PROJECT TYPE: 3 -- Applied/Fundamental Research

PROJECT TITLE: **Development of High-Resolution, Digital, Color and Infrared Photographic Methods for Preserving Imagery on Hopewellian Copper Artifacts.**

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PROJECT ABSTRACT:

Visual examination, ultra-high resolution enhanced digital color and infrared photography, and physico-chemical assays of Ohio Hopewell copper artifacts indicate that they commonly bear mineral pigments, modified plant and animal products, and other substances that are unnatural to copper corrosion, and that repeatedly pattern into apparent, sometimes subtle, Hopewellian-style artistic compositions. State-of-the art developments in digital color and infrared photography and image enhancement will be tailored to better reveal, display, and preserve these undocumented potential images. A model guiding the application of these techniques to Hopewellian copper artifacts from many regions will be built. Mineralogical, metallurgical, and organic-materials analyses will support model development.

AUTHORIZED SIGNATURE: Christopher Carr

PROJECT DESCRIPTION

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Project Narrative

Overview and Goal. Prehistoric Hopewellian peoples of the Eastern United States (ca. 100 B.C. - A.D. 400) are well known for their artworks of copper, which were buried with their dead or in caches within earthen mounds. A systematic, in-depth survey of 320 copper ceremonial plaques, headresses, and celts from southern Ohio and Indiana, and chemical and microscopic analyses of a sample of these, have revealed that the majority of these bear the remains of mineral pigments, fabrics, other modified plant and animal products, and/or other substances that are unnatural to copper and its corrosion products. Studies of the spatial distributions of these materials over the objects have allowed the definition of repeated, apparent design elements and compositions similar in style to those of known Hopewellian and Adena art in other media from the Eastern United States. While it is clear that certain copper objects bear artistic imagery, many are harder to decifer by the naked eye, alone. More sensitive, technologically aided methods of observation are required to accurately discern what remains of images they may bear, to test the hypothesis that they do bear images, and to resolve them. It is possible that copper items from other regions of Hopewellian development in the Eastern United States, beyond Ohio and Indiana, also bear imagery that has gone unnoticed.

The purpose of the proposed research is to develop a systematic, integrated set of digital photographic techniques for efficiently recovering, recording, and displaying images on Hopewellian copper artifacts, as one approach to preserving the images and their information. Initial testing has shown certain methods to be effective, but the range of materials and preservation conditions for which this is true, and the tailoring of specific techniques to given material types, remain to be systematically investigated. In the course of the proposed methodological work, potential images on the items will also be preserved photographically.

Previous Research and Literature Review

The Archaeological Context. The Ohio Hopewell were semi-mobile, apparently swidden horticulturalists and hunter-gatherers (Wymer 1996, 1997) who lived in the major river valleys of south-central Ohio. The flamboyant material symbols and iconography, mortuary practices and remains, and social organization and ideology that archaeologists use to identify and characterize the Ohio Hopewell cultural system (e.g., Griffin 1967) spanned the period of ca. 150 or 50 B.C. to A.D. 350 or 500, depending on the locale and aspect of culture in question (Carr 1996). Related archaeological complexes that have similar ceremonial and material characteristics occur across the Eastern United States from the Great Lakes to the Gulf Coast, and from New York to western Missouri (Griffin 1967:181).

Ohio Hopewellian peoples lived in small homesteads and camps of one or a few households each, which were dispersed over valleys in response to their subsistence practices. Multiple homesteads were probably organized into communities which centered around earthwork-burial mound sites that held their dead (Brose and Greber 1979;Brown 1981, 1982; Carr and Maslowski 1995; Dancey 1991; Dancey and Pacheco 1997; Greber 1979; Greber and Ruhl 1989; Konigsberg 1993; Pacheco 1988; Prufer et al 1965). Communities appear to have been integrated and regulated in several fashions: (1) ritually by periodic mortuary and other ceremonies, and perhaps feasts, within the earthworks (Seeman 1979; Smith 1992); (2) socioeconomically by local utilitarian exchange (Carr and Komorowski 1995); (3) politically by shaman-like leaders and clan or lineage heads (e.g., the deer-"rabbit" impersonator from Mound 25, Hopewell site, Moorehead 1922:128; the Wray figurine bear impersonator from Newark; the decorated stone head from Edwin Harness, Greber 1983:33; see also the earlier Lakin A and Gatskill "dancing shaman" Adena tablets, Webb and Baby 1957), and (4) most important to this grant, symbolically by the art and exotic raw materials apparently displayed (e.g., Greber and Ruhl 1989) and used by such leaders in mortuary and other ceremonies.

The Ohio Hopewell are well known for their fine mortuary and ceremonial art, and their procurement of fancy raw materials from distant sources over the continent to make much of that art. Geometric and representational line engravings on animal and human bone, terra-cotta and stone sculptures, and forms created out of copper, silver, meteoritic iron, mica, shell, obsidian, and other materials comprise the most common kinds of published art (e.g., Brose et al. 1985; Otto 1992; Penney 1983, 1985, 1989).

Problem Development. Over the course of 37 weeks during 1995-1997, and with support from the Wenner-Gren Foundation of Anthropological Research,, the Chicago Field Museum, and Arizona State University, the PI made a visual survey of nearly all extant major collections of Ohio Hopewell and Mann-Phase (Indiana) Hopewell artifacts housed in museums, universities, and the private sector in the Unitied States. The purpose of the survey was to search for unpublished examples of Hopewellian art. The collections examined are those of: the Ohio Historical Center (Columbus), the Chicago Field Museum of Natural History, the Peabody Museum of Harvard University, Hopewell Culture National Historical Park, the Ross County Historical Society (Chillicothe, OH), the Johnson-Humrickhouse Museum (Coshocton, OH), the Glenn Black Laboratory of Indiana University, the Indiana Department of Transportation, the Kent State University photographic collection of Mt. Vernon artifacts, and the private collections of Robert Harness (Chillicothe, OH), Robert Converse (Plain City, OH), and Charles Lacer (Evansville, IN).

In the course of this work, the PI noticed that some copper plaques, headplates, and celts appear to have on them the remains of artistic design elements and compositions that resemble other Hopewellian and Eastern Woodlands art, and that previously had gone undetected. Although the possible images range greatly in their degree of preservation to the naked eye, they repeat among objects and can be characterized. The images are primarily of apparent animals, humans, or animal-human composites like those mentioned above. The animal species most frequently represented are bear, wolf, raptorial bird, deer, and cat. -- species that commonly served as clan totemic animals and names of clans or phratries in the historic northern Woodlands (Trigger 1978). The figures are arranged in compositions that have bilateral or quadripartite symmetry, figure-ground reversal, and complex intertwining of shapes. These are traits of Hopewell iconography, generally. Thus, both the content and style of the apparent images lend them credibility.

The methods by which the imagery appears to have been made include: painting with mineral pigments, and the application and arrangement of a variety of materials, including cut-out shapes of textiles, bark, ground up plant material, small segments of plant stems, untwisted plant fibers, cordage, sand, bone, pearls, and feathers. In some cases, it looks like a fiber-paste layer was built up over the copper surface, and then differentially removed to create bas-relief area-fills or to expose the underlying plate so as to create images in the negative. A pigmented, sap-like, possible adhesive has also been observed. In retrospect, artistic work of these various kinds on copper Hopewellian artifacts is not unexpectable: plaques, headplates, and earspools were sometimes decorated with designs by other, better preserved, sometimes conceptually-related means, including embossing, area cut-outs, and silver and meteoric iron applique'.

The potential images, tentative identifications of surface materials, and the possible artistic processes enumerated thusfar are hypotheses to be tested formally through the technical expertise of professionals in digital image processing and enhancement, metallurgy, mineralogy, and analysts of archaeological textiles and other organic materials. This testing work has been started, and will continue in the course of developing and applying preservation methods aimed at recovering, clarifying, recording, and displaying the possible images. Both testing and methodological development are intrinsically intertwined.

Preliminary Studies and Methodological Development. In order to understand how images on the copper objects were manufactured, to gain insight into their taphonomy, and to assess methods for better resolving images, two kinds of preliminary studies were made: (1) chemical and microscopic studies of the materials comprising the images, and (2) digital photographic and other methods of image enhancement. The studies were designed and made by Carr, Kopala, Preston, Lydecker, Colwell, Pride, and Hoffman, who will continue as team researchers on the proposed project (see cover page).

Preliminary analytical chemical and microscopic studies. Microsamples of 11 differently colored surface materials -- 10 thought to be mineral pigments and one an organic binder or adhesive -- were removed from 63 locations on 11 copper plaques, headplates, and celts and analyzed by five methods for their material identity. The objects came from four different Ohio Hopewell archaeological sites (depositional and taphonomic environments): Hopewell, Seip, Ater, and Fortney. The samples from each item were taken from areas that are integral parts of likely human or animal images of various kinds or their contrasting backgrounds, and that appear unnaturally homogeneously colored. The methods used to analyze the samples and determine their material type were: (1) electron microprobe analysis using the energy dispersive method, to determine the samples' elemental concentrations; (2) Raman microspectroscopy using 514.5 nm and 785 nm excitation wavelengths, to determine the samples' inter-atomic bonding characteristics; (3) x-ray diffraction using a Debye-Scherrer camera, to determine the samples' crystallographic structure; (4) SEM microphotography at approximate 50 - 200X and 3000X, to document the samples' crystal morphology; and (5) petrological description under a zoomscope at 6 - 31X, to document the samples' crystal morphology.

