A CASE STUDY USING MULTIBAND AND HYPERSPECTRAL IMAGING FOR THE IDENTIFICATION AND CHARACTERIZATION OF MATERIALS ON ARCHAEOLOGICAL ANDEAN PAINTED TEXTILES

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ABSTRACT—Spectral imaging techniques, including infrared reflectography and ultraviolet-induced visible fluorescence, have been used by conservators since the 1930s. These techniques are relatively accessible and have become routine in research and conservation. Institutions with imaging, color science staff, and high-end spectral imaging equipment can create and process large spectral data cubes that provide information for the identification of materials. Combining a low-resolution hyperspectral camera with a high-resolution digital camera modified for multiband imaging may present an alternative imaging option to aid identification and characterization of materials in cultural heritage objects. This paper presents a case study of the combined use of multiband and hyperspectral imaging to investigate the materials of four archaeological Andean painted textiles from the collection of the National Museum of the American Indian. The goals of this project are to explore various spectral imaging options, present a technique that can be used on a variety of cultural heritage objects, and offer new insights that previous routine imaging could not provide.

ESTUDIO DE UN CASO EN EL QUE SE UTILIZARON IMÁGENES MULTIBANDA E HIPERESPECTRALES PARA LA IDENTIFICACIÓN Y CARACTERIZACIÓN DE MATERIALES EN TELAS ARQUEOLÓGICAS ANDINAS PINTADAS: RESUMEN—Desde 1930, los conservadores han estado utilizando técnicas de imágenes espectrales que incluyen la reflectografía infrarroja y la fluorescencia ultravioleta visible. Estas técnicas son relativamente accesibles y se han convertido en prácticas de rutina en el campo de la investigación y conservación. Las instituciones que cuentan con equipos de imágenes, personal especializado en la ciencia de los colores y equipos de imágenes espectrales, pueden crear y procesar grandes cubos de datos espectrales que proporcionen información para la identificación de los materiales. La combinación de una cámara hiperespectral de baja resolución con una cámara digital de alta resolución modificada para imágenes multibanda, podría ser una opción alternativa para identificar y caracterizar materiales en objetos de herencia cultural. Este escrito presenta el estudio de un caso en el que se utilizó una combinación de imágenes multibanda e hiperespectrales para investigar los materiales de cuatro telas arqueológicas andinas pintadas, de la colección del Museo Nacional Indoamericano. Los objetivos de este proyecto son explorar varias opciones de imágenes espectrales, presentar una técnica que puede ser utilizada en una gran variedad de objetos de herencia cultural y aportar nuevos conocimientos que las imágenes de rutina no ofrecen.

1. INTRODUCTION

Spectral imaging techniques, specifically infrared reflectography and UV-induced visible fluorescence, have been used by conservators since the 1930s (Warda et al. 2011). These nondestructive and noninvasive techniques have become routine for material characterization and differentiation, as they are relatively accessible in terms of cost and ease of use. Hyperspectral and multispectral imaging have been more recently incorporated into cultural heritage conservation and research for material identification through the creation and processing of spectral data cubes. These instruments, however, are expensive for many institutions and conservators in private practice and can involve complex processing. This project explores a lower-cost imaging option that combines a high-resolution digital camera, modified for multiband imaging, with a low-resolution hyperspectral camera to aid in the identification and characterization of materials in cultural heritage objects. These techniques were applied to four archaeological painted Andean textiles from the collection of the National Museum of the American Indian, Smithsonian Institution (NMAI).

The techniques used for this project are multiband and hyperspectral imaging, which can carry a range of definitions depending on the project and application. These techniques, along with reflectance imaging spectroscopy and multispectral imaging, are defined here to clarify the differences between them. Multispectral and hyperspectral imaging are both types of reflectance imaging spectroscopy, which Ricciardi et al. (2013, 13) define as the "collection of images at many different wavelengths to obtain reflectance spectra over a large spatial area." Reflectance refers to the light reflected or scattered by a material relative to the incident light, and reflectance spectra is a curve illustrating the amount of reflectance at each wavelength over a defined spectral range (Fischer and Kakoulli 2006). Ricciardi et al. (2013) define multispectral imaging in the context of reflectance imaging spectroscopy as the acquisition of calibrated images with bandwidths of tens to hundreds of nanometers and hyperspectral as the collection of images with bandwidths of a few nanometers or less. Multiband imaging is similar to these techniques; however, it refers to the acquisition of uncalibrated images with bandwidths of hundreds of nanometers that are captured using a modified digital SLR camera and bandpass filters. Similar to hyperspectral and multispectral imaging, multiband imaging captures characteristic spectral information about objects; however, the uncalibrated image sets cannot produce reflectance spectra.

