water, spectrally identified as indigo, appears light to medium gray using either techniques. In the left kimono of the left panel, the contrasting appearance of the spectrally identified colorants, indigo (medium blue) and Prussian blue (dark blue), is patently evident in both ultraviolet and infrared examination as well (fig. 11).

As mentioned in several literature sources, the iron in Prussian blue makes it absorb under infrared examination, appearing moderately dark gray in tone, depending on its saturation. Dayflower and indigo appear light gray under the same viewing conditions. Under ultraviolet, Prussian blue appears bright blue versus the more subdued grays...
for which the dayflower and indigo are notable. These observations are exemplified by the two prints by Hiroshige (1856–59) (figs. 12–13).

SUMMARY

The comparison between the spectral identifications for reds provided by the micro-fading tester and appearance in ultraviolet and infrared examination are summarized in table 4. All of the reds spectrally identified as safflower were consistent in UV fluorescence and luminescence when viewed with the infrared video camera. The two colors identified as vermilion were also consistent in their appearance under ultraviolet and infrared examination.

Thirty colors were unidentified by spectra. Not all of these could be categorized according to their appearance using ultraviolet and infrared examination. However, of these thirty unidentified reds, the paired pattern of appearance under ultraviolet and infrared examination strongly suggests an identification for an additional six safflower and three vermilion examples.

Five of the prints examined exhibited a distinctive mauve color in ultraviolet light. Infrared examination shows a fairly consistent reflectance in a light gray tone. None of these pinkish colors were spectrally identified by Connors. More research needs to be done on identifying the use of sappanwood, madder, and cochineal in Japanese woodblock prints.

The comparison between spectral identifications for blues provided by the micro-fading tester and appearance in ultraviolet and infrared examination is summarized in table 5. All of the blues identified as Prussian blue were consistent in ultraviolet light and when viewed with the infrared video camera. The four colors identified as indigo also were consistent using this paired examination method.

Using the ultraviolet and infrared examination results for the one color spectrally identified as dayflower made it possible, using ultraviolet and infrared examination, to suggest that three more unidentified colors are possibly dayflower. However, indigo and dayflower can be difficult to differentiate. Here the discernable difference between these two blues seen in visible light also must be considered.

It is anticipated that a clearer pattern will emerge in the next phase of this investigation, during which the red, blue, as well as yellow colorants will be prepared from natural dye stuffs, printed onto a Japanese printing paper, artificially aged, and observed using the daylight-fluorescent, ultraviolet, and infrared examination methods described.
CONCLUSIONS

• Reflectance spectroscopy is useful in identifying many organic and inorganic colors used in Japanese woodblock prints.
• Ultraviolet and infrared examination can be applied to identify several Ukiyo-e colors with moderate reliability:
  • Vermilion, red lead, safflower red.
  • Prussian blue, indigo, dayflower blue.
• Ultraviolet and infrared examination also can help identify faded colors.

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