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More Than Meets the Eye: Fluorescence Photography for Enhanced Analysis of Pictographs

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The study of rock art has traditionally focused on the analyses of style and technique rather than of materials and technology, in part because it is often considered undesirable to remove pigment samples for laboratory analysis. Pictographs and petroglyphs, more than many other potentially diagnostic artifacts, are often seen as one of a kind, finite resources that need to be spared from even the minimal damage caused by procedures such as X-ray fluorescence and radiocarbon dating. As such, only a limited amount of data have been generated in the last twenty years that deal with the technology involved in the manufacture of rock art. However, recent advances in photography-based procedures involving digital image enhancement (Clogg et al. 2000) and multispectral imaging (Kamal et al. 1999) have successfully highlighted the possibilities of using non-conventional photographic techniques as in situ methods of analysis, and are currently supplying new information about aboriginal pigment and stone working technologies to the field of rock art studies. As will be shown below, ultraviolet fluorescence photography also warrants consideration as a non-destructive, on-site procedure that can yield valuable data for rock art pigment recording and analysis.

Some pictograph pigments emit visible, colored light when exposed to ultraviolet radiation, and this paper describes a method in which this normally invisible color component is isolated and recorded on standard photographic film. When used in the field this recording technique has the ability to serve two functions: in degraded rock art panels it may reveal traces of pigment that are otherwise invisible to the eye or to conventional photographic techniques; and analyses of these fluorescence attributes may function as a non-destructive tool for comparisons of pigment compositions.

Ultraviolet fluorescence recordings of CA-KER-735 and CA-KER-736, two pictograph sites in Kern County, California, demonstrate the ability of this procedure to fulfill these objectives. The techniques described in this paper are not new – they have been regularly employed in the laboratory for decades by conservators and forensic scientists who specialize in the analysis of paint and ink characteristics (von Bremen 1965; Radley and Grant 1959:440-452; Riordan 1991). To my knowledge, however, there is no published literature that addresses the use of ultraviolet stimulated fluorescence for rock art analysis.

ULTRAVIOLET FLUORESCENCE PHOTOGRAPHY

This procedure relies on the ability of ultraviolet light to act as an exciting source that triggers a release of visible light in certain substances. This phenomenon, when it occurs in organic and other naturally occurring substances, is known as primary fluorescence or autofluorescence: as the photons of an exciting source strike a subject and are absorbed, they cause electrons of the subject's atoms to temporarily move from their normal, ground state to the higher energy orbit of an excited state (McGown 1986:73; Guilbault 1990:5-7). The absorbed energy is then released, often in the form of heat, as the atoms return to their ground state. In a substance that has fluorescent capacities, however, this return to a ground state is very rapid and is accompanied by an emission of photons. These photons are of a lower energy, and therefore of a longer wavelength, than the photons that were originally absorbed (McGown 1986:75; Williams and Williams 2003). When the exciting source is ultraviolet radiation, which has a wavelength that is slightly shorter and higher in energy than the lower threshold of visible light (400 nm.), it is light in the visible portion of the spectrum (400 – 700 nm.) that is emitted by the subject (Becker 1969:87-90; Robbins 1983:195).

The objective of ultraviolet fluorescence photography is to make the film react to the various wavelengths of light in the same way that the human eye does: to see only the effect of the photons returning to their ground state, while at the same time being blind to the ultraviolet radiation that is causing the subject to fluoresce. Most photographic emulsions and digital cameras, however, possess a fair degree of sensitivity to the ultraviolet wavelengths, and this complicates the process of photographing exclusively the visible fluoresced light (Kodak 1972). The subject is illuminated with a light source rich in ultraviolet radiation, but this same radiation must be kept from reaching the film after reflecting off the subject so that only the visible wavelengths actually emitted by the subject are recorded. To accomplish this, a barrier filter (also termed an exciting filter) that holds back all visible light and transmits only ultraviolet is used between the light source and the subject. Any ambient visible light that strikes the subject will overpower the relatively faint fluorescence, and therefore absolute darkness must be maximized – in the procedures described in this paper, the rock art panels were photographed only on moonless nights. Thus, exposed only to invisible ultraviolet light, the subject might react with visible fluorescence. To photograph this reaction, a second type of barrier filter is placed between the subject and the film – this filter holds back the shorter ultraviolet wavelengths that are reflecting off the subject while transmitting only the longer, visible wavelengths, so that finally only the visible light being fluoresced by the subject reaches the film (Fig. 1) (Kodak 1972; Dorrell 1994:198-202).

Previous research on the fluorescence of pigments has been concerned primarily with modern paints and inks. Several of these analyses, performed in the laboratory, have been successful in recording fluorescence in both the visible and the long ultraviolet portions of the spectrum, and the technique has been used to analyze alterations and overpainting with modern materials (von Bremen 1965; Crown 1968:175-176; Riordan 1991). None of these