All told, these studies clearly identified seven materials and suggest possible identifications for the remaining. The mineralic materials fall into two groups: (1) noncopper compounds that do not derive from copper corrosion and that, from all evidence, appear to be applied pigments, and (2) copper corrosion products that could, on the basis of their chemistry alone, be either applied pigments or in situ developments. The noncopper compounds are red, yellow, white, and brown-black in color -- the same colors used in other Ohio Hopewell art work, the colors of the soils used in contrasting distributions to build some Ohio Hopewell mounds and earthworks, and the colors found in much historic Woodland Indian art and ceremony. The compounds include: (1) hematite; (2) a highly crystalline white substance that appears to be powdered serpentine in its crystal shape, refractive index, and composition (primarily silicon and magnesium); (3) a yellow material that is phosphorus and calcium rich, possibly bone, and that includes a small amount of calcite, dolomite, shell, pearl, and/or some other primarily calcium carbonate material; and (4) a brown substance that is largely acrystalline, has moderate amounts of silicon, and that most likely is an organic-rich soil. The copper-based compounds include cuprite (red), chrysocolla (aqua), malachite (blue-green), turquoise (turquoise), azurite (deep blue), and perhaps others in minor amounts. The one possible organic binder for pigments, or adehsive, was found to bubble under the heat of the microprobe electron beam, as expected. It is noncrystalline, and contains red and yellow colorants fully dissolved within it.

The copper-bearing compounds, which form integral parts of images like the noncopper ones, logically could indicate artistry in either of two ways: directly or indirectly. These hypotheses are still being investigated. (1) Natural copper corrosion products could have been scraped from native copper, or mined along with native copper at its source, to form pigments of green, blue, or red, which were then added to some vehicle/binder. Different corrosion-derived paints of different colors could then have been applied to different areas of a composition. (2) Different corrosion products of varying colors could have developed naturally in different images or parts of images because these areas were originally treated with different fugitive substances (e.g., organics) to form images. Areas treated differently would then have posed varying corrosion environments, differing in pH, available elements, and/or water-retention, leading to the formation of different corrosion minerals of different colors. In this case, the shapes of any images would have been preserved, but their original colors would not have. Jakes and Sibley (1984:421) have documented the differential formation of black tenorite corrosion and green malachite corosion in prehistoric silk threads placed near copper, and attribute it to whether or not the threads were dyed and the effect of this on the pH of the corrosion setting.

Observation of the 11 sampled copper objects and others under 5 - 31X magnification by the PI and copper corrosion professional Dr. Jeffery Colwell, and an analysis of phase-equilibrium diagrams for copper-aqueous systems, tentatively support the hypothesis that, where corrosion-derived minerals form integral parts of images on the copper objects, the minerals were more likely applied as paints. (1) Areas of chrysocolla, malachite, and azurite development that comprise apparent images or parts of images have crisply bounded, smooth, linear or curvilinear edges in a way that in situ copper corrosion does not naturally grow. (2) A few cases have been found of apparent "drying lines"-- where apparent malachite and azurite pigments accumulated at a drying edge. (3) Some colors appear to have been produced by the mixing of two copper corrosion pigments, the particles of which are jumbled together randomly. Natural growth of the corrosion products from the copper substrate is lacking. (4) Some images are comprised of apparent copper corrosion pigments on top of applied organic materials. Again, the corrosion products did not develop from the copper substrate. (5) A few celts and plaques with possible figures have a uniform background color of azurite blue, despite coming from multiple sites and depositional-corrosion environments. Mathematical modeling of the equilibrium thermodynamics of copper-aqueous systems by Colwell shows that azurite is not a stable compound in the soil conditions (pH, temperature, water, dissolved ions) that abound in Ohio, and is unexpectable as a natural corrosion product on the celts and plaques. In addition, neither azurite nor turquoise, which also is found on one of the studied copper items, are reported as naturally occurring, in-situ developed components of the Ohio geological landscape. However, phase diagrams do indicate that where cuprite and malachite have natural appearing spatial distributions on copper items, they could have developed naturally within the Ohio weathering environment. Finally, the hypothesis that copper corrosion minerals were applied as paints to objects that appear to bear imagery does not deny that there are other objects, or parts of objects, that do not seem to bear any imagery and whose corrosion mineral types and distribuions are entirely natural in origin.

A variety of other observations support the painting hypothesis for the copper and noncopper-based potential pigments. Delamination of possible paint layers, drying cracks, and a related tradition of painting with copper-based pigments on textiles are reported in Appendix 1.

Resolving better the images and apparent images on the copper objects, ultimately in order to preserve them, was the goal of a second line of preliminary work. This work has involved (1) high-resolution color digital photography, (2) computerized color digital image enhancement on CRT, (3) color digital enhancement printing, (4) near infrared, midrange infrared, thermal infrared, and ultraviolet photography with tungsten illumination, (5) short and long wavelength ultraviolet "black lamp" illumination and observation, and (6) photomosaicing. An explanation and/or literature review of the more essential methods is now presented.

Literature review of digital photography and image enhancement methods and studies. Digital imaging has a long history in the fields of remote sensing by satellite and aerial photography, using both the visible and infrared portions of the light spectrum (American Society of Photogrammetry 1968,1983, 1984; Castleman 1979; Pratt 1978; Gonzalez and Wintz 1977; Lilles and Kiefer 1987). However, only in the past several years have color digital cameras with the fine resolution, compact size, and reasonable cost that is required in conservation and analytical work in archaeology been available. Thus, such applications have been few. Digital photography is now used in some museums (e.g., American Musuem of Natural History) to make permanent, nondeteriorating records of irreplacable objects that are subject to degradation, loss of ownership, or repatriation. Davis and Steponaitis (1996) used digital photography for this purpose and to provide concerned Native American tribes with visual records of burial goods housed at the University of North Carolina. Bearman (1996) used a digital camera with near-infrared sensors to photograph portions of the Dead Sea scrolls in preparation for enhancing the writing on darkened, unreadable portions. One of the earliest applications of digital photography to archaeology was made underwater. An electronic still camera with direct digital output, which allowed the operator to preview images, was used to document the U.S.S. Hamilton, which sunk in Lake Ontario during the War of 1812 (Stewart 1991, the Jason Project).

Computerized digital image enhancement methods include several major classes of display and mathematical routines, which are designed for a variety of tasks. All of the methods involve analyzing and/or modifying the grey-scale values, or red, green, and blue-scale values, or other spectral values of the pixels that comprise a digital image. Pixel value modifications can be made in an exploratory or deductive manner, using either the image itself, its histogram of pixel values, or its Fourier transform. (1) Improving image contrast can be achieved using color or other spectral band selection, interband calculations, contrast-stretch histogram modification, histogram equalization, and spectral analysis. (2) Sharpening boundaries with images can be accomplished with mathematical filters sensitive to gradients. (3) Determining the frequencies/scales at which image intensity varies more or less is done with spectral analysis in either the Fourier or spatial domains. (4) Partitioning overlaid images of different scales can be achieved to varying degrees with spectral analysis and band-pass filtering in the spatial and Fourier domains. (5) Partitioning and removing high-frequency noise or low-frequency trends or disjunctures are accomplished with the same methods. Relevant overviews of how each method works mathematically and in application are provided by Castleman (1979), Gonzalez and Winz (1977), and the PI (Carr 1987).

Image enhancement methods have been used for about thiry years for remote sensing by satellite and airplane (see above), geophysical prospecting (Davis 1973; Holloway 1958; Robinson et al 1970; Zurflueh 1967, archaeometric prospecting (Carr 1977,1982; Linington 1969; Scollar 1969, 1970; Weymouth 1985), and/or intrasite archaeological spatial analysis (Carr 1987; Lang 1992). In archaeological work with photographs, Haigh and Ipson (1989) used a combination of Fourier analysis, linear contrast stretch, and histogram equalization to compensate for fogging and uneven partial darkening of an aerial photo of a hillfort in Scotland. Bearman (1996) applied convolution, sharpening, and histogram adjustments in Adobe Photoshop and NIH Image to a series of narrow, near infrared bands recorded from the Dead Sea Scrolls, in order to read lines of text that were hidden by the fading of carbon ink and the darkening of the papyrus. Salzer (1987) and Valiga and Scherz (1987) used image enhancement methods to improve the resolution of false-color infrared and color photographs of rock art, respectively. Stewart (1991) did the same on underwater photographs of the U.S.S. Hamilton (above). Carr (1987) and Lang (1992) used a wide variety of image enhancement methods to resolve patterns in intrasite artifact distributions likened to poor quality photograph.

Infrared (IR) photography using infrared-sensitive film or a digital camera with sensors sensitive to infrared waves have been used commonly in art history for several purposes: (1) to view underdrawings below a painting's surface, (2) to view layers of painting over painting, and (3) to pinpoint areas of aging and damage. Such documentation is made in order to study a painting's planning and development during production, to determine its authorship, to study workshop traditions, and to reconstruct areas of restoration or other alterations (e.g., De Boer 1970; Desneux 1958; Dunkerton et al 1987; McKim-Smith 1988; Panofsky 1958; Roy 1988; Marijnissen 1967; Taubert 1956. 1959; Verougstraete and van Schoute 1997). The approach has been particularly popular in examining 15th Century Flemish paintings. The method is based on the fact that different elements and compounds vary in their reflectance of IR waves when illuminated with incandescent light, allowing areas of different material composition to be distinguished and some materials to be seen through. False-color infrared photography, which combines information on visible and near-infrared light, was used by Hirsch (1987) with incandescent lighting to resolved floor-tile paintings, and by Salzer (1987) with ultraviolet lighting and resulting material fluorescence to distinguish the pigment of rock art images from natural mineral stains and plant growth on sandstone cave walls.

