The Macrotube: An Inexpensive Device to Improve Photodocumentation of Surfaces

L. BRAD SHOTWELL, JOSHUA FREEDLAND, AND DAVID A. WAUGH

When used with a low-cost digital camera that has "super macro" capability, the macrotube can rapidly and consistently collect high-quality, uniformly lit field images of small-scale features.

Introduction

The conservation of a historic facade often begins with accurate documentation of initial surface conditions followed by selection and monitoring of an appropriate cleaning program. Since significant features are often visible only on a microscale, adequate surface characterization often requires microscopic examination.

Throughout the years, various techniques have been used to document surface conditions of dimension stone, masonry, and concrete, etching on glass, and results of trial cleaning of building surfaces. For example, the authors have examined molds of eroded stone surfaces made before and after the evaluation of various surface-cleaning methods. Casts that were subsequently prepared were examined and photodocumented in the laboratory.[1] This procedure yielded excellent 3D representations of facade surfaces that could be examined at very high magnifications. However, this procedure was judged to be impractical, particularly on projects where multiple cleaning techniques were being evaluated. Similarly, reflectance transformation imaging (RTI) has been applied in the field to document prehistoric rock art.[2] While the reported results are striking, the equipment needed for this method will not fit into the conservator's tool bag. It was determined that improvement of photodocumentation, including development of a method to rapidly collect stereo images, was the more practical approach.

Fig. 1. A simple and effective field microscope. All images courtesy of the authors.

Fig. 2. The same microscope with a digital camera attached.

Stereo Images

By taking a photograph, moving the camera just a small distance, and taking a second photograph of virtually the same area, it is possible to obtain pairs of stereo images. In certain cases, the effect provided by surface shadows in the stereophotography has also been found to be useful in the microscopic assessment of surface relief using a single image. If the spacing or relative alignment between stereo images is held constant, it is possible to quantify variations in surface relief and obtain documentation comparable to that available in a cast of the surface.

Current Building-Facade Documentation Methods

A hand lens or a field microscope is a useful tool that can detect significant surface detail when used by an experienced investigator. When advantageous natural lighting is available on the surface of interest, significant textural features can be documented when a camera is attached to the field microscope. Experience has shown that im-

Fig. 3. The vertical surface of weathered dimensional limestone. The photograph was taken with the field microscope and camera shown in Figure 2, using natural, low-angle lighting. The width of the field of view is 3/16 inch.

portant textural features are easiest to assess when the surface is illuminated with a low-angle unidirectional light. This type of light casts shadows on surface irregularities, providing the observer with the needed depth cues to interpret the photograph in only two dimensions. Variations in natural lighting make collection of consistent images difficult at best — a significant problem when consistency of lighting is essential to obtaining comparable photographs that may be taken days, months, or even years apart.

A simple and practical field microscope is pictured in Figure 1. The clear base allows for natural lighting and keeps the microscope a consistent distance from the surface of interest. When a field microscope is fitted with a camera (Fig. 2) and natural lighting is advantageous, good photodocumentation of surface features is possible (Fig. 3). Digital field microscopes that are tethered to a laptop computer are also available. A camera fitted with a macro lens and held at a proper distance from the surface of interest also has the capability to capture images that can document the efficacy of a cleaning procedure, provided it can be held steady and the surface is adequately lit. But without the positive contact between the camera and the surface and sufficient consistent lighting, using a camera alone to collect images is difficult at best.

Most field documentation techniques include various combinations of field microscopes and cameras. The equipment, once assembled, may be expensive and has often proven to be cumbersome and fragile, especially considering less-than-ideal field conditions. Further, the techniques are often time consuming and not conducive to taking the comparable before-and-after photographs of specific locations necessary to document changes, such as during trial evaluations of different facade-cleaning methods. The results of these photodocumentation procedures often yield mixed and uneven results.

The inconsistent results are due primarily to variations in lighting, changes or lack of control in magnification, inadequate camera support, and limitations in the skill of the photographer. The authors have also attempted to modify a field microscope to provide consistent low-angle lighting (Fig. 4). The simple addition of a light shroud and an LED flashlight provided consistent lighting and fixed magnification. This system makes it possible to collect pairs of stereo images of a feature of interest. To do this, the first picture is taken, and the microscope is then moved several millimeters across the surface to where a second image is taken. The resulting two photos represent a pair of stereo images. Unfortunately, this system cannot yield repeatable results.