2. OBJECTS

A sample set of four archaeological painted Andean textiles (fig. 1) was selected to investigate the materials and manufacturing techniques used in their creation. The textiles are in the collection of the NMAI. They are attributed to Peru but beyond that have minimal provenience. Research and consultations with Andean textile scholars helped identify the cultural attributions of three of the textiles as Chancay style fragments (23/9073, 22/0497, 23/9038) and one as a Middle Horizon textile (23/9040). The four painted textiles are a subset of a larger project investigating the materials and techniques used to create 21 archaeological Andean painted textiles in the NMAI's collection. The larger project included other noninvasive analytical techniques, such as XRF and FORS, as well as invasive techniques such as FTIR, XRD, and LC-diode array detector-MS (Summerour et al. n.d.).

All four textiles are plain-woven cotton fabrics with colorants applied to one side (fig. 2). The colorants are referred to as paints because they appear to have been selectively applied in a paste or semi-liquid form, which distinguishes them from immersion dyes. They are embedded in the fibers on one side of the fabrics. Most appear matte, suggesting they contain minimal or no organic binder. Some of the browns, however, appear thick and shiny in select areas as if they do contain an organic binder. These thicker brown colors are most prominent on the three Chancay-style fragments where brown outlines separate colored shapes. Overall, the linear designs on the Chancay style fragments are carefully applied in regular repeating patterns, while colors on the Middle Horizon textile are more freely applied in a looser style.

2.1 PREVIOUS WORK ON SIMILAR PAINTED TEXTILES

Few studies have been published on the materials and techniques used to create painted archaeological Andean textiles. The present work builds on three of the previous studies, published by Saltzman, Keay and Christensen (1963), Smith (1986), and Boucherie (2009). Saltzman, Keay and Christensen used a spectrophotometer to identify shellfish purple dye in Paracas and Ocucaje painted textiles. Smith used XRF and polarizing light microscopy to identify iron-based pigments, carbon black, and lead-based pigments on Late Intermediate

Figure 1: Visible light images of the four archaeological painted Andean textiles selected for this project. (top left): NMAI 22/0497, Chancay style fragment; (top right): NMAI 23/9073, Chancay style fragment; (bottom left): NMAI 23/9040, Middle Horizon textile; (bottom right): NMAI 23/9038, Chancay style fragment

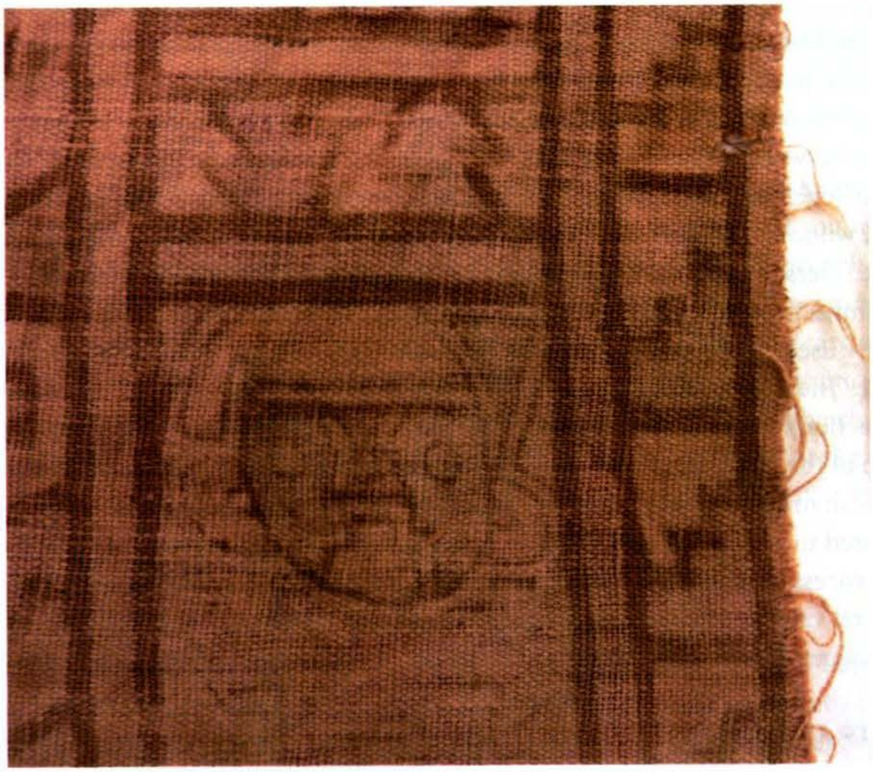

Figure 2: Reverse of a Chancay style fragment showing how the colorants, applied to the opposite side, partially bled through to the reverse. National Museum of the American Indian, Smithsonian Institution (22/0497).