In IR applications in art history, typically, a wide range of wavelengths are sensed, from near to mid-range infrared, to produce a single image. In contrast, in related approaches used in infrared aerial and satellite remote sensing for surveying, prospecting, and surveillance purposes, often the infrared spectrum is broken into multiple bands of varying wavelength. Only certain bands relevant to the spectral response of a particular material may be monitored, as in mineral prospecting (e.g.Goetz 1976, 1984; Goetz et al. 1985; Hunt et al 1971 Nicolais 1974; Smith 1977) or vegetational mapping (e.g., National Academy of Sciences 1970; Sadler 1987; Savastano et al.1984). Alternatively, a very large number of narrow bands (e.g., 10 nm) covering a wide range of wavelengths (e.g., .4 - 2.5 microns) may be sensed simultaneously, resulting in a digital image where each pixel documents a spectrum of wavelengths. Pixels may then be characterized for their spectra in order produce compositional maps of mineral distributions or forest canopy species distributions, which are most interpretable when reference spectra for minerals or plant species are known (e.g. Kruise 1990; Hook and Rast

1990; Johnson et al 1992) Such "hyperspectral imaging" or "image spectrometry" approaches were used by Bearman (Bearman et al 1993; Bearman and Spiro 1996) to read faint lettering on darkened sections of the Dead Sea Scrolls. Bearman is one of this project's team members.

Ultraviolet photography has been found in art history to be optimal for detecting discontinuities in painted surfaces. Ultraviolet light incident on a material may produce fluorescence or phosphorescence in the visible spectrum, and/or ultraviolet radiation, any of which may be sensed and recorded (Derbiere 1947; de Wild 1929; Eastman Kodak 1998; Radley and Grant 1954).

Photomosaicing is a procedure for constructing a flat layout photograph of a curved surface from multiple photographs of it taken from different vantage points. It can be done manually with photographs or digitally in the computer. The method is most commonly used in aerial landscape surveying, but will be used here to make layouts of images on curved copper headplates. In this case, operationally, the process can be achieved by keeping a digital camera in one position and rotating the curved headplate about its approximate center of curvature on a formed, Styrofoam support. Photographs are taken at several rotation positions so as to overlap in coverage. The multiple photographs are then spliced together to create the layout using image scaling, rotating, skewing, and stretching routines in Adobe Photoshop. This application has been successfully employed on archaeological artifacts by Carr and Lydecker (1997).

Preliminary studies of image enhancement methods. With funding from Eastern National Parks and Monuments Association and Arizona State University, the methods of image capture, enhancement, and display reviewed above were explored for their capability in resolving potential images on copper objects bearing a variety of material types. State-of-the-art color and infrared digital cameras, computer image processing software, and printing systems were employed--the same to be used in the proposed project.

(1) In preparation for these studies, color slides were taken of all copper plaques, headplates, and celts in the museums and collections listed above, totalling 317 objects and over 600 observable sides. Canon 800 color prints of all slides were made with machine settings that maximized the contrast among differently colored and textured areas within each item. In most cases, the copies significantly enhanced subtle color and texture differences, boundaries, and apparent artistic images that were sometimes difficult to see in the original.

(2) The enhanced Canon prints were compared and sorted, in order to define various kinds of image patterns that repeat among the copper objects and that appear to represent artistic compositions. This use of the Canon prints, though simple, was a significant development. Objects stored in multiple drawers and museums can be directly compared only a few specimens at a time, which hampers image pattern recognition. In contrast, the prints permitted wide-ranging comparison among objects and the definition of image classes.

(3) The enhanced Canon prints were used to select 35 sides of 17 plaques, 5 celts, and 5 headplates that varied in the classes of apparent images they bore, and that spanned many of the kinds of materials and apparent artistic processes described above. Color digital photographs were taken of these 35 potential compositions using an ultra-high resolution portable digital camera with 3360 x 2253 pixels with incandescent illumination. Photomosaicing strategies were used where necessary on curved objects. The specifications of the powerful computer system used to support the photography and its storage are given in Appendix 2.

(4) A large suite of image enhancement methods was tested on the 35 item-sides for their effectiveness in improving the contrast, boundary sharpness, and definition of potential compositions, and in revealing previously unseen figures of kinds known or thought to occur on other objects. Adobe Photoshop was used to make the enhancements. One general strategy of enhancement was found most useful, but remains to be tested thoroughly with better information on the nature of the materials on the objects and how material type effects enhancement results. The strategy is as follows. (a) Two copies of a given potential composition were made on the CRT screen. (b) Image contrast of the two copies was optimized using two different routines on them: contrast-stretch histogram modification operating on the red, green, and blue bands together, and contrast-stretch histogram modification operating on these bands individually. The more information-bearing image was then selected for further study. (A third contrast-improving routine--histogram equalization--was seldom found effective.) (c) The modified, individual red, blue, and green bands of the selected image and their inverses (negative images) were assessed for which ones contained the greatest information about potential figures. Almost uniformly, the red and blue bands or their inverses proved most revealing, apparently because they minimized the noise of any greenish, natural corrosion products. (d) The most informative bands or their inverses were multiplied by, divided by, added to, and subtracted from each other, in order to enhance various suspected figures or to reveal unsuspected ones. (e) The contrast of each resulting calculated band was then optimized using a contrast-stretch histogram modification. (f) The bands were compared to each other in search for either quasi-stable patterns that repeated over several bands, or for figures that uniquely occurred in one band but that were known to resemble figures on other copper objects. These two criteria afforded a level of confidence in the reality of the images found. (g) Found images were ground-truthed for their visibility in the original copper objects as a final test of their reality. In practice, the strategy commonly led to the finding of images that were not at first seen on an object but that became recognizable once the naked

eye's attention was brought to it. Example, tangible products of this enhancement process are shown in the figures in Appendix 3.

(5) A strategy was developed for separately displaying each of the multiple, individual design aspects (layers of information) of a composition. This was necessary because the potential compositions, like much of Hopewellian art, often involve multiple conjoined, nested, and/or overlaid figures, with figure-ground reversal; these figures are hard to see and make sense of when displayed simultaneously. The display strategy involved: (a) laying acetate sheets on the enhanced image and making line tracings of each individual layer of information/figure on its own sheet; (b) raster-scanning the tracings into the computer; (c) autotracing the raster scans into a vector version, so as to produce line drawings of consistent line width; (d) reconverting the tracings to a raster image and superimposing it on the enhanced image; and (e) printing a combination of the image enhancement and a tracing, one for each layer/tracing made (e.g., Figure 1c).

(6) The possibility of image enhancement using ultraviolet light to illuminate and distinguish materials was explored with short and long-wavelength black lamps (.254 and .366 microns) on approximately 20 items with diverse surface materials, including the 11possible pigments/binders. Fluorescence was encountered for only the white pigment, and inconsistently. None of the surface materials phosphoresced. Consequently, this approach does not seem useful.

(7) Near-infrared (.715 - 1.1 microns), midrange infrared (1.0 - 1.8 microns), thermal infrared (8 - 14 microns), and ultraviolet (.35 - .38 microns) cameras were used to photograph 6 sides of 6 items bearing the 11 potential pigments/binders and certain organic materials. The work showed that near and midrange infrared frequencies are most useful. These allowed the boundaries of some artistic images to be sharpened, the revealing of some largely hidden images, and the mapping of sparce distributions of at least the white and yellows pigment that otherwise are invisible to the naked eye. The three different infrared frequency ranges were compared to each other and to color photography in the surface materials they distinguished, making it clear that any systematic exploration of imagery on copper artifacts should use near and midrange infrared frequencies as well as visible light. An example of the infrared work is shown in Figure 3. The ultraviolet camera work did not discrimate any of the 11 possible pigments/binders. As expected, it revealed primarily differences in surface relief. All of this work was done by Kopala, Preston, and Carr at Battelle Laboratories.

(8) Various hardware and software for printing enhanced color and infrared digital photographs were compared for the resolution,contrast, and texture they offer. The Canon 800 series color copier, with its good resolution (400 dpi) and an edge enhancement routine, was found to offer the most information-laden images.

Specific Objectives, Tasks, and Tangible Products of the Project

The preliminary studies described above will be extended in order to develop a more systematic approach for recording, resolving, and displaying imagery on Hopewellian copper artifacts. Attention will focus on exploring the integration of color, near-infrared, and midrange-infrared responses in image enhancement; hyperspectral imaging; systematically correlating surface material types with their photographic responses; and systematically evaluating alternative photographic procedures. In addition, in the course of this methodological work, potential images on the studied items will also be preserved photographically.

(1) The sample of objects selected for study includes 200 item-sides of copper plaques, headplates, and celts that are housed in the Ohio Historical Center. The items come from 8 different archaeological sites (Hopewell, Seip, Liberty, Ater, Ft. Ancient, N. Benton, Esch, Fortney) representing diverse depositional environments in south-central, southwestern, and northeastern Ohio. The items represent well the range of variation in surface material types and potential image types found on copper artifacts in the Ohio Hopewell archaeological collections of other institutions, including the Chicago Field Museum, Peabody Museum of Harvard University, Hopewell Culture National Historical Park, the Ross County Historical Society, and the Johnson-Hummrickhouse. The surface material types minimally represented are: (a) the ten noncopper and copper-based possible pigments described above, (b) applied clay, (c) sand, (d) fabrics and cordage probably with material diversity (Song 1991), (e) bark, (f) finely ground up plant material embedded in adhesive as a layer, (g) small segments of plant stems applied as a layer, (h) feathers, (i) hide, (j) copper pseudomorphs (copper replacements) of the previous organic materials, (k) calcined bone, (l) charred bone, (m) charred wood, and (n) other unidentified materials. Half of the item-sides bear organic and inorganic materials; the other half only inorganic materials. The potential images range from distinct, to very subtle and inconclusive to the naked eye. Ten items with apparently plain or very heterogeneous surfaces and no visible indications of imagery will be examined for their potential, as well.