To alleviate these difficulties, the macrotube has been developed (Figs. 5 and 6). Specifically, the device described here solves these issues by integrating the lighting and camera support in a portable, simple, and cost-effective unit capable of generating both high-quality and repeatable images. It allows the user to take full advantage of the capability of the low-cost digital cameras currently available, and the device can be constructed using commonly available components. In addition to solving the issues of camera support and lighting, the macrotube is capable of taking consistent pairs of stereo images. Since pairs of stereo images can be reproduced and transmitted electronically, they may actually provide a method to document surface relief that is as useful and more practical than preparation of a 3D casting of the surface of interest.

Rationale for Design of the Macrotube

In addition to difficulties obtaining consistent lighting and magnification, the authors felt that field microscopes did not provide documentation of a sufficiently large portion of the surface of interest. In other words, getting "too close" to a subject can reduce the usefulness of an image to the conservator. Modern digital cameras have macro capabilities and sufficient memory to save large-format image files and can resolve surface features that are approximately 1/2 millimeter in size. This capability makes it possible to record images at a level of detail that can be used to characterize many surface conditions, and in particular changes that occur during the trial cleaning of surfaces. At the same time, the 3-centimeter field of view typically obtained using a digital camera set in macro mode can provide the added context often lost using a field microscope that offers higher magnification but restricts the field of view. But without a camera support and consistent lighting, the full capabilities of the digital camera cannot be realized under typical field conditions. The physical contact between the field microscope and the surface of interest eliminates focusing difficulties, reduces camera shake, and makes it possible to maintain consistent magnifications. The authors realized that if these advantages of the field microscope could be adapted to a modern digital camera with "super macro" capability and the capacity to save 10-megapixel files, a viable and often superior imaging-capture setup could be constructed.

Fig. 4. The field microscope with a light-shroud base and low-angle lighting.

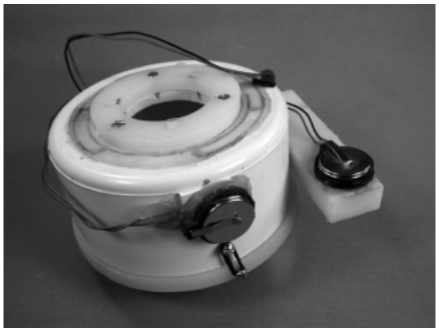


Fig. 5. An assembled macrotube. For more detail, see Figure 7 and Table 1.

Detailed Description of the Macrotube

The macrotube provides both repeatable and controllable light using internally housed light-emitting diodes (LEDs); at the same time it restricts entrance of stray ambient light. Its small size makes it easy to use in the field and, by design, supports the camera during use to prevent operator movement from blurring the images during exposure. The parts of the device are shown in Figure 7, and a description of the parts required and the general steps in construction are given in Table 1. The body of the macrotube is a standard, 4-inch PVC pipe cap that has been modified as described in Table 1. Six LEDs embedded in the top of the unit provide overhead illumination, and eight LEDs embedded in the light bar that provide low-angle lighting are wired in separate parallel electrical circuits so that they may be independently operated (Table 1). Once wired in parallel, the LEDs and lead wires are coated with hot-melt glue to fix them to the macrotube. The battery holders are fixed to the macrotube body and the light bar using hot-melt glue. Alternatively, the low-angle LEDs contained in the light bar could have been built into the side of the macrotube body; however, it was found that alignment of the LEDs in a straight line resulted in sharper shadows than when embedded in the curved inner surface of the macrotube body. Instructions for wiring LEDs are available online; it proved easiest to simply wire the LEDs in two separate parallel circuits using separate 6-volt battery packs. Since the microswitch used in the circuit is normally off, the batteries easily last long enough to conduct a typical field assignment.

Fig. 6. The macrotube with a digital camera attached.

The camera collar ring is made of 1/4-inch-thick high-density polyethylene (HDPE). This piece is the only part that is specific to the camera used with the macrotube. The inner diameter of the ring must match the outer diameter of the telescoping lens where it protrudes from the body of the camera. The surface-contact ring used to align the macrotube on the surface to be photographed is also made of the same HDPE stock. The light bar is made from 1/2-inch HDPE stock and contains eight 3-mm LEDs that operate from separate 6-volt battery packs. It provides low-angle lighting to the area of interest. The light bar is the most difficult piece of the macrotube to fabricate since it requires closely spaced holes that are the same diameter as the LEDs to be drilled into the HDPE. These holes serve as sockets for the LEDs. After these sockets are drilled, two smaller holes must be drilled into the back of the sockets to allow the LED leads to pass through the light bar. Set screws on the bottom of the body allow the macrotube to pivot left or right relative to the surface-contact ring. This movement makes it possible to collect "left and right" pairs of stereo images. By altering the height of the set screw "feet," the angle between stereo images can be altered. The optimal angle between pairs of stereo images is between 6 and 10 degrees.