Period textiles that are probably from the central coast of Peru. Boucherie used optical microscopy, Raman spectrometry, SEM-EDS, FTIR, and HPLC to analyze colorants in Nasca painted textiles and identified carbon black, iron oxides, calcium sulphate, indigo, a copper-containing blue mineral (possibly azurite), and cinnabar.

2.2 POTENTIAL COLORANTS

A literature review of Peruvian colorants revealed a group of materials that might be present on these textiles. This group included cochineal dye, *Relbunium* species dyes, mineral red pigments, carbon black pigment, and indigo (Smith 1986; Roquero 2002; Cardon 2007; Roquero 2008; Boucherie 2009; Phipps 2010). Initial work with FORS and XRF identified iron-rich mineral reds, an insect-based pink,[1] and indigo on the textiles. Plant-based reds, such as *Relbunium* species dyes, and heavy-metal red pigments, such as cinnabar and red lead, did not appear to be present.

3. METHODOLOGY

The methodology used at the Smithsonian Museum Conservation Institute (MCI) for the imaging and analysis of the Peruvian archaeological textiles included (1) multiband imaging to explore the various bandwidths and responses for the materials and (2) hyperspectral imaging to acquire reflectance spectra for regions of interest. Reflectance spectra from individual points were also acquired using fiber optics with a visible-near infrared spectrometer (vis-NIR) for comparison with the hyperspectral reflectance spectra.

3.1 MULTIBAND IMAGING

A modified Canon 5D Mark II was used for multiband imaging with a Coastal Optics 60mm UV-VIS-IR APO lens and a set of MidOpt bandpass filters with bandwidths in the hundreds of nanometers. Modifications to the camera included removal of the IR-cut filter from the sensor and the removal of the color filter array (CFA), which were done by MaxMax. After modification, the camera acquires monochrome images and has a maximum potential sensitivity between 350 and 1200 nm (MaxMax). The textiles were illuminated with two Lowel Pro lights with Impact halogen lamps (125W 3200K). The camera was mounted on a studio stand and the filters were changed manually, without changing the focus or position of the camera. Movement of the camera or focus while changing the filters manually could affect the alignment of the images. A filter wheel could be useful to avoid these small shifts; however, this increases setup costs, and manual changing was adequate for this project.

Nine filters were used, producing nine monochrome images for each textile in addition to a visible light image for reference. The transmission curve for the filters can be seen in figure 3. Each monochrome image recorded the interaction of light (reflection and absorption) with the material of the textile and pigment at the specific bandwidth of the filter. The variation of the interaction of the light with the different bandwidths can reveal and distinguish materials. Image subtraction with image processing software such as Adobe Photoshop or ImageJ can be used to process images to better reveal some of the pigments used. Image subtraction is a simple, powerful process that can be applied for visualizing the difference or changes between two images (Jain 1986). The pixel values of two images are subtracted resulting in an image that reveals the differences between the pixel values of two images.

3.2 HYPERSPECTRAL IMAGING

Hyperspectal imaging was carried out using the Surface Optics Corp. 710 (SOC710) with a CCD sensor and spectral sensitivity from 400 to 1000 nm. The SOC710 acquires 128 images between 400 and 1000 nm