(2a) Each item-side will be photographed with digital cameras of three kinds: (a) ultra-high resolution color --3360 x 2253 pixel image, (b) near-infrared, and (c) midrange infrared cameras. These camera systems are described in Appendix 2. Photomosaicing procedures will be used with curved headplates . Each image will be enhanced using the wide variety of alternative techniques reviewed above, only some of which have thusfar been explored on the copper objects: (a,b) contrast-stretch histogram modification operating on the

RGB and infrared bands separately and together; (c) R, G, B, and/or infrared band selection; (d-h) addition, subtraction, division, multiplication, and/or inversion R-G-B-infrared band calcuations; (i) edge enhancement; and (j) band substitution, which involves replacing one or two color bands by one or two infrared bands so as to produce a hybrid image. Integration of color and infrared signals in these enhancement processes will be a fundamental addition to our previous imaging work. Systematically, each alternative technique for each item-side will be evaluated and rated for its effectiveness in producing images that are information-laden in terms of their detail, contrast, and the recognizable figures that they reveal. Techniques and their effectiveness will be correlated with material conditions later (Step 4).

(2b) A subsample of item-sides that show some photographic patterns in Step 2, but that require further image refinement for the patterns to be recognizable and useful, will be photographed with a color-through-infrared-sensitive hyperspectral imaging system yielding much narrower (10 nm) color and infrared bands (Appendix 2). More refined band selection, and routines that classify pixels based on their individual spectra, will be used to attempt the refinements. This approach, too, is a fundamental addition to our previous work. It will be evaluated for its effectiveness, as well.

(3) Each item-side will be evaluated by three to five expert materials scientists in order to identify the categories of surface materials found on it and to map their spatial distributions directly on prints of the enhanced images generated in Step 2. Two mineralogists, a copper corrosion metallurgist, a prehistoric textile analyst, and a paleoethnobotanist will do this work, with joint observation and discussions among them for each object. General material categories likely to differ in their absorption and reflectance properties will be focused upon (see list in Step 1, above). Examination will be (a) by stereozoomscope and microscope with tungsten, polarized and/or ultraviolet light, (b) with the aid of the enhanced photographs, and (c) by SEM and/or electron microprobe for select samples. Potential pigments and other inorganic materials will be tentatively identified to mineral species by their color and structure compared to reference samples identified in the preliminary research described above, geological reference standards, and geological/material science literature. Plant and animal materials will be tentatively identified to general category by archaeobotanical and archaezoological criteria, and visual criteria used for copper-preserved organics (see references, Appendix 4). The organic categories to be recorded will float explicitly in their level of generality and probability among areas and specimens, depending on the degree of preservation and mineralization of the material. Some visual identifications will have to be considered tentative until verified and/or made more specific by analytical chemical techniques (a later step, beyond the immediate goals of this proposed project).

(4) The responses of each category of identified material to color, near-infrared, midrange infrared, and hyperspectral photography, and to the several kinds of image enhancement routines, will be compared to the responses of other categories of materials where they occur on the same item-sides, and systematically described. Tallies of cases of distinguishability and indistinguishability of each pair of materials by each photographic and enhancement method will be made. The particular photographic and image-enhancement tools most and least suited for distinguishing pairs of materials will be concluded, in order to specify optimal image recovery and display techniques under various material conditions.

(5) A summary model will be built to guide others in photographing potential images on Ohio Hopewellian copper artifacts. The model will include: (a) lists of photographic and image enhancement techniques that are most and least suited for resolving, recording, and displaying potential images made of given kinds of materials; and (b) visible characteristics of materials that can indicate their general type to the researcher. This step constitutes one of the primary goals of this research.

(6) While studying the items for their surface materials, observations pertinent to their production, post-burial taphonomy, and curation history will be recorded, with especial focus on whether intentional prehistoric application of materials and artistic work can be verified or excluded. Example kinds of observations to be made include: (a) stratigraphic relationships of in situ growth or layered application of surface materials relative to the underlying copper substrate, in areas of relief and on broken edges, which are frequent; (b) intermixing of particles of two or more possible pigments in a random fashion, rather than in a copper corrosion growth pattern; (c) jumbled orientation of the particles of a possible pigment, rather than a copper corrosion growth pattern; (d) segregation and thickening of potential pigments that result from drying, at an edge; (e) drying cracks in thick layers of potential pigments; (f) brush or other application marks; (g) adhesive residues; (h) apparent fabric cut-outs with possible cuts that cross warp and weft elements obliquely; and (i) unanticipated, telling observations. Item-sides will be rated for their probability of bearing intentional artistic works: definite, highly probable, possible, or unlikely/entirely absent.

(7) For those item-sides bearing convincing visual and material evidence of artistry, tracings of potential images will be made on acetate laid over one or more optimally enhanced photographic prints, while the tracer makes reference to the original item (i.e., ground-truthing). During the drawing process, information on the spatial distributions and identitites of different surface materials, and their production, taphonomy, and curation history, as provided by consultation with the five material scientists and their written notes, will be heavily relied upon . A composite of an enhanced image and a tracing for each layer of information for each

item-side will be produced by the computer methods described above. Thus, in the course of the methodological work of this project, preservation of some the studied artifacts will have been accomplished.

All photography, materials, and drafting work with the copper artifacts, themselves, will be done at the Ohio Historical Center. Digital enhancement and/or evaluation will be performed at Archaeological Services, Consultants, Battelle Columbus Laboratories, and the Jet Propulsion Laboratory. Any SEM and/or electron microprobe analyses will be made in the Department of Geology, Ohio State University.

Work Schedule. Step 2: May 3 - July 2. Steps 3,4,6,7: June 21 - July 23. Step 5: Aug 9 -Oct 30.

Tangible Products and Dissemination of Results. The proposed work will lead to: (1) a model specifying (a) the kinds of photographic and image enhancement techniques that are best and least suited for discriminating among different surface materials on Ohio Hopewellian copper artifacts and for resolving, recording, and displaying imagery on them, and (b) the visible characteristics of materials that indicate their general type to the researcher; (2) suites of ultra-high resolution enhanced digital color and infrared photographs for each of 200 item-sides of plaques, headplates, and celts, constituting preservation of their visual appearance; (3) a list of item-sides thought to bear or not bear artistic images; (4) one or more traced layers of imagery information for each item-side evaluated by the materials experts as bearing convincing evidence of artistic production, constituting additional preservation of artifact conditions; (5) written notes and maps of the materials experts that describe the identity and spatial distribution of surface materials found on each of the 200 item-sides studied, and the experts' assessments of item production, taphonomy, and curation history; and (6) national-level journal publications, and national and regional conference papers, on the imaging methods found most and least useful and why, the nature of the surface materials of the copper artifacts, the artistic production processes revealed, and the formal nature of the imagery clarified.

Significance. (1) The photographic and image enhancement procedures to be developed will employ state-of-the-art technologies and software, and tailor advances made in a diversity of other disciplines to archaeological documentation and conservation. (2) Copper items of the kind to be photographed here are common, comprising a large corpus of artifacts to be explored for potential artwork. Over 320 are extant from Ohio sites; an additional ca. 75 have been found elsewhere in the eastern United States. The procedures to be developed would benefit multiple curation institutions over this broad region. (3) The procedures to be used hold the possibility of clarifying and/or revealing Hopewellian art works, and augmenting the current corpus of art work significantly. Unlike some other kinds of Hopewellian art that are partial, often broken ceremonially, the copper items to be studied are typically whole with minor breaks, potentially affording much cultural information. (4) Documentation and preservation of the corpus is imperative, given both the possibilities of repatriation and the need to inform Native Americans of the nature of curated archaeological collections, under NAGPRA legislation (Davis and Steponaitis 1996). The methods to be developed will extend documentation opportunities considerably beyond those offered by simple color photography.

Project Budget

1. Salaries. No salary will be charged by the PI.(Steps 1-7)	
2. Contracts:	
* Battelle Columbus Laboratories. NIR and MIR infrared digital photographs and contrast-stretch photographic enhancements of 200 item-sides, by E. Kopala and E. Preston (Step 2). 200 item-sides x.4 hrs/item-side x $137.50/hr =	$11,000.
* Archaeological Services Consultants. (a) Color digital photographs of 200 item-sides, by A. Lydecker (Step 2). 200 item-sides x .2 hrs/item-side x $38/hr. =	$ 1,520.
(b) 10 methods of enhancement of each of the 200 color and IR bands, by A. Lydecker (Step 2). 200 item-sides x 1.20 hrs/side x $38/hr =	$ 9,120.
(c) Insurance on ASC digital camera and computer system for 5 days at the Ohio Historical Center	$ 74.
* Gregory Bearman, Ph.D., Jet Propulsion Laboratory. Hyperspectral imaging and image enhancement of 27 item-sides (Step 2). 27 item-sides x ca. 1.5 hrs/item-side x $75/hr =	$ 3,000.
* Jeffery Colwell, Ph.D. Examination and assessment of corrosion products and other minerals for 200 item-sides (Steps 3,4,6,7). 200 item-sides x .5 hrs/item-side x $25/hr =	$ 2,500.
* Douglas Pride, Assoc. Prof., and Steven Hoffman, Ph.D. Examination and assessment of the mineralogy of inorganic surface materials for 200 item-sides (Steps 3,4,6,7) x .5 hrs/side x $20/hr =	$ 2,000.
* DeeAnne Wymer, Prof., & Virginia Wimberley, Asst. Prof. Examination &assessment of organic surface materials for 94 item-sides (Steps 3,4,6,7). 100 item-sides x 1 hr/side x $23.75/hr =	$ 2,375.
* OSU Department of Geological Sciences, SEM and electron microprobe analyses (Step s 3,6). Costs will be underwritten by the PI or a small grant from Arizona State University.	$ 0.
3. Other: (a) Canon color copy prints of each photographic enhancement. 200 item-sides x an average of 4 prints/side x $1.50/print = $1200. (b) Film & processing to record surface materials. Costs will be partially underwritten by the PI or a small grant from Arizona State University	$ 157.
4. Total direct costs:	$31,746.
5. Indirect costs (26%)	$ 8,254.
6. **TOTAL:**	**$40,000.**