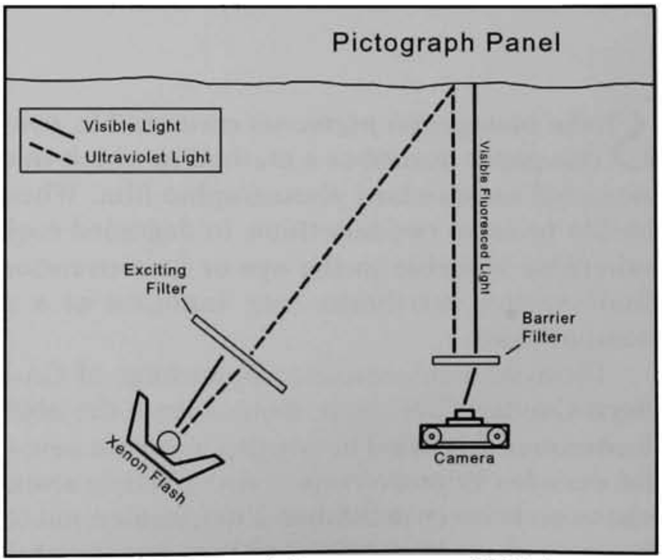

Figure 1. Diagram of the camera and lighting setup used for ultraviolet fluorescence photography.

fluorescence studies, however, have specifically addressed either aboriginal pigments or rock art, and none have involved gathering data outside of the laboratory. The few successful experiments pairing rock art with non-visible wavelengths have focused on the manner in which pigments reflect ultraviolet light – they have shown that the use of this type of illumination often results in an increase in image contrast and clarity over what can normally be seen in the visible spectrum (Webster 1966). Much more refined techniques analyzing the reflectance qualities of paints exposed to light in the visible and near-infrared regions have been used to classify pigment types in Mayan murals (Kamal et al. 1999; Ware et al. 2001). Those experiments focused on the ways in which pigments absorb and reflect various wavelengths of light, but the study described herein uses an alternative approach in which the light that is recorded by the camera is actually generated by the pigment, rather than reflected off of it.

CONSIDERATIONS OF PIGMENT COMPOSITION

Aboriginal paints of the type used in the creation of pictographs generally had three main components: the pigment itself, which was often a dry, mineral-based powder; a binder, such as vegetable oil, animal fat, blood or egg yolk, which acted as a fixative to hold the color to the painted surface; and a vehicle, either water or another fluid element in the paint that allowed it to be handled and applied easily (Gorden 1996). The fluorescent reaction of many minerals to ultraviolet light has been well documented (Robbins 1983: passim; Henkel 1989), but any or all of these pigment components, including fixatives derived from organic sources, may possess fluorescent properties. Unfortunately, ethnographic evidence of paint compositions in the Great Basin and California areas is fairly thin – many published accounts contain only information related specifically to body paints, and in most cases these discuss only the mineral component of the pigments in very broad terms (Driver 1937:76, 120; Voegelin 1938:23-24; Steward 1941:298, 341; Grant 1965:84-86). In contrast, Mary Gorden's (1996) compilation of the sources and composition of Yokuts paints is unusually comprehensive, and constitutes a synthesis of most of the relevant ethnographic data from California. Her work serves to illustrate the high level of variability and complexity that existed in prehistoric paint compositions, and the degree to which many of the ingredients, particularly the binders and vehicles, still remain unknown.

Over the last two decades X-ray fluorescence and diffraction analyses have been performed on paints from several sites, giving clues to the mineral content of their pigments (McKee and Thomas 1973; Garfinkel 1978; Thomas et al. 1983; Whitley and Dorn 1984; Clottes 1993), and protein residue analyses have confirmed that blood was sometimes used as a binder (Loy et al. 1990; Reese et al. 1996; see Rowe [2001] for a comprehensive summary of the most commonly employed methods of pigment analysis.). The fact that radiocarbon dating of pigments has become commonplace (Loy et al. 1990; Geib and Fairley 1992; Russ et al. 1992; Chaffee et al. 1994) is by itself demonstration that many paints contained organic components, and are therefore also good candidates for the procedure of fluorescence analysis proposed here.

THE INDIAN WELLS PICTOGRAPHS

The methods of ultraviolet fluorescence photography outlined in this paper were developed through preliminary tests at several rock art sites in the Western Mojave and Southern Sierra, and pigment fluorescence was recorded to some degree at every site tested. Two sites, CA-KER-735 and CA-KER-736, were subjected to a more intensive recording effort. KER-735 is a locally well-known pictograph site located at the upper end of Indian Wells Canyon, at an elevation of about 6000 feet on the southeastern flank of Owens Peak (Fig. 2). On the border between the southern Sierra Nevada Mountains and the western Mojave Desert, this site also marks a general boundary of two

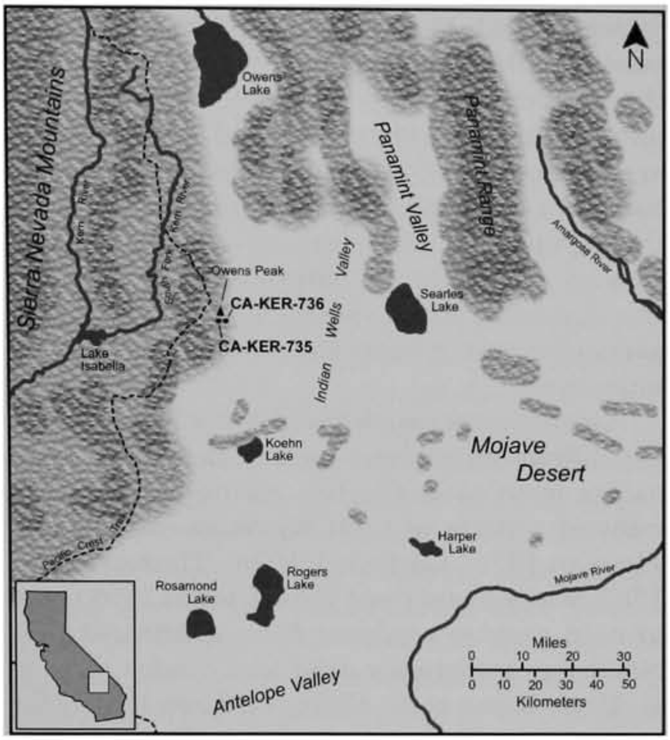

Figure 2. General map of the Western Mojave Desert and Southern Sierra areas showing the approximate locations of the Indian Wells pictograph sites.