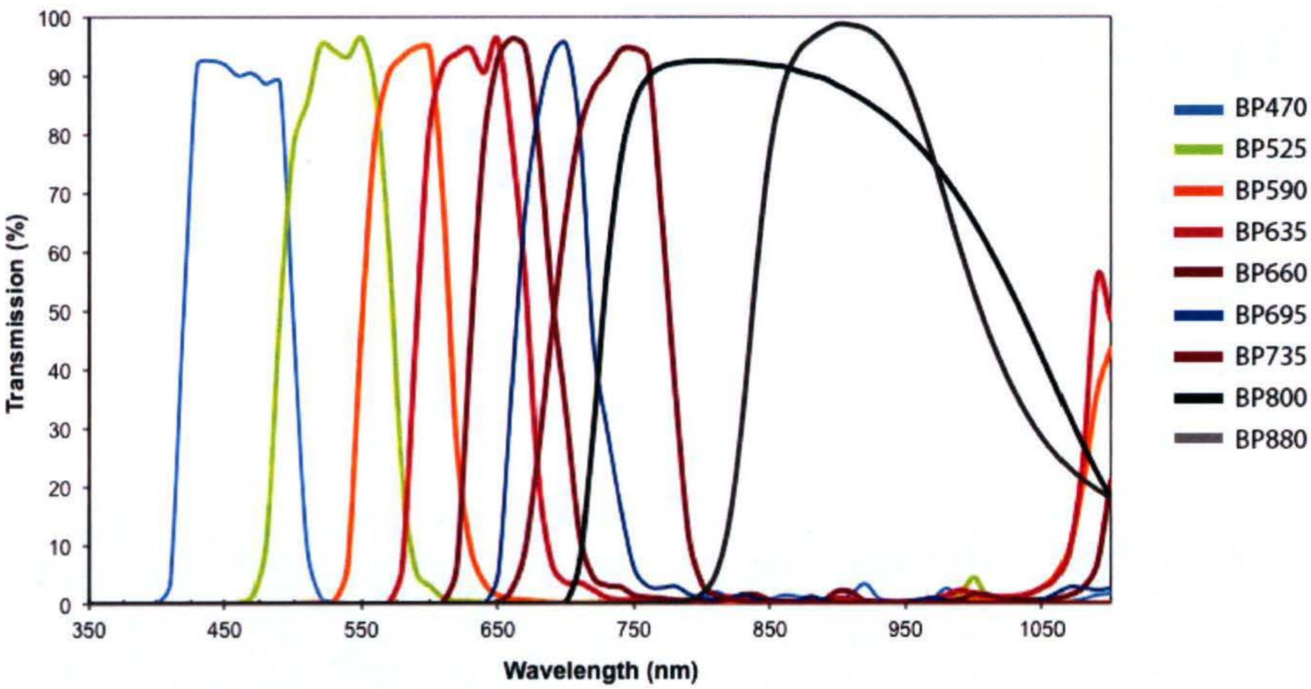

Figure 3: Transmission curves of MidOpt Bandpass filter kit used for multiband imaging. Graph from MidOpt website

creating a data cube that can provide reflectance spectra for pixels or areas of interest, as well as images of the area analyzed at a particular wavelength. The sensor captures images of 696 x 520 pixels. The textiles were illuminated with two Lowel Pro lights with Impact halogen lamps (125W 3200K).

3.3 FIBER OPTIC REFLECTANCE SPECTROSCOPY (FORS)

Point reflectance spectra were acquired using an ASD FieldSpec Hi-Res near infrared spectrometer with Indico Pro software. Spectra were collected from 375 to 2500 nm adding 50 scans at 1 nm resolution. The light source was a 70W 3100K halogen bulb. Spectra were acquired with either (1) direct halogen lighting and the instrument's original fiber optics to capture the reflected light from an approximately 1cm spot size or (2) a microfiber optic attachment in which both the source and reflected light were carried through fiber optics and there is a 1–2-mm spot size. In both cases, spot size is determined by the distance of the fiber optics from the sample. Jumps in the spectra at 1000 and 1800 nm are present due to the change in detector between the three regions of the spectra. Two spectra were taken from each spot and background spectra were acquired using a Spectralon 99% white reference and unpainted areas of textiles.

4. RESULTS AND DISCUSSIONS

4.1 BLUE PIGMENT

The signature reflectance spectrum for indigo includes a strong absorbance around 660 nm and a high reflectance just under 800 nm (Leona and Winter 2001). This drastic difference in absorbance can be captured with an image subtraction using the 735 nm bandpass filter and the 660 nm bandpass filter (fig. 4). The resulting image highlights the blue regions (figs. 5, 6). This result was supported by point reflectance spectra (fig. 7), which indicated that blue pigments in textiles 22/0497 and 23/9038 were indigo.