APPENDIX 1.
MATERIALS OBSERVATIONS SUPPORTING THE HYPOTHESIS THAT PAINTS AND OTHER MATERIALS WERE APPLIED TO OHIO HOPEWELL COPPER ARTIFACTS

Observations at 5 - 31X, beyond those reported in the text of the proposal, support the interpretation that paints and other materials were applied to copper objects to produce images. (1) Several cases were found where the yellow, noncopper possible pigment and the malachite (green) possible pigment were clearly placed down as layers and subsequently delaminated partially, in a way that in situ corrosion does not develop or alter. (2) Locations occur where the yellow and brown apparent pigments have a network of cracks similar to drying cracks. The organic apparent binder or adhesive has a similar network of cracks. (3) Instances have been found where suspected images seemingly cut out of fabric and applied, and sometimes apparently painted, clearly have edges where thread ends align with each other to form a straight or regularly curving edge. Significantly, some regular lines of apparent cutting cross both warp and weft elements, in a way unlike the natural untangling or decomposition of a fabric. These possibly cut edges remain to be verified by SEM observation and comparative experimental fiber processing. (4) The hypothesized fabric cut-out images on the copper artifacts seem to have analogs in unattached fabric remnants that have consistent shapes and painted patterns (raptor, bear, and duck?), according to observations made by the PI, Woodland art expert D. Penney, and textile analyst V. Wimberley (see also Song 1991). Painting of repeated patterns with green (malachite? chrysocolla?) copper corrosion pigments on Ohio Hopewell fabric remnants has tentatively been identified by the PI, Penney, and Wimberley. Analogous painting on artifacts of other media, including the copper items addressed here, is possible in this light.

APPENDIX 2.
SPECIFICATIONS OF THE CAMERA AND COMPUTER SYSTEMS TO BE USED IN THIS PROJECT

Color Digital Camera System (at Archaeological Services Consultants Group, Inc.)

Digital Camera System, by Leaf Lumina

3 CCDs, 12 bit RGB color
3380 x 2253 maximum image size
62 mm and 28 mm Nikon lenses
2 Smith-Victor 500 W lamps

CPU

TCR Systems PC
Asus Computer P/I-P55TP4N motherboard with an Intel 133 mhz Pentium processor
32 MR RAM
2.1 GB hard drive
Diamond Multimedia Stealth 64 Video VRAM graphics accelerator card
Soundblaster 16 bit audio card
Adaptec AHA 2940 SCSI interface card
Hewlett Packard HP Surestore 4020i CD writer, 2x write, 4x read
1.44 MB 3.5" floppy disk drive
Colorado T1000 tape backup drive
Supraexpress 288 28.8 v. 34 internal fax/modem
Panasonic Panasynch/Pro C-2192P 21" super VGA monitor
Microsoft Mouse
Fujitsu keyboard

Printers

Sinko CHC-S446i dye sublimation color printer -- 300 dpi maximum resolution
Lexmark Optra R+laser printer -- 1200 dpi maximum resolution

Software

Microsoft Windows 95
Adobe Photoshop v. 3.01
Lumina Easyscan v. 1.1
Macromedia Freehand v. 5.0

The resolution of this system is state of the art, currently. Also, the system was custom-deisgned in both its software and hardware to efficiently and effectively document archaeological specimens. The system is owned and made available for this project by Archaeological Services Consultants Group, Inc., Columbus, OH.

Infrared Camera System (at Battelle Columbus Laboratories)

Battelle has used four state-of-the-art imaging sensors to view selected Ohio Hopewell copper artifacts in preliminary studies. These sensors included: (1) an ultra-violet camera, (2) a near-infrared camera, (3) mid-infrared camera, and (4) a far-infrared (thermal) camera.

The ultra-violet camera consists of a Cohu 4810 series solid-state CCD camera coupled to a Nikkor 105mm f4.5 UV lens. The camera has a 2/3-inch format frame transfer charge coupled (CCD) with an active imaging area measuring 8.8mm (horizontal) x 6.6mm (vertical). The active imaging area is an array of 754 horizontal by 488 vertical picture elements. This results in a field-of-view of 84 mrad (horizontal) by 63 mrad (vertical) and, at a viewing distance of 28 inches, a spatial resolution of 0.1 lmm (horizontal) by 0.26 (vertical). A special quartz faceplate installed over the CCD, coupled with a UV filter and special UV "black" lighting, results in an imaged wavelength region of 360-380 nm. The video output from the camera, in RS170 format, is directly inputted into the PC frame grabber.

The second, near-infrared camera also consisted of a Cohu 4810 series camera. A Nikkor 105mm *f*4.5 IR lens is used with this camera, and when coupled with a spectral filter, results in an imaged bandwidth of 700-1000 nm. Diffuse quartz-halogen lighting operated at 3000^0K provid specimen illumination. The field-of-view and resolution for the mid infrared camera was the same as for the ultra-violet camera.

The third, mid-infrared camera consists of a Hamamatsu C1000-03 infrared TV camera coupled to a Nikon 24mm *f*1.4 IR lens. The camera uses a special infrared vidicon that is responsive to energy out to 1800 nm. With an active imaging area of 12.7mm (horizontal) x 9.5mm (vertical), the camera has a field-of-view of 529 mrad (horizontal) by 398 mrad (vertical). At a specimen viewing distance of 28 inches, this camera has a spatial resolution 0.54mm (horizontal) by 0.63mm (vertical). Spectral filters used with this camera result in a wavelength sensing region of 1000 to 1800 nm.

The fourth, far-infrared camera consists of a Mikron Model TH1101 Thermal Imager. The Mikron TH1101 thermal imaging system is a high precision infrared thermal imaging system that optically scans IR energies emitted naturally from the surface of an object in the horizontal and vertical directions. This imager displays the measured temperature distributions as color or black and white images, stored either digitally in real time, or to a video output for analog recording. The system consists of lenses, filters, mirrors, the detector unit, and a control unit. The 8-bit signal output can be an analog temperature signal, an RGB analog video signal, an NTSC color output, a monochromatic video signal, or a GP-IB interface to a personal computer. It has a focal range of 20 cm to infinity. The optical zoom has a range of up to 5 times in steps of 0.1. The detectors require an LN_2 dewar (77° K), and the array has a horizontal resolution of 344 by a 260 line vertical resolution. The imager is sensitive to thermal radiation within the 8000-14,000 nm wavelength band. Objects that are at thermal equilibrium (e.g., laboratory setting) display contrast patterns that are indicative of emissivity or surface roughness changes. The thermal resolution of the Mikron THI 101 used was 0.025°C.

Only the near infrared and mid infrared camera systems will be employed in the proposed research. These, alone, provided imaging advantages when examining the copper items (see text).

All video signals from the four imaging sensors are processed with a 266 MHz Pentium II PC equipped with a Meteor Frame Grabber board. The Meteor Frame Grabber board, manufactured by Matrox Incorporated, is used to convert the analog video signal (camera output) to a digital image. This frame grabber "digitizes" the input imagery from the various sensors at a resolution of 640 x 480 pixels.

The Matrox Meteor board key features include: (1) Captures NTSC/PAL/SECAM, RS-170/CCIR and standard RGB; (2) single slot PCI frame grabber; (3) real-time transfer to system or display RAM; (4) multiple video inputs (up to 4 channels); (5) high-quality video scaling unit; (6) live video-in-a-window; (7) stable synchronization; (8) support for Windows NT, Windows 95, and DOS4GW 32-bit DOS extender.

The Matrox Meteor is a high-quality color and monochrome PCI frame grabber that provides real-time image transfer to host, video-in-a-window, and support for the Matrox Imaging Library (MIL) and Matrox Inspector interactive imaging software. The use of this board and its associated image processing software allow users to develop powerful, yet cost-effective host-based machine vision, image analysis and medical imaging systems. The Matrox Meteor transfers image data in real-time to the CPU RAM for processing or the display buffer for real-time display. The Meteor is capable of up to 45 MB/sec transfers.

Other features of this frame grabber board include: (1) the incoming video stream can be tuned through software adjustable brightness, contrast, hue, and saturation; (2) excellent synchronization even when grabbing from still video cameras and VCRs in playback and pause modes; (3) high-quality live video-in-a-window display that can be scaled down to any size and positioned anywhere on the screen; and (4) the Digital Video to PCI Interface unit, which supports various data transfer formats (8-bit mono, 15-bit and 24-bit RGB).

Software used in support of the frame-grabbing board included two packages developed by Matrox, Incorporated: Inspector and the Matrox Imaging Library (MIL).

Matrox Inspector is a Windows-based software that offers interactive access to an extensive set of imaging operations. Features of this software package include: (1) complete set of imaging functions; (2) easy-to-use interactive work environment; (3) interfaces to standard and non-standard cameras; (4) loading and saving in many file formats (5) display of color and monochrome images; (6) scaling, zooming, panning and scrolling; (7) selection arid processing of non-rectangular regions of interest; (8) returning of results with sub-pixel accuracy; (9) image annotation; (10) automation of routines with powerful scripting; and (11)"Collection" for visually tracking and managing images.

MIL is a high-level 'C' library with commands for image processing, pattern matching, blob analysis, gauging/measurement and OCR, as well as image acquisition, transfer, and display. MIL has been designed to fully exploit the power of Intel MMX™ technology. The MIL software allows more flexibility for image processing/analysis than does the Inspector software.

Color and Infrared Hyperspectral Imaging System (at the Jet Propulsion Laboratory)

There are several imaging instruments at the Jet Propulsion Laboratory that are suitable for the hyperspectral imaging and other aspects of this project. The Liquid Crystal Spectroscopy Laboratory has electro-optical tunable filters that cover 0.4-1.1micron, with bandwidths from 5-20 nm. In addition, there are 3 cooled 16 bit digital cameras as well as video 8 bit cameras.