neighboring sociopolitical groups, the Koso Shoshone and the Tubatulabal (Kroeber 1925:589-590, 606-608; Steward 1938:71-72), and this boundary may be reflected in the dual styles of rock art. The site contains two polychrome pictograph panels, in black, white and red paint, that show elements of both the Southern Sierra and the Coso painted styles: the spoked, rayed, and concentric circles, semicircular designs and diamond chains common in Tubatulabal pictographs, and the bighorn sheep, shield figures and solid-body anthropomorphs that typify Coso rock art sites (Grant 1968:16-24; Andrews 1977; Whitley 2000:50-54). This possible mixing of styles is consistent with the views of some researchers that the canyons in this area acted as trade routes between the two cultural groups (Garfinkel 1982). Horse-and-rider figures are also present and serve to provide a post-contact date for at least some elements at the site. The presence of these relatively recent components gives credence to the notion that ethnographic territories may be reflected in the rock art styles. The second pictograph site, KER-736, is located two kilometers to the east of KER-735 in a lower portion of Indian Wells Canyon. It also seems to contain components of both the Southern Sierra and Coso styles, although no examples of the bighorn sheep element that is considered a hallmark of the Coso style are present at this site. At both sites there is an unusually heavy application of paint in some areas, as well as evidence of overpainting and superimposition of elements. These sites have been extensively examined and recorded previously (Andrews 1980; Whitley 1982a, 1982b; Whitley and Dorn 1984). Whitley (1984) considers the two sites to be stylistically equivalent, and both he and Andrews (1980) consider them to be contemporaneous.

Past researchers have performed standard X-ray fluorescence analyses on samples of pigment from both sites in an effort to determine the composition of their mineral components: white pigment from KER-735 was analyzed by Garfinkel (1978) and red pigment was tested by Whitley (1984); Whitley also tested white pigment from KER-736. Although absence of lead and the presence of only trace amounts of titanium in all of the samples strongly suggest that the pigments are native in origin, Whitley concluded that the white pigments used in the two Indian Wells sites were chemically different from one another (Whitley and Dorn 1984).

The breadth and quality of the previous recordings of these sites, the supplementary data offered by their chemical analyses, and their assumed temporal and stylistic equivalency make these sites excellent candidates for tests of the fluorescence photography procedure. Additionally, the horse-and-rider figures present at both sites offer unequivocal historic period dates for specific components at each site, offering the potential for an examination of chronological differences among the elements.

METHODS

The most complete and useful outline of ultraviolet fluorescence photographic procedures is offered by Kodak (1972), and the guidelines presented therein provide a starting point for the development of the methods associated with this research.

The film used for these photographs was Fuji RHP Provia 400, a high-speed daylight balanced color reversal (slide) film. This film was chosen for its high sensitivity, its ability to handle underexposure with a minimum of color shift, and its minimal reciprocity failure during long exposure times; this film also has a moderate sensitivity to ultraviolet light (Fujifilm 2003). Transparency film was preferred over negative film because of its higher color saturation and its tendency to enhance contrast in areas of relatively shallow exposure range. Other slide films, including the lower speed Fuji RDPIII and Kodak Kodachrome, have given good results in preliminary tests, but their exposure times are prohibitively long, and it is a small sacrifice in image sharpness to use the higher-sensitivity Fuji RHP. The film was processed in a standard fashion, to an ISO of 400, by Fuji. Manual, mechanical Nikon F2 cameras with Nikkor 35 mm f/2 and Nikkor 20 mm f/2.8 lenses were used, always on a tripod or other stable support.

The lighting equipment was a slightly modified Vivitar 283 off-camera electronic flash unit. Xenon electronic flashes generate a large amount of both ultraviolet and infrared radiation in addition to visible light (Kodak 1972; McGown 1986:76; Williams and Williams 2003), and are well suited for ultraviolet fluorescence photography in the field because of their high light output relative to their small size. This flash, which is designed to run on penlight batteries, was hard-wired to a 6-volt lantern battery to keep the capacitor recycling times to a minimum. A plastic fresnel lens, which normally serves to focus and protect the flash tube, was removed because its slightly yellow tint absorbed a portion of the ultraviolet light. The flash was not connected to the camera with a sync cord, but instead was triggered by a hand-held switch.

The flash unit was adapted to hold a Schneider B&W 403 filter. Constructed of Schott UG1 glass, this visibly black filter is designed to transmit only the near ultraviolet wavelengths between 320 and 385 nm. A slight (<10%) amount of transmission into the lower portion of the visible spectrum still exists with this filter, so that when the flash is fired the burst of light is not quite invisible to the eye, but has a barely perceptible violet tint.