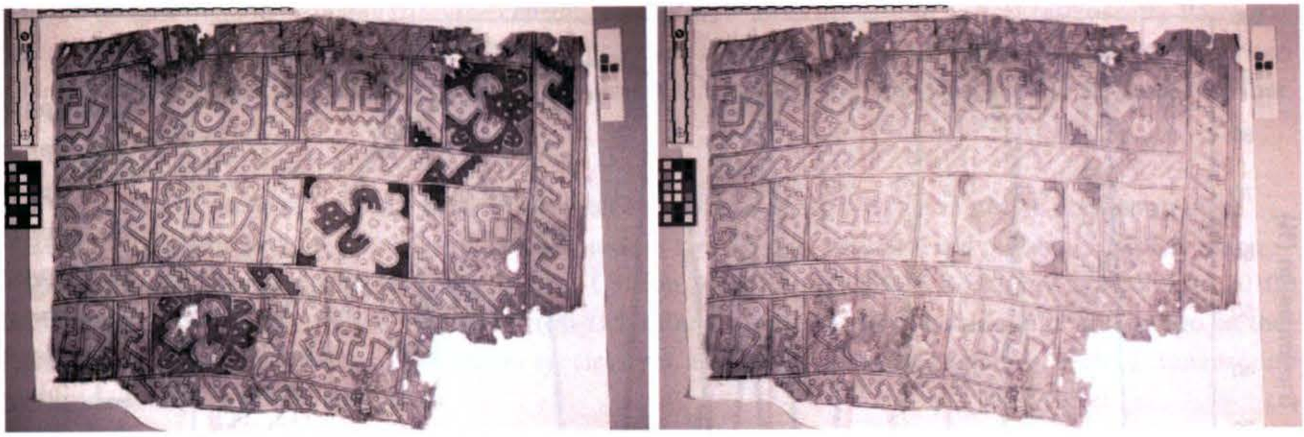

Figure 4: NMAI 23/9038 660 nm bandpass image (left) and 735 nm bandpass image (right)

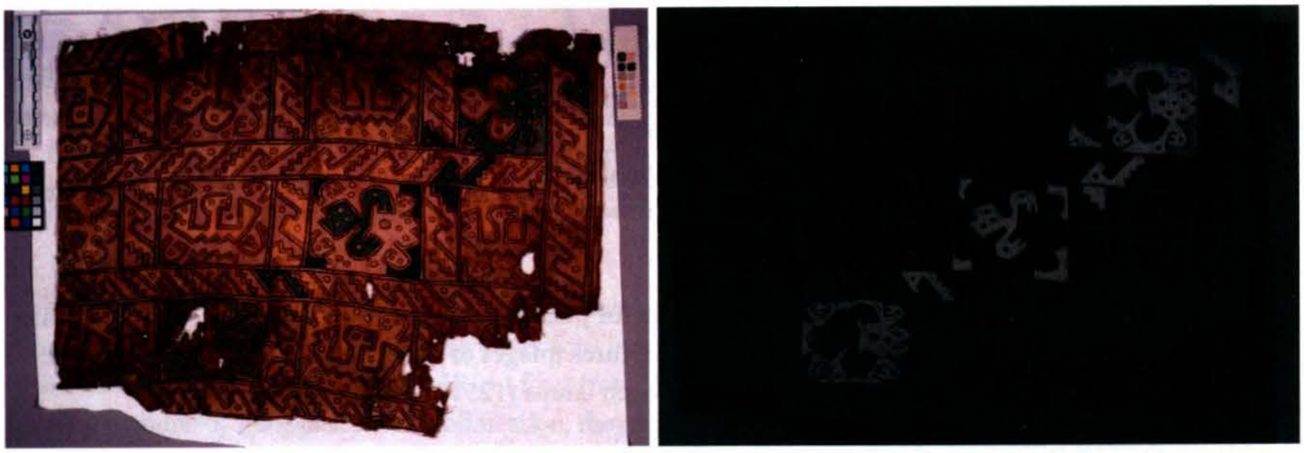

Figure 5: NMAI 23/9038 visible light image (left) and image subtraction of the 735 nm bandpass image and the 660 nm bandpass image emphasizing the areas of indigo in resulting image (right)

Figure 6: Detail of NMAI 22/0497 visible light image (left) and image subtraction of the 735 nm bandpass image and the 660 nm bandpass image emphasizing the areas of indigo in resulting image (right)