The liquid crystal tunable filters have a clear aperture of 18 mm and can be used with any imaging optics. We currently have 105 mm, 135 mm, and 200 mm Nikon lenses that can provide image sizes from about one square inch to several feet. The filters are tuned electronically and are controlled through the serial port on a PC. One filter covers the 0.4 - 0.72 micron range and another spans 0.65 - 1.1 micron, providing spectral overlap.

The major workhorse cameras are cooled 16 bit CCDs designed originally for astronomy, so they have very low, dark current. Manufactured by Spectrasource Instruments, two cameras have 1024 x 1024 detectors, while a third is 1536 x 1180. All three cameras provide spatial resolution much better than video devices. For these cameras, the frame rate is relatively slow, mostly slowed by the 16 bit digitization.

Besides these visible and NIR cameras, there is also a 256 x 256 InSb camera that covers the 3 - 5 micron region.

The laboratory also has a full complement of calibration equipment, standard lamps, color targets, wavelength sources, and monochromators.

APPENDIX 3: FIGURES

*(Reviewers are invited to examine the images on screen at **WWW.public.asu.edu/~ccarr.** Image quality will depend on the resolution and color-balance of the CRT used.)*

Figure 1. A copper plaque, Ohio Historical Center, catalog no. 957/-, Carr no. B031, Side 1. (A) A high-resolution, color digital photograph of the plaque without enhancement. (B) Imagery is enhanced using a contrast-stretch histogram modification operating on the red, green, and blue bands together. (C) One layer of graphic information, separated out by a computerized line drawing, from other layers of information in the image. The plaque is known to have been painted with at least yellow and white noncopper pigments, based on chemical and visual tests described in the text. The plaque is one of two from the Great Multiple Burial in Seip Mound 1, which both have similar painted designs on one side and similar dyed fabric designs on the other side. The composition is most easily understood as the upper half of a human face analogous to that of a bone carving shown in Figure 2. The face is defined by a semicircular arc that is wide at the sides and narrows toward the top. The arc is comprised of a yellow pigment that is rich in calcium and phosphorus and may be bone, with some admixture of ground limestone, dolomite, shell, and/or pearl. The paint has drying cracks like those that form in drying mud. The material is a distinct layer, separate from the substrate, and delaminated in places, unlike corrosion. The eyes of the face are represented by the two holes in the plaque. Within the face are white curvilinear markings that possibly represent face painting, tatooing, or scarification, similar to the decorated stone head from the Edwin Harness mound (Greber 1983:33). The top of the markings contains a motif that mimics the shape of the deer antlers shown in the engraving in Figure 2. The white pigment has the composition (silicon, magnesium) and refractive index of serpentine. Above the hairline are possible new-growth deer antlers, similar to the copper effigy new-growth deer antlers on a copper headplate from Mound 25 of the Hopewell site, as well as those pictured in the engraving in Figure 2.

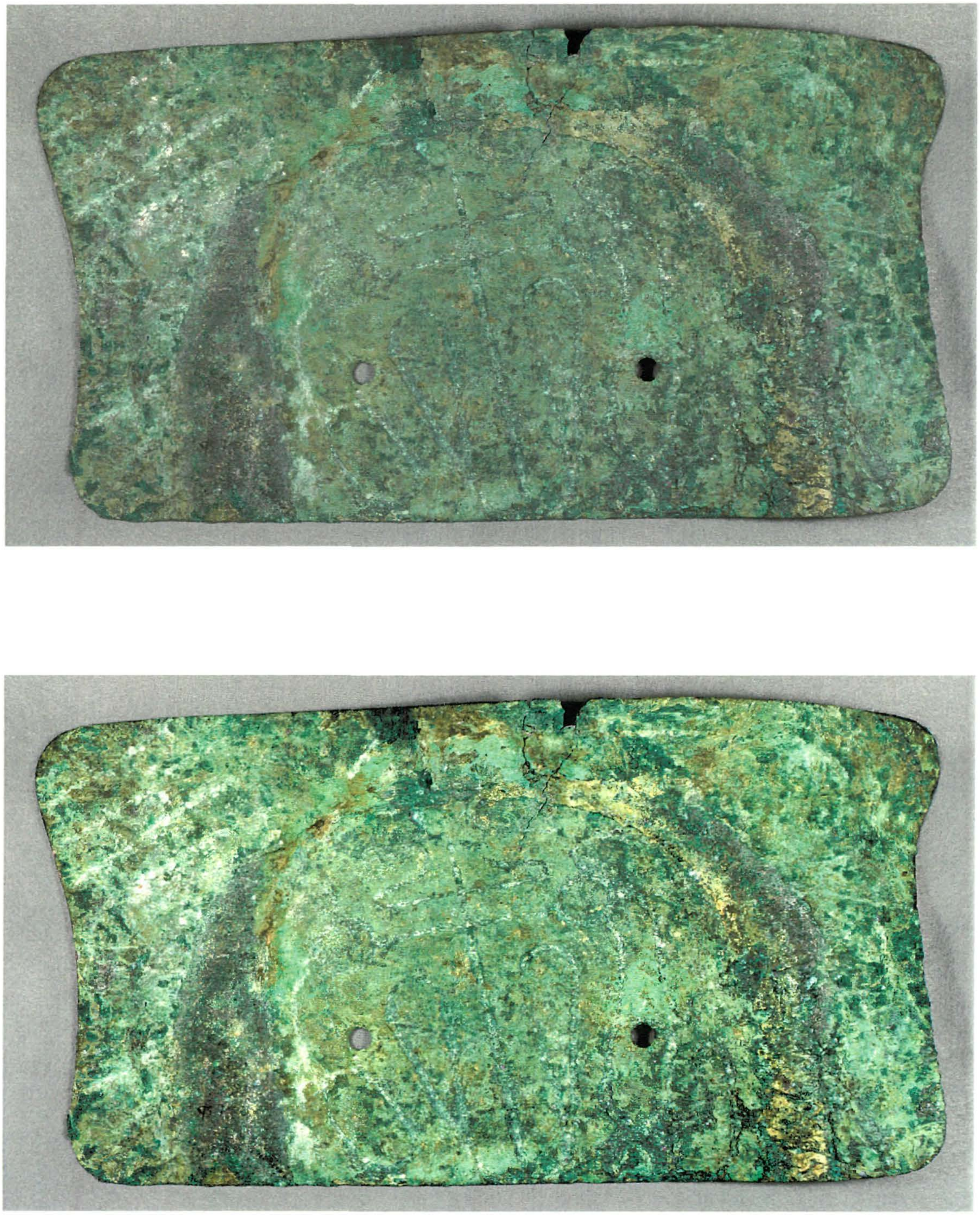
Figure 2. Engraving of a deer-rabbit or deer-snake impersonator on a human femur from Mound 25 of the Hopewell site (Moorehead 1922:128). (A) The total face. (B) A part of the face, analogous to the partial face on the copper plaque shown in Figure 1.

Figure 3. Photographs of the same copper plaque shown in Figure 1 using cameras with different frequency responses. (A) A color digital photograph without enhancement, as in Figure 1A. (B) An enhancement of the image in 3A using a contrast-stretch histogram modification operating on the red, green, and blue bands together, as in Figure 1B. (C) A near-infrared image of a portion of the plaque, shown at the same scale as 3A and 3B. (D) A midrange infrared image. (E) A thermal infrared image. All images were made with incandescent lighting. The midrange infrared image reveals the arc-like distribution of the yellow pigment beyond that visible in the color photographs using visible light, or easily visible with the naked eye. The near-infrared image clarifies the distribution of the white pigment in the upper left by revealing some locations beyond those visible in the color photographs or easily visible by eye, and by minimizing variation in the green malachite background corrosion.

Figure 4. A copper plaque, Ohio Historical Center, catalog no. 957/-, Carr no. B080, Side 1. (A) Color digital photograph without enhancement. (B) Color digital image enhancement using a contrast-stretch histogram modification operating on the red, green, and blue bands together, as in Figure 1B. (C) One layer of graphic information, separated out by a computerized line drawing. The plaque is the complement to the one shown in Figure 1. Both come from the Great Multiple Burial in Seip Mound 1. The plaque in Figure 1 was found with the southern-most of four, aligned, adult skeletons (Burial 5), while the plaque in Figure 2 was found in with the northern-most of the four skeletons (Burial 2). Both have fabric on the sides opposite shown here, with dyed maroon and tan curvilinear designs outlined in black. Both also share a similar kind of painted design on the sides shown here and in Figure 1. Like the plaque in Figure 1, this one bears a face defined by a semiciruclar arc that is wide at the sides and narrows toward the top. Eyes are again represented by the two holes in the plaque. Coloration is the complement of the plaque shown in Figure 1. A yellow pigment colors all but the semicircular arc on this plaque, where as it is restricted to the semicircular arc on the plaque in Figure 1. Dualistic contrast, and complementary renderings of figure and ground, are common stylistic features of Ohio Hopewellian art. The face shown here also contrasts with the one shown in Figure 1 in not having any clear face painting, tatooing, or scarification.

Figure 5. A partial copper plaque, Ohio Historical Center, catalog no. 957/26, Carr no. B044, Side 1, from Seip earthworks. (A) Color digital photograph without enhancement. (B) Color digital image enhancement using a contrast-stretch histogram modification operating on the red, green, and blue bands together. (C) One layer of graphic information, separated out by a computerized line drawing. Patterning on the plaque derives from the contrast between broad areas of yellow-brown and areas of brown-black. Chemical analyses of these surface materials have not been made. The design is bilaterally symmetrical. At the center of the plate, below the two perforations in it, is a large circular area of yellow brown. Surrounding this is a brown-black "annulus" that is wider at the bottom and narrower at the sides and top, with two protrusions at the top. Beyond the "annulus" is a background field of yellow-brown. At least three other copper plaques, from the same site or nearby ones, have similar design layouts (OHC no. 957/-, Carr no. B079, Side 1, from Seip; OHC no. 283/-, Carr no. B020, Side 2, from Hopewell; OHC no. 7/-, Carr no. B055, Side 1, from Edwin Harness).