The camera lens held a Schneider B&W 420 filter. In a sense this filter is a reverse of the 403 filter used on the flash: made of Schott GG420 glass, it has greater than 95% transmittance in the wavelengths longer than 385 nm. With a 75% transmission at 425 nm, there is a slight overlap in the portions of the spectrum covered by the two filters – thereby counteracting the slight violet tint that was a residual component of the 403 filter's transmission curve (Schneider-Kreuznach 2003). The 420 filter, then, efficiently holds back the same set of wavelengths that are transmitted through the flash's 403 filter, while at the same time allowing approximately 98% of the visible spectrum to pass. With this combination of filters on the flash and the camera, ultraviolet radiation can be used to trigger fluorescence in the subject, yet only the visible light emitted by the fluorescence is actually recorded on the film.

Preliminary experiments showed that the camera exposure necessary to record dim fluorescent light generated by the pigment is approximately 4000 times greater than that needed to record the same rock art with a conventional photograph. This high exposure requirement necessitates placing the camera and flash quite close to the rock panel, in order to maximize the flash's output while minimizing the amount of light falloff at the edges of the frame; the best results were obtained when the camera and flash were 85 to 110 cm from the rock face. Because the only light photographed is the light being emitted from the pigment itself, there is no need to angle the flash in relation to the rock wall in an attempt to minimize spectral reflectance – the flash may be placed as close as possible to the lens axis. In total darkness the camera's shutter is locked open, and the flash triggered manually multiple times until the desired exposure is obtained. Due to the unknown nature of the fluorescence, exposures on each section of panel should be bracketed in one stop increments, with the number of flashes doubled for each successive exposure. The final exposures selected for study consisted of 30 to 40 full-power flashes for each continually exposed frame of film. The correct exposure is determined more by distance between the flash and the rock face than by the quantity of light being generated by the pigment itself.

Using these methods, the central areas of the main panel at KER-735 and a portion of KER-736 were photographed for pigment fluorescence. After each fluorescence photograph was taken, a standard color photograph was taken for reference from the same camera position and with a matching lens. This makes it possible to digitally overlay the fluorescence photograph onto the standard photograph, which allows for a more precise analysis of the pictographs, the recorded fluorescence and the characteristics of the host rock.[1]

RESULTS

New Elements Recorded:

KER-735. Seven previously unrecorded elements can be seen: a pair of simple anthropomorphs and two small bighorn sheep (Fig. 3), a horse-and-rider figure next to a zoomorph with bovine-type incurving horns (Fig. 4), and a spoked circular element (Fig. 5). Several indistinct, amorphous areas of violet-blue fluorescence are also visible.

KER-736. No new elements were recorded at this site.

Inter- and Intra-element Comparisons:

KER-735. Various areas of white pigment were shown to emit blue-green, yellow-green and violet-blue fluorescence. Six of the seven bighorn sheep elements present on the panel fluoresce in the blue-green color; this color also seems to overlay the yellow-green in places, and this appearance of superimposition is particularly evident in the horse and rider figure (Fig. 5). Inclusions in the unpainted areas of the host rock fluoresce in a green color which, although less saturated, is similar in hue to the yellow-green pigment fluorescence, and the two are difficult to differentiate in several areas. A second horse figure, unusual because the horse carries two riders, fluoresces weakly in the violet-blue color, as does a single bighorn sheep and a large horned zoomorph classified by Theresa Whitley as bovine (Whitley 1982a). No fluorescence was recorded in the areas painted with black, orange or red pigments.

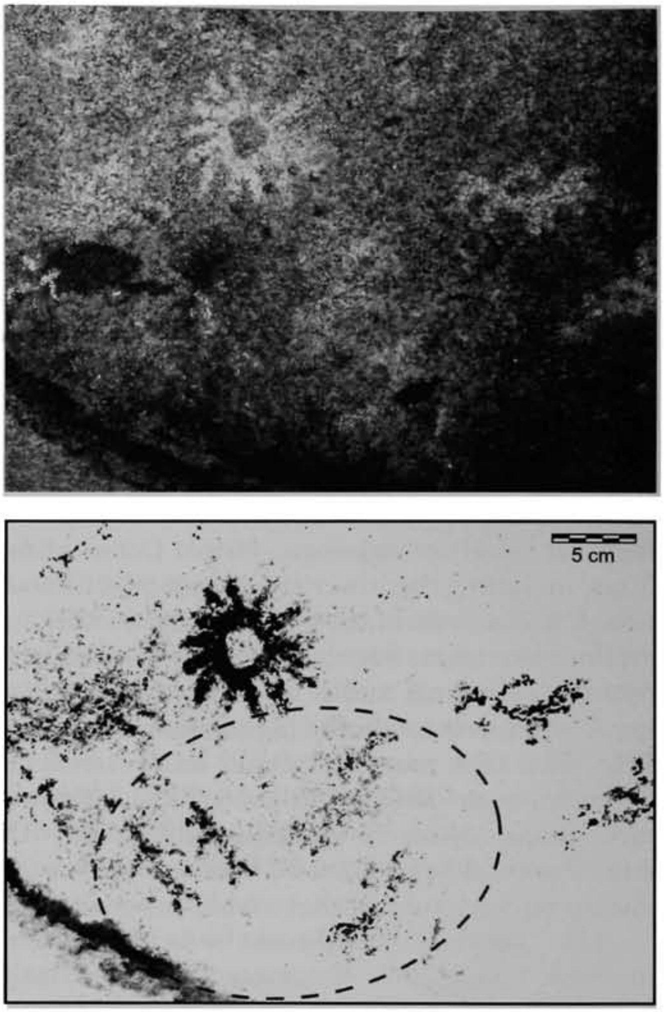

Figure 3. Conventional (top) and ultraviolet fluorescence (bottom) photographs of a portion of the main panel at CA-KER-735. The dashed line encircles the anthropomorph and sheep elements that were discovered through the fluorescence process.