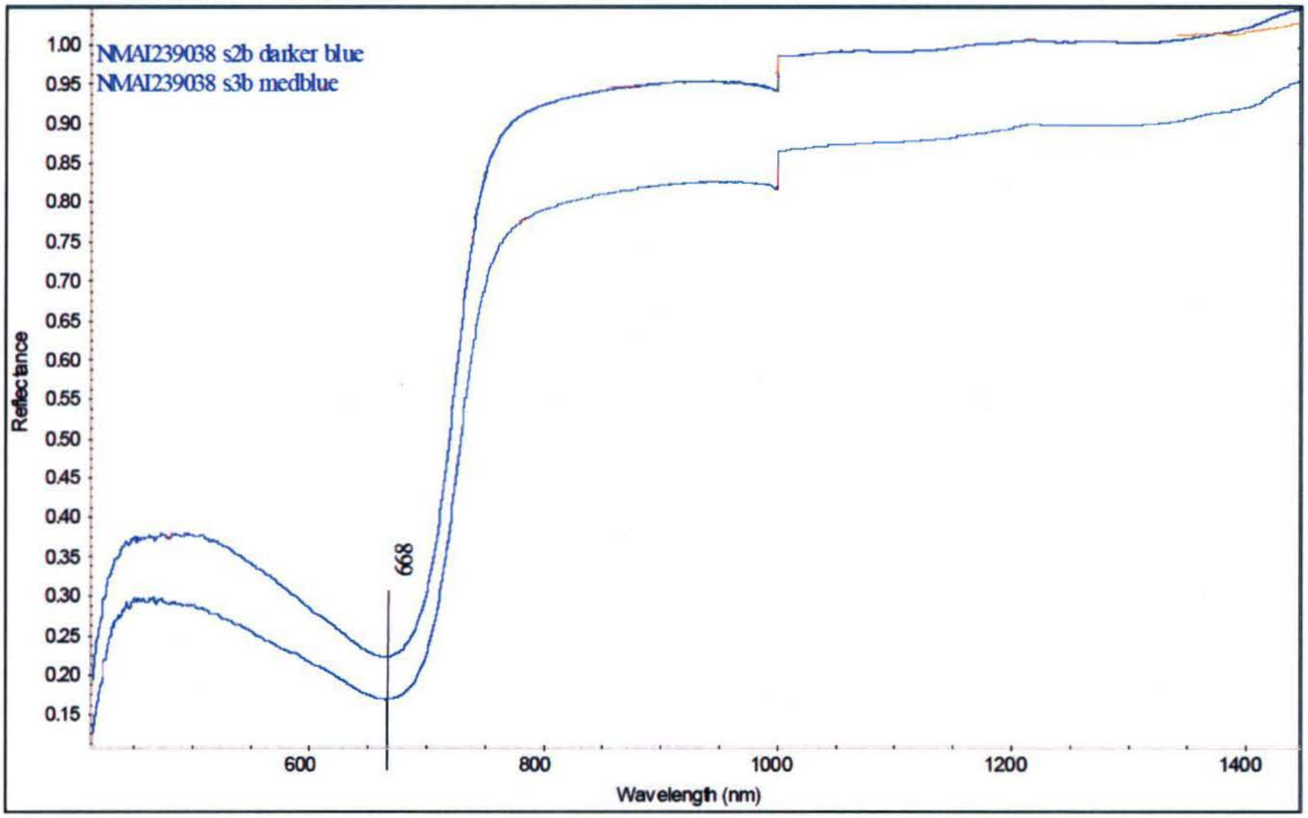

Figure 7: NMAI 23/9038 FORS spectra of blue pigment showing the signature spectra for indigo.

Image subtraction using the 735 nm and 660 nm bandpass filter images was also performed for the Middle Horizon textile (NMAI 23/9040) even though there was no indication that indigo would be present. The results suggested that the black pigment included indigo (fig. 8), which was supported by the reflectance spectra from FORS and the hyperspectral camera (fig. 9).

Figure 8: Visible light image of NMAI 23/9040 (left image) and the results of image subtraction of the 735 nm bandpass image and the 660 nm bandpass image (right image)

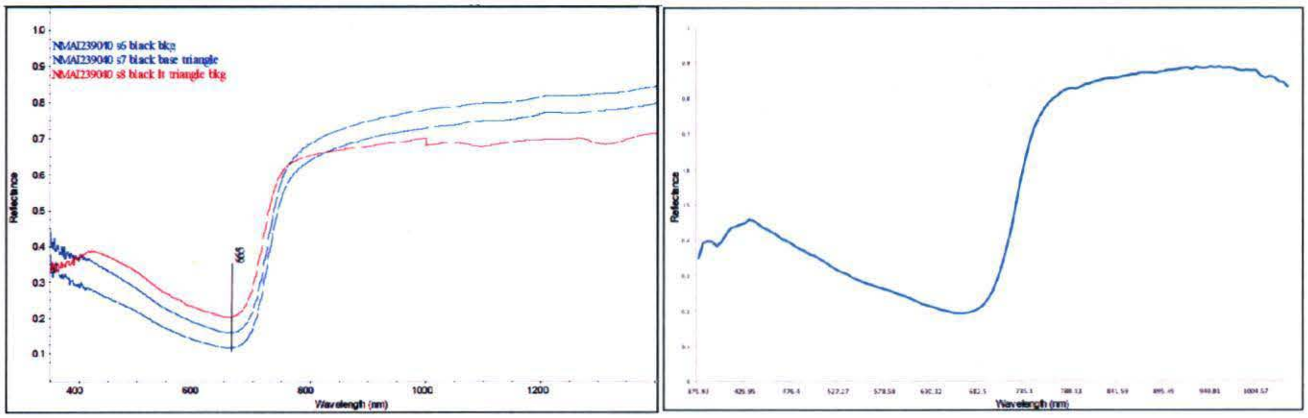

Figure 9: FORS spectra of black pigment (left) in the Middle Horizon textile (NMAI 23/9040) and hyperspectral spectrum of black pigment (right) confirming that the black pigment includes indigo.