A



B

Figure 1.

C

Figure 1., continued.

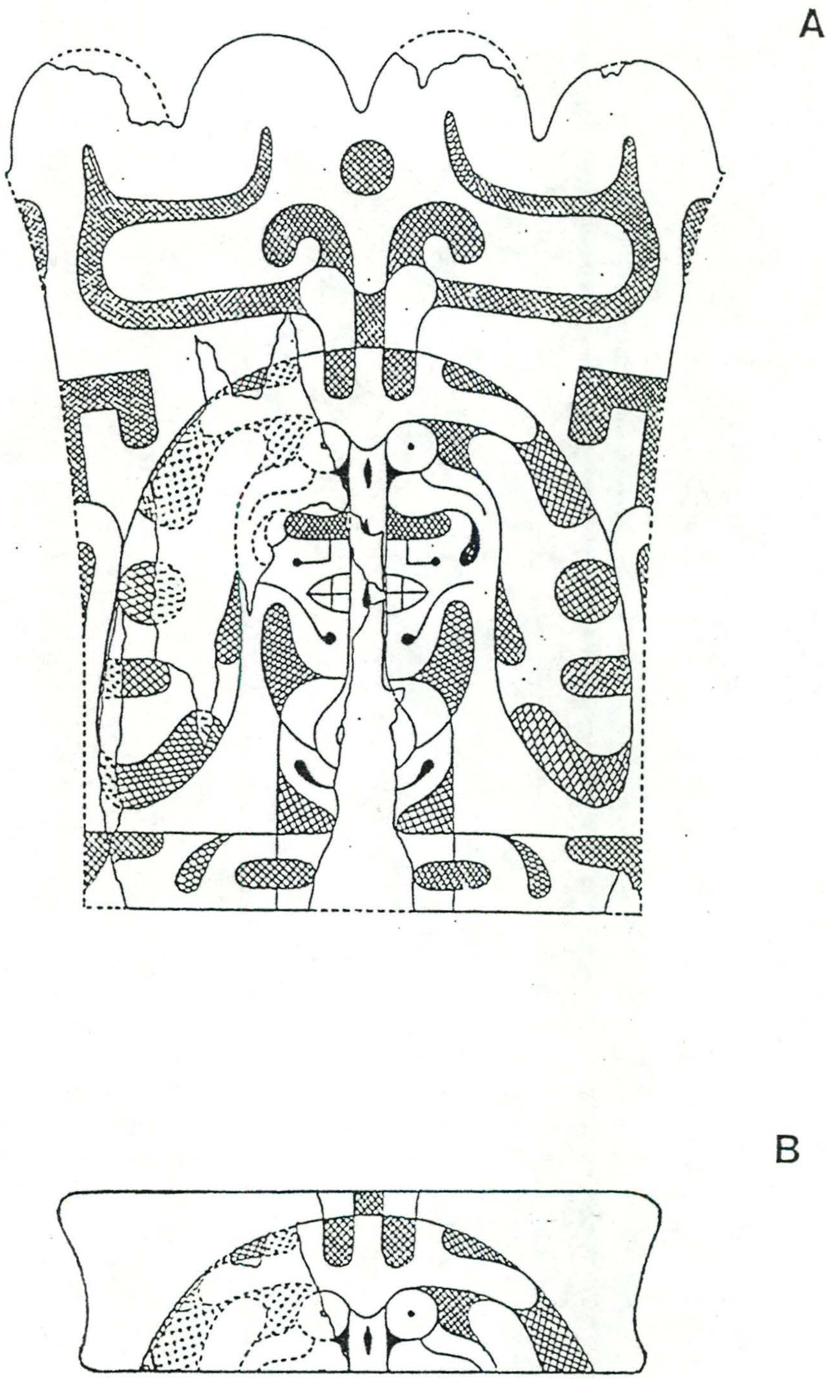
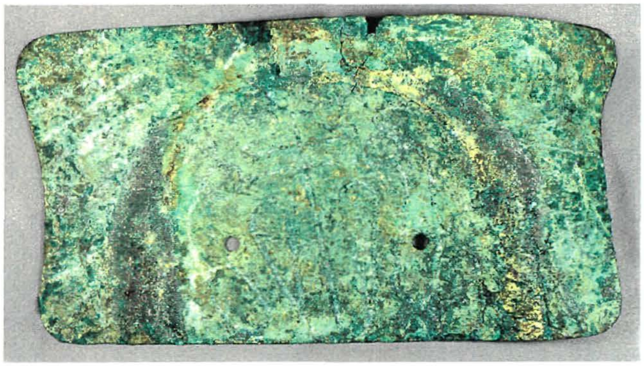


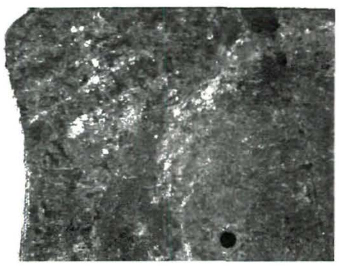
Figure 2.

RGB
without
contrast
enhancement



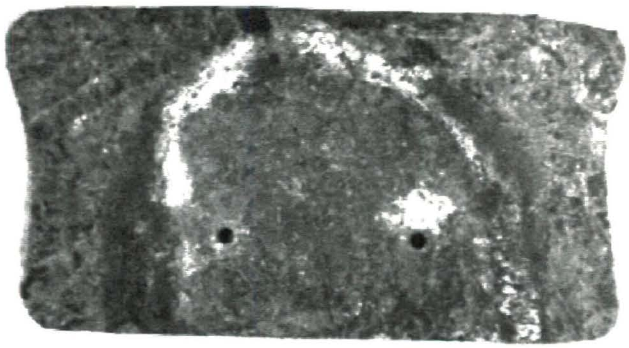
RGB
with contrast
enhancement

C



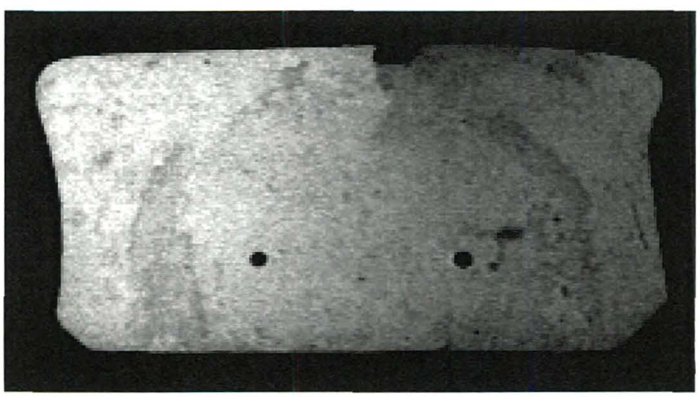
NIR

D



MIR

E



TIR

Figure 3.

A

B

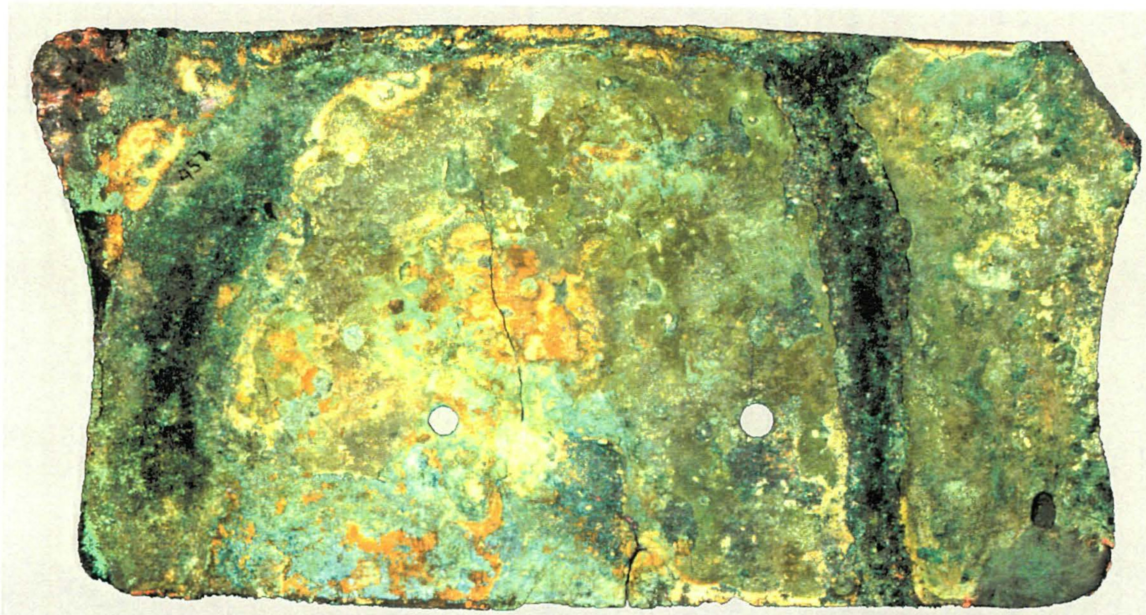


Figure 4.

C

Figure 4., continued.