KER-736. White paint in the area tested at this site strongly emits the same violet-blue color of fluorescence seen in the second horse-and-rider and the bovine figures at KER-735. No fluorescence has been observed in the black,

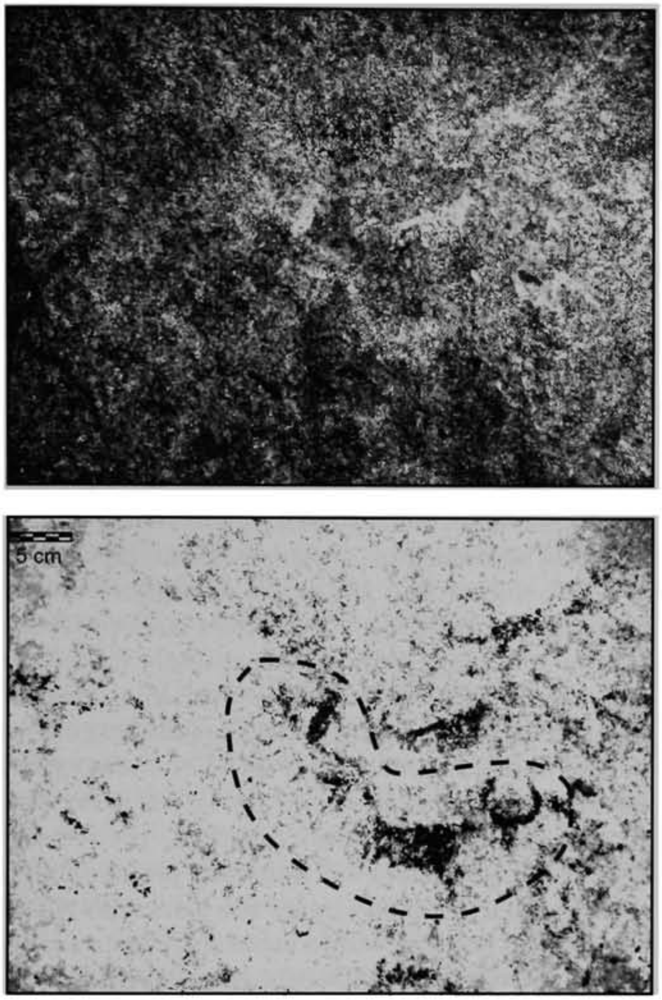

Figure 4. Conventional (top) and ultraviolet fluorescence (bottom) photographs of a portion of the main panel at CA-KER-735. The dashed line encircles newly discovered horse-and-rider and zoomorph elements.

orange or red painted areas. Previous researchers have concluded that red elements at this site were overpainted in white (Whitley 1982b), but close inspection of the fluorescence photographs shows that the two pigment colors may have been applied concurrently, with the two pigment types mixing together while still wet. Trace elements or inclusions in the host rock emit a particularly strong fluorescence at this site.

DISCUSSION

This study has attempted to assess the capability of ultraviolet fluorescence photography to reveal traces of pigment that would otherwise be invisible to the naked eye or to standard photographic methods, and to determine whether the procedure could serve as a non-destructive tool for the comparison of pigment compositions. When applied to site KER-735, the technique made possible the identification of at least seven previously unrecorded pictograph elements. Fluorescence photography highlights and gives shape to areas of pigment previously unseen through normal observation and photography, either because the paint had been indistinguishable from the host rock, appeared to the eye as an amorphous shape or was simply too faint to be seen conventionally. The panel was re-examined in daylight after performing this procedure, and by using the fluorescence photographs as a reference it was possible to visually discern portions of the pigment that were highlighted by the fluorescence process. It is easy to see how these areas were previously overlooked – without having the fluorescence photographs as a guide the newly discovered elements appeared simply as areas of light colored rock or random dabs of pigment.

In all, three different colors of fluorescence were displayed by the white pigments at KER-735: blue-green, yellow-green and violet-blue. Each color is discussed in turn below.

Areas of bright and highly saturated blue-green fluorescence represent the strongest reaction to the ultraviolet light. Previous researchers have remarked on the thickness of the white paint in these same areas (Garfinkel 1978), and noted that this paint was actively flaking off of the host rock (Whitley 1982a). Small spots and flecks of this blue-green fluorescence can be seen throughout the pictograph panel, both in association with visible elements and in areas where no other pigment can normally be seen. Thus, it seems reasonable to assume that the fluorescence provides evidence that the thick white paint was once more extensive at this site than is presently indicated in daylight. The blue-green color is also clearly seen to overlay areas of the pigment that fluoresce yellow-green. For example, the horse-