4.2 RED PIGMENTS

4.2.1 Mineral Reds

The FORS spectra of mineral reds show a sharp incline starting just before 600 nm and an absorption valley around 880 nm (fig. 10), which is characteristic of iron oxides (Cornell and Schwertmann 2006). This incline and absorption valley can be seen in the hyperspectral spectra, but image subtraction was not successful in differentiating mineral reds from the insect-based red colorant. The 880 nm bandpass filter passes 840–1010 nm and does not appear to be narrow enough to show the difference between the reflectance recorded with the filtered images, and therefore is unable to characterize the mineral reds.

4.2.2 Insect-based Reds

The spectrum for cochineal has a signature double peak around 525 nm and 565 nm, which is seen in the FORS spectrum for NMAI 23/9038 in figure 11 (Winter, Giaccai, and Leona 2003). This double peak for the insect-based colorant can sometimes be difficult to see in the hypersepctral spectrum but is visible in figure 11. There is no significant change in the spectrum that might be useful for an image subtraction using multiband imaging to characterize insect-based colorant.

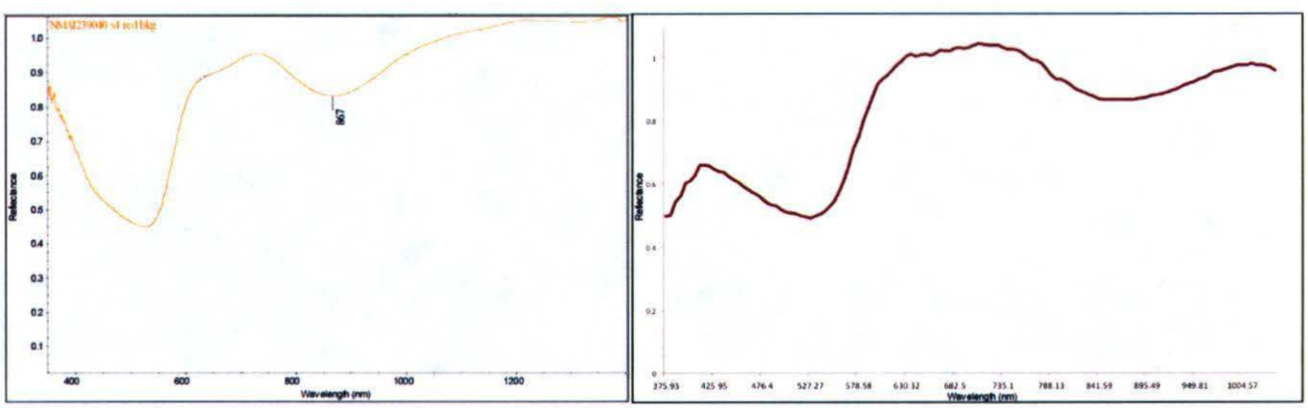

Figure 10: FORS spectrum for mineral red (left) in textile NMAI 23/9040 and hyperspectral spectrum of mineral red (right)

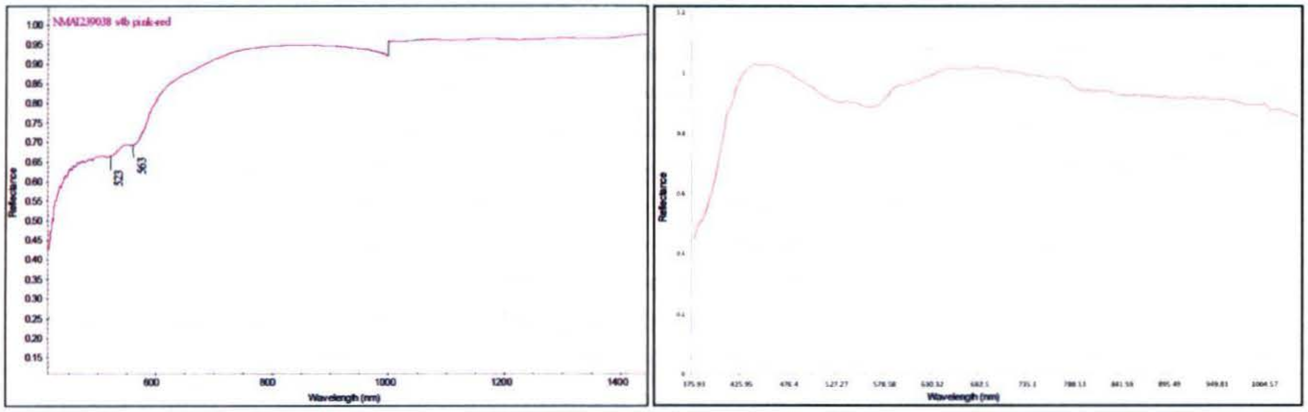

Figure 11: FORS spectrum for cochineal (left) in textile NMAI 23/9038 and hyperspectral spectrum (right)

4.3 BROWN PIGMENTS

Multiband and hyperspectral imaging were not helpful in distinguishing between different types of brown colorants. Analytical techniques such as XRF and HPLC were found to be more informative in characterizing the mineral and plant-based brown colors. Preliminary analysis suggests that a combination of earth pigments and tannin-based dyes are present, but additional analysis is underway.