A

B

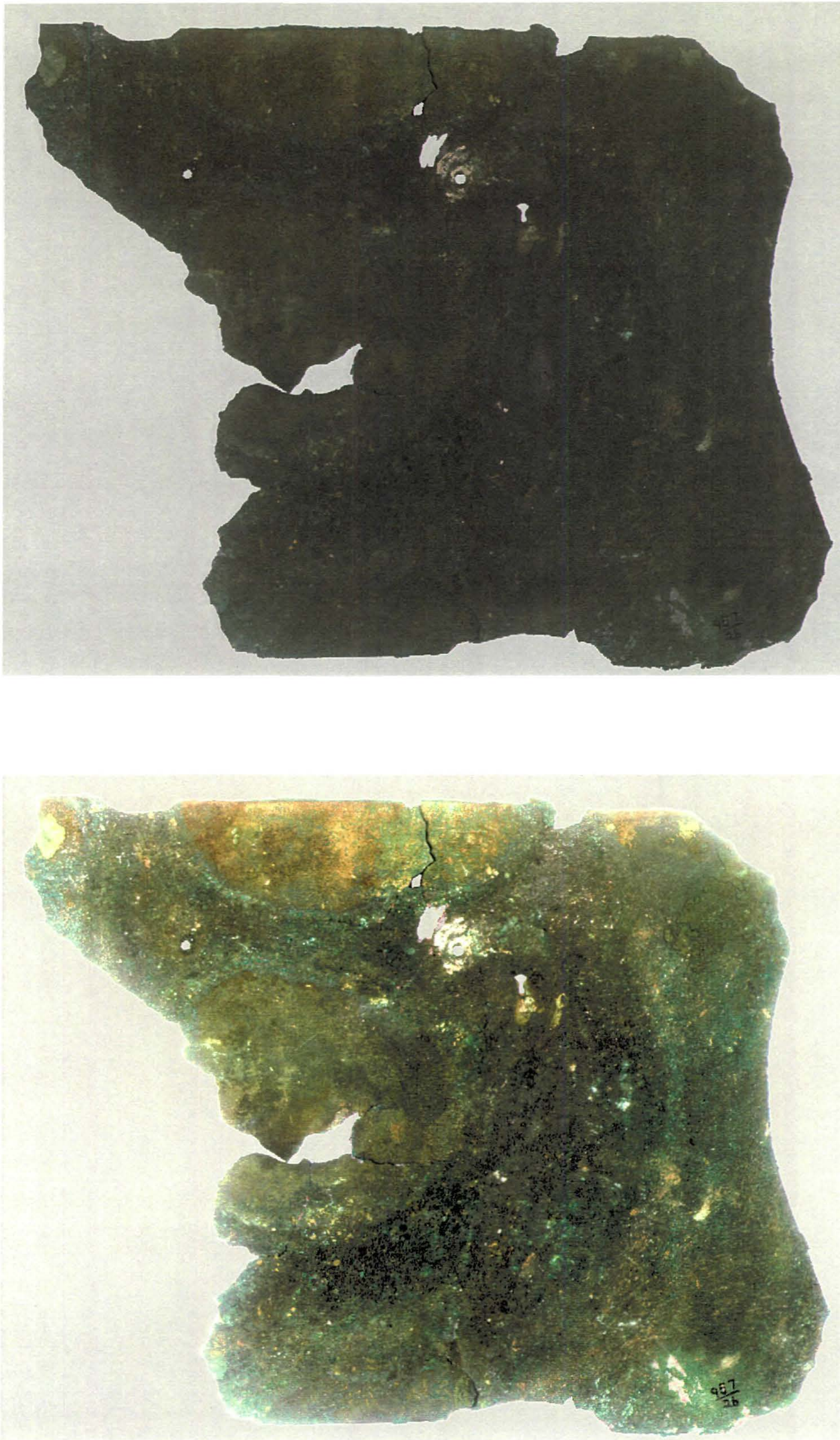


Figure 5.

C

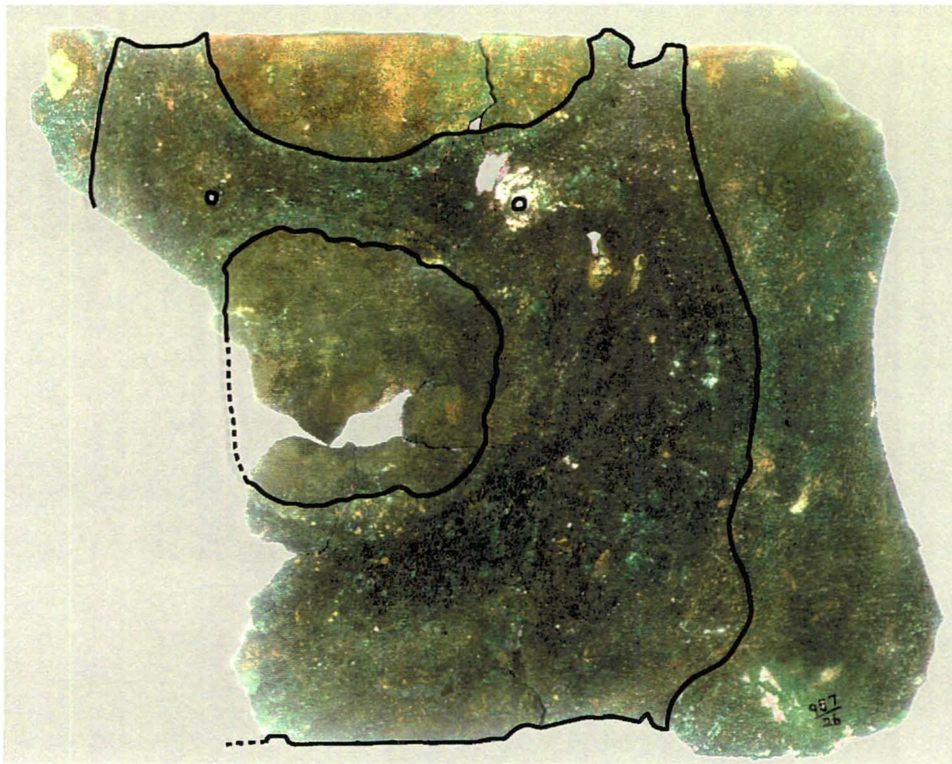


Figure 5., continued.

APPENDIX 4.
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APPENDIX 5.
LETTER OF PERMISSION AND
VITAE OF THE PRINCIPAL INVESTIGATOR AND PROJECT TEAM

Ohio Historical Center

1982 Velma Avenue
Columbus, Ohio 43211-2497
614/297-2300
Fax: 297-2411

OHIO
HISTORICAL
SOCIETY
SINCE 1885

December 4, 1998

Dr. Mark Gilberg
Research Coordinator
National Center for Preservation Technology and Training
NSU Box 5682
Natchitoches, LA 71497

Dear Dr. Gilberg:

I am writing with regard to the proposal, "Development of High-Resolution Digital, Color, and Infrared Photographic Methods for Preserving Imagery on Hopewellian Copper Artifacts", submitted by Dr. Christopher Carr, Department of Anthropology, Arizona State University.

Dr. Carr has permission to undertake the research described in this proposal utilizing the Ohio Historical Society's collections of prehistoric Hopewell culture copper artifacts, in accordance with the Society's Guidelines for Researchers.

If I can be of any further assistance in this matter, please do not hesitate to contact me directly.

Sincerely,

Martha Potter Otto

Martha Potter Otto
Curator of Archaeology

614/297-2641
e-mail: motto@ohiohistory.org

CURRICULUM VITAE: CHRISTOPHER CARR

ADDRESS:	Arizona State University Department of Anthropology Box 85287 Tempe, AZ 85287-2402	**TELEPHONE:**	Work: 602-965-6213 Fax: 602-965-7671 Home: 602-967-5936
		SOCIAL SECURITY:	342-40-2933

CURRENT AND PREVIOUS POSITIONS:

1995-	Professor, Arizona State University
1988-1995	Associate Professor (tenured), Arizona State University
1985-1988	Assistant Professor, Arizona State University
1985	Associate Professor (tenured), University of Arkansas-Fayetteville
1983-1985	Director, Institute for Quantitative Archaeology, University of Arkansas-Fayetteville
1979-1985	Assistant Professor, University of Arkansas--Fayetteville

EDUCATIONAL HISTORY:

1976-1979	University of Michigan, Ann Arbor, Michigan	Ph.D. Anthropology
1974-1976	University of Michigan, Ann Arbor, Michigan	M.A. Anthropology
1970-1974	University of Illinois at Chicago Circle	B.A. Anthropology

RESEARCH AREAS:

Archaeology; development of theory and methods; quantitative analysis; stylistic,technological, and physico-chemical compositional analyses of ceramics,textiles, copper artifacts; iconography, symbolism, and world view; mortuary practices; prehistory of the Eastern U.S.

BOOKS PUBLISHED OR IN PROGRESS (*Peer-reviewed):

*1982 *Soil Resistivity Surveying: Interpretation of Data from Earthen Archaeological Sites.* Center for American Archaeology, Evanston, IL. 678 pp. (on digital mathematical filtering procedures, and soil chemistry and physics)

*1989 *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory*, 2nd edition, edited by C. Carr. Waveland Press, Prospect Heights, IL. 648 pp. (1st edition 1985)

*1995 *Style, Society, and Person*, edited by C. Carr and J. Neitzel. Plenum, NY. 471 pp.

n.d. *Hopewell Society, Ritual, and Religion: Evidence and Inference,* edited by C. Carr and D. Troy Case. In progress, 15 chapters.

SOME ARTICLES AND CHAPTERS IN BOOKS, PUBLISHED OR IN PRESS (*Peer-reviewed):

Total: 3 books, 40 articles or chapters, authored or coauthored, published or in press. 2,084 pp.

*1987 Dissecting Intrasite Artifact Palimpsests Using Fourier Methods. In *Method and Theory for Activity Area Research,* ed. by S. Kent, pp 236-291. Columbia University Press, NY

*1990 Advances in Ceramic X-Radiography and Analysis: Laboratory Methods. *Journal of Archaeological Science* 17(1):35-66.

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*1995 (1st au. with J.C. Komorowski). Identifying the Mineralogy of Rock Temper in Ceramics with X-Radiography. *American Antiquity* 60(4):723-749.

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