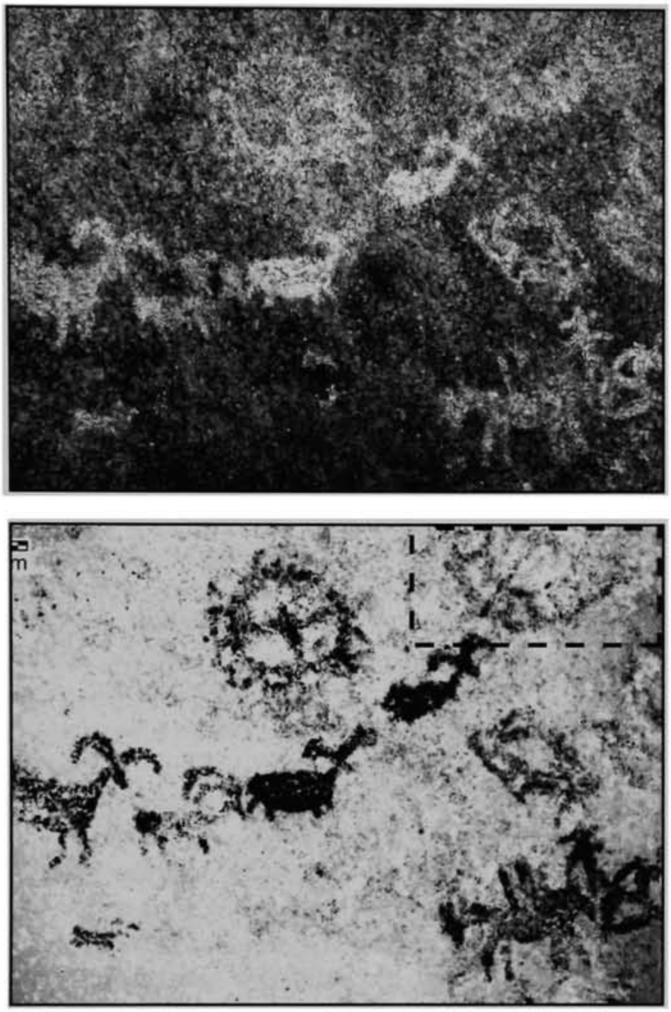

Figure 5. Conventional (top) and ultraviolet fluorescence (bottom) photographs of a portion of the main panel at CA-KER-735. The dashed line highlights the newly discovered spoked circular element. The horse-and-rider element exhibiting differential fluorescence is located at the bottom right in the photographs.

and-rider motif (Fig. 5) shows the horse's body primarily as yellow-green fluorescence, while the horse's rider is composed strictly of the blue-green pigment type.

Several elements composed of white paint fluoresce either exclusively in the yellow-green color, or in this color combined with additional flecks of the blue-green fluorescence. Large areas of the granite host rock fluoresce in a similar, but less saturated, shade of yellow-green. By visually inspecting the rockshelter during daylight it can be seen that smoke blackening has darkened the rock wall that holds the pictographs; this darkening is most pronounced at the bottom of the wall, but in the area where the pictographs are located, at approximately one to two meters above the rockshelter's floor, the smoke blackening consists only of a gray film covering the surface of the host rock. Under daylight inspection the application of white paint in the areas fluorescing yellow-green is extremely thin, and in many spots is essentially non-existent. By considering that these areas and the unpainted host rock both exhibit fluorescence that is essentially equivalent in hue but not in saturation, that blue-green fluorescent specks are present at the margins of the painted elements which fluoresce mainly in yellow-green, and that a smoke film is visible on the host rock, it is concluded that the areas of higher yellow-green fluorescence saturation are indirect evidence of paint that has completely flaked off the rock. If the period when the smoke blackening occurred followed the painting of the pictograph elements, and if these elements then deteriorated or flaked off the rock after the rockshelter was no longer utilized, then these elements should have left a shadow of their shape in the smoke film that coats the host rock. This shadow is visible in some areas during daylight, but it is most clearly seen as areas of bright yellow-green fluorescence in the ultraviolet photographs. The flecks of blue-green fluorescence in the margins of these areas may constitute the only remaining trace of the pigment that originally formed these elements.

The third color of fluorescence recorded is violet-blue. This reaction is present in only three elements at KER-735, while the white pigment at KER-736 emits exclusively this color. Although the violet-blue hue is identical at both sites, the saturation of the fluorescence is relatively weak at KER-735, suggesting a further effect of smoke blackening. David Whitley (1984) used X-ray fluorescence to analyze the composition of the white pigment at KER-736, and compared his results with a chemical analysis of white pigment from KER-735 performed by Alan Garfinkel (1978). Whitley concluded that trace elements present in the two respective pigments indicated that they are of different chemical compositions.

The ultraviolet fluorescence photography offers evidence in support of Whitley's conclusion – the predominant white pigment at KER-735 is of the type that fluoresces blue-green, while the white areas at KER-736 are composed exclusively of the violet-blue fluorescing variety. However, the appearance of this second pigment type in a small cluster of elements at KER-735, particularly in the horse with double rider and the newly discovered horse-and-rider and bovine elements, implies that a technological connection does exist between the two sites. It may be speculated that the violet–blue elements at KER-735 were painted during the same period or by the same artists responsible for KER-736; likewise, the blue-green fluorescing pigment recorded at KER-735 does not appear to have been used two kilometers down the canyon at KER-736.

It should be noted that the complete absence of fluorescent properties in the various red pigments at both sites may offer some evidence concerning their composition. Even small amounts of iron in a substance are known to retard or completely inhibit any fluorescent properties that would otherwise be present in that substance (Robbins 1983:191). Ethnographic data most commonly identifies red pigment as derived from hematite (Gorden 1996), the principal ore of iron. Any tendency for an organic binder or vehicle in the red paint to fluoresce may have been suppressed by iron if powdered hematite was used as a pigment. An examination of the red pigmented elements in both sites shows that fluorescence is completely absent in these areas, and even in spots where the paint has been applied very thinly there is no evidence of fluorescence from the underlying host rock.