4.4 CALIBRATION, LIGHTING, AND FUTURE WORK

As mentioned earlier, the multiband imaging in this project did not use calibrated images. A few steps added to the image acquisition process allow calibration of the images, changing the technique from multiband to multispectral imaging. These steps would include correction for each image using flat fielding and reflectance standards (Ricciardi et al. 2009). The resulting data produces quantitative information and not just visualization of spectral differences.

After executing the research and imaging for this project, we realized that the light source being used in multiband and hyperspectral imaging did not provide even light around 400–500 nm. Author Webb is in the process of creating a new lighting setup with light sources that are stronger in these wavelengths, for a wider and better spectral distribution for future imaging.

5. CONCLUSIONS

The investigations presented in this paper illustrate how multiband and hyperspectral imaging can be useful for nondestructive identification and differentiation between pigments and materials in textiles. Multiband imaging proved useful for characterizing select materials, especially when used in combination with hyperspectral imaging or fiber optic reflectance spectroscopy. Multiband imaging was useful for highlighting the consistency of materials throughout each textile because each image can encompass the entire textile, rather than small select areas.

Indigo was successfully characterized with both multiband and hyperspectral imaging. The image subtraction with multiband imaging accurately mapped the location of indigo over an entire textile. The image subtraction alerted researchers that the black colorant in the Middle Horizon textile included indigo, which was supported by the hyperspectral imaging and FORS spectra. This technique using image subtraction with multiband images is likely to be useful for characterizing indigo on other types of objects, such as ceramics or paintings.

This project did not provide conclusive information for the identification of red or brown colorants. On the basis of the characteristic reflectance spectra of cochineal and mineral red pigments that can be acquired with FORS, it seems likely that these materials could be characterized using modified versions of the multiband and hyperspectral imaging setups applied in this project. Additional work remains to be done for imaging analysis of the red colorants found in these textiles. The similarity between all brown reflectance spectra, for both organic and inorganic colorants, suggests that these imaging techniques will not be useful for characterizing browns.

The multiband and hyperspectral imaging worked well as a means of characterization and identification for the painted Andean textiles because the textiles contained a limited palate that did not include complex mixtures. For example, had ultramarine been present, the image subtraction processing would not have been successful because ultramarine reacts very similarly to indigo. This reminds us how vital our understanding of the historical and cultural context of the object is to our interpretation of image analysis. Multiband and hyperspectral imaging are important tools that offer a nondestructive option for material characterization within the context of the entire object.

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NOTES

1. This insect-based colorant is presumed to be cochineal based on the established use of cochineal in the Andes (Phipps 2010). FORS does not distinguish between different types of insect-based dyes.

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SOURCES OF MATERIALS

Azurite, "Gunjyoo No. 9" purchased at Kukodo, Kyoto 1986;
Red lead, F. Weber Co.
Freer and Sackler pigment reference collection
1050 Independence Ave SW
Washington DC 20560

Black Walnut Whole Fruits Harvested autumn 2010Buffalo, NY

Bone Black, French Yellow Ochre Deep, Lamp Black, Prussian Blue
Conservation Materials Ltd. (out of business)
240 Freeport Blvd, Box 2884
Sparks, NV 89431
Tel: 702-331-0582

Burnt Sienna, Burnt Umber, Indian Red, Raw Umber
Conservation Materials (out of business)
1165 Marietta Way
Sparks, NV 89431
no number

Vermilion (HgS), Winsor & Newton
Museum Conservation Institute pigment reference collection
4210 Silver Hill Road
Suitland, MD 20746-2863

Cochineal
Kremer Pigments
247 W 29th StNew York, NY 10001
Tel: (212) 219-2394
Fax: (212) 219-2395
http://www.kremerpigments.com/

Ferrous sulphate
Fisher Scientific
Tel: (800) 766-7000
https://www.fishersci.com/

Indigo, Madder Root
Earth Guild
33 Haywood St
Asheville, NC 28801
http://www.earthguild.com/

Jagua (Genipa Americana)
Ink Gel Tattoo
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www.freshjagua.com.

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