This study set out to discover whether ultraviolet fluorescence photography, when adapted for use as a field procedure at pictograph sites, could reveal otherwise invisible traces of pigment and act as a tool for the comparison of pigment compositions. The results demonstrate a successful achievement of both these objectives: at KER-735 seven elements were discovered that were either previously unrecorded or too indistinct to be interpreted; three different sets of fluorescent attributes were found among white pigments assumed to be homogeneous, and therefore an unexpected technological discontinuity is indicated; and despite the close proximity and stylistic similarity of the two Indian Wells sites, the fluorescent attributes of the white pigment at KER-736 are seen only in a single, tight cluster of elements at KER-735, thereby demonstrating a technological link between the former site and only a limited portion of the latter. Future research should focus on expanding these types of intra- and inter-site comparisons to a regional level, with an emphasis on developing a catalog of paint fluorescence attributes that can be collated with known culture areas, motif typologies and absolute chronological data.

Despite the complex nature of the chemical reactions involved in fluorescence, the procedure itself is relatively simple. Except for the two special filters needed, which are readily available, chances are that most archaeologists who regularly record rock art already have the necessary equipment in their camera bags to perform this procedure. Furthermore, this type of photography is perhaps unique in the field of rock art studies in its ability to record comparative data about paint compositions in a completely non-destructive way. The successful application of this procedure at the Indian Wells pictograph sites demonstrates the potential for ultraviolet fluorescence photography to make a substantive contribution to the study of rock art.

NOTES

1. The black and white figures for this paper were created from 2400 dpi scans of the original color transparencies. Using Photoshop 6.0 software, the RGB files generated by the scanning process were converted to the CIE Lab color model. Lab is a three-dimensional color space consisting of one luminance component (L, a single axis that corresponds to lightness) and two chromatic components (two axes that bisect the color wheel at right angles, with A as the red to green axis and B as the yellow to blue axis). Working in the

Lab space allows the user, through manipulation of the contrast curves of the separate components, to isolate specific hues of color more precisely than in the RGB space. For instance, when the intent is to isolate the predominantly blue fluorescence in the image, the luminance and A channels of the Lab model are discarded, leaving only the B portion of the model as an alpha channel. This alpha channel, which holds only the blue and yellow color information from the original photograph, is converted to a gray scale (black and white) file. In the resulting image, darker tones represent the blue component of the original photograph and lighter tones represent the yellow component. The contrast of this black and white version is then raised to eliminate the majority of the middle and light gray tones, thereby rendering the blue fluorescence as shades of dark gray and black in the final image. While these additional steps are necessary to distill the color image into legible black and white for publication, and have the added benefit of clearly isolating the shapes of fluorescing areas, they are ancillary to the process of fluorescence photography. The color slides by themselves possess all of the data needed to analyze the recorded fluorescence.

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REFERENCES

Andrews, Stephen B.

1977 Pictographs of the Tubatulabal. Kern County Archaeological Society Journal 1:33-42.

1980 Pictographs. In: Archaeological Investigations in the Southern Sierra Nevada: The Lamont Meadow and Morris Peak Segments of the Pacific Crest Trail, Alan P. Garfinkel, Robert A. Schiffman and Kelly R. McGuire, eds., pp.326-347. MS on file at the Bureau of Land Management, Bakersfield, California.

Becker, Ralph S.

1969 Theory and Interpretation of Fluorescence and Phosphorescence. New York: Wiley Interscience.

Chaffee, Scott D., Marie Hyman, Marvin W. Rowe, Nancy J. Coulam, Alan Schroedl and Kathleen Hogue

1994 Radiocarbon Dates on the All American Man Pictograph. American Antiquity 59:769-781.

Clogg, Phil, Margarita Diaz-Andreu and Brian Larkman

2000 Digital Image Processing and the Recording of Rock Art. Journal of Archaeological Science 27:837-843.

Clottes, Jean

1993 Paint Analyses from Several Magdalenian Caves in the Ariege Region of France. Journal of Archaeological Science 20:223-235.

Crown, David A.

1968 The Forensic Examination of Paints and Pigments. Springfield: Charles C. Thomas.

Dorrell, Peter G.

1994 Photography in Archaeology and Conservation. Cambridge: Cambridge University Press.

Driver, Harold E.

1937 Culture Element Distributions: VI, Southern Sierra Nevada. University of California Anthropological Records 1(2).

Fujifilm

2003 Data Sheet: Fujichrome Provia 400 Professional [RHP]. Tokyo: Fuji Photo Film Co.

Garfinkel, Alan P.
1978 'Coso' Style Pictographs of the Southern Sierra Nevada. Journal of California Anthropology 5(1): 95-101.
1982 The Identification of Prehistoric Aboriginal Groups through the Study of Rock Art. In: Pictographs of the Coso Region: Analysis and Interpretation of the Coso Painted Style, Robert A. Schiffman, David S. Whitley, Alan P. Garfinkel and Stephen B. Andrews, eds., pp.67-78. Bakersfield: Bakersfield College Publications in Archaeology.

Geib, Phil R. and Helen C. Fairley
1992 Radiocarbon Dating of Fremont Anthropomorphic Rock Art in Glen Canyon, South-central Utah. Journal of Field Archaeology 19(2):155-168.

Gorden, Mary
1996 An Ethnographic Comparison of the Sources, Composition and Uses of Paints by the Yokuts of the Southern San Joaquin Valley and Sierra Nevada, California. Kern County Archaeological Society Journal 7:36-58.

Grant, Campbell
1965 The Rock Paintings of the Chumash. Berkeley: University of California Press.
1968 Rock Drawings of the Coso Range, Inyo County, California. China Lake, California: Maturango Museum.

Guilbault, George G.
1990 General Aspects of Luminescence Spectroscopy. In: Practical Fluorescence, George Guilbault, ed., pp.1-40. New York: Marcel Dekker.

Henkel, Gerhard
1989 The Henkel Glossary of Fluorescent Minerals. Journal of the Fluorescent Mineral Society 15:1-91.

Kamal, Omar S., Gene A. Ware, Stephen Houston, Douglas M. Chabries, Richard W. Christiansen, James Brady and Ian Graham
1999 Multispectral Image Processing for Detail Reconstruction and Enhancement of Maya Murals from La Pasadita, Guatemala. Journal of Archaeological Science 26:1391-1407.

Kodak
1972 Ultraviolet & Fluorescence Photography: Technique & Application. Rochester: Eastman Kodak Company.

Kroeber, A. L.
1925 Handbook of the Indians of California. In: Bureau of American Ethnology Bulletin 78.

Loy, T. H., Rhys Jones, D. E. Nelson, Betty Meehan, John Vogel, John Southon and Richard Cosgrove
1990 Accelerator Radiocarbon Dating of Human Blood Proteins in Pigments from Late Pleistocene Art Sites in Australia. Antiquity 64:110-116.

McGown, Linda B.
1986 Molecular Fluorescence Spectroscopy. In: Metals Handbook 9th Edition, Ruth E. Whan, ed., pp.72-81. Metals Park, Ohio: American Society for Metals.

McKee, Edwin H. and David H. Thomas
1973 X-Ray Diffraction Analysis of Pictograph Pigments from Toquima Cave, Central Nevada. American Antiquity 38(1):112-113.

Radley, J. A. and Julius Grant
1959 Fluorescence Analysis in Ultra-Violet Light. London: Chapman & Hall Ltd.

Reese, R. L., M. Hyman, M. W. Rowe, J. N. Derr and S. K. Davis
1996 Ancient DNA from Texas Pictographs. Journal of Archaeological Science 23:269-277.

Riordan, William M.
1991 Detection of Nonvisible Writings by Infrared Luminescence and Ultraviolet Fluorescence. Journal of Forensic Sciences 36:466-469.

Robbins, Manuel
1983 The Collector's Book of Fluorescent Minerals. New York: Van Nostrand Reinhold Company.

Rowe, Marvin W.
2001 Physical and Chemical Analysis. In: Handbook of Rock Art Research, David S. Whitley, ed., pp.190-220. Walnut Creek, CA: AltaMira Press.

Russ, J., M. Hyman and M. W. Rowe
1992 Direct Radiocarbon Dating of Ancient Rock Art. In: Rock Art Papers Volume 9, Ken Hedges, ed., pp.121-128. San Diego: San Diego Museum.

Schneider-Kreuznach Optics
2003 B&W Filter Handbook. Electronic document: http://www.schneideroptics.com/filters/filters_for_still_photography/handbook/pdf/B%2BWHandbook_Full.pdf, accessed August 3, 2003.

Steward, Julian H.
1938 Basin-Plateau Aboriginal Sociopolitical Groups. Bureau of American Ethnology Bulletin 120.
1941 Culture Element Distributions: XIII, Nevada Shoshone. University of California Anthropological Records 4(2).

Thomas, David Hurst, Jonathan O. Davis, Donald K. Grayson, Wilton N. Melhorn, Trudy Thomas and Dennis T. Trexler
1983 The Archaeology of Monitor Valley: 2, Gatecliff Shelter. Anthropological Papers of the American Museum of Natural History, Vol.59.

Voegelin, Erminie W.
1938 Tubatulabal Ethnography. Berkeley: University of California Anthropological Records 2(1).

Ware, Gene A., James E. Brady and Curtis E. Martin
2001 Multispectral Imaging and Spectral Classification of Naj Tunich Pigments. Proceedings of the IS&T 2001 PICS Conference, pp.211-214.

Webster, W. J. E.
1966 Ultra-Violet Photography of Australian Rock Paintings. Antiquity 40 (158):144.

Whitley, David S.
2000 The Art of the Shaman: Rock Art of California. Salt Lake City: University of Utah Press.

Whitley, David S. and Ronald I. Dorn
1984 Chemical and Micromorphological Analysis of Rock Art Pigments from the Western Great Basin. Journal of World Archaeology 6(3):48-51.

Whitley, Teresa C.
1982a Coso Style Pictographs of CA-KER-735. In: Pictographs of the Coso Region: Analysis and Interpretation of the Coso Painted Style, Robert A. Schiffman, David S. Whitley, Alan P. Garfinkel and Stephen B. Andrews, eds., pp.22-46. Bakersfield: Bakersfield College Publications in Archaeology.
1982b The Rock Art of CA-KER-736. In: Pictographs of the Coso Region: Analysis and Interpretation of the Coso Painted Style, Robert A. Schiffman, David S. Whitley, Alan P. Garfinkel and Stephen B. Andrews, eds., pp.47-66. Bakersfield: Bakersfield College Publications in Archaeology.

Williams, Robert and Gigi Williams
2003 Fluorescence Photography. Electronic

document, http://msp.rmit.edu.au/Article_02/01.html, accessed October 20, 2003.

von Bremen, Ulf
1965 Invisible Ultraviolet Fluorescence. Journal of Forensic Sciences 10(3):369-375.