When the surface to be photographed is illuminated with low-angle light, the pivot action of the device causes a change in shadow length between the

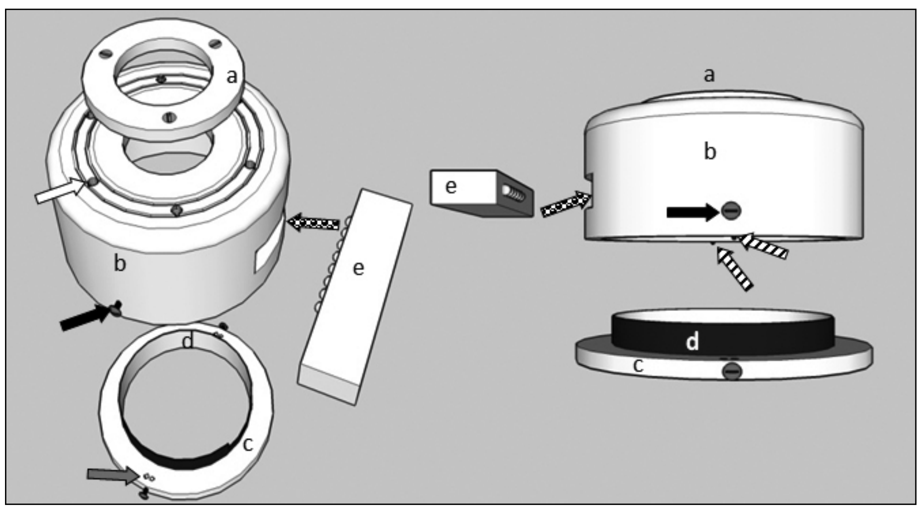
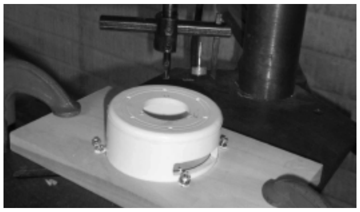
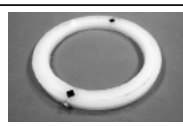
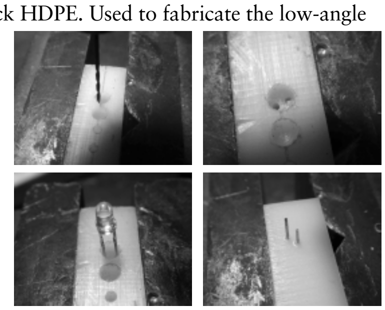
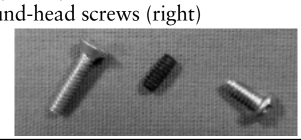
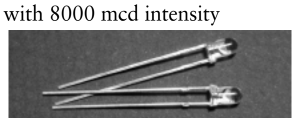
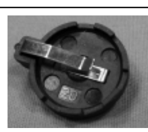
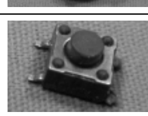


Fig. 7. The parts of the macrotube shown in exploded drawings. The camera collar ring (a) must have an inner diameter that matches the diameter of the camera lens when extended. The ring is attached to the macrotube body (b) with three flat-head screws. The white arrow marks one of six holes spaced 60 degrees apart that were drilled through the top of the macrotube; these holes serve as sockets for the overhead LEDs. The two circular grooves (one on either side of the LED sockets) are used to embed the wiring needed to power the LEDs. Once the LEDs are wired together, the wires are set into the grooves and fixed in place with hot-melt glue. The dotted arrow marks the rectangular hole cut into the side of the macrotube body (b) where the light bar (e) is inserted. The surface-contact ring (c) and light shroud (d) are attached to the macrotube body (b) with small rubber bands wrapped around the round-head screws , which are marked with black arrows. The striped arrows mark the location of set screws on the bottom of the macrotube body (b) that are used to pivot the body relative to the surface-contact ring. The pivot points on the surface-contact ring (c) are marked with a gray arrow and are shown in the enlarged view in Table 1. The light shroud (d) is made of black vinyl tape applied to stiff paper and affixed to the contact ring using double-sided tape. The light bar (e) contains eight 3 mm LEDs set in holes spaced 5 cm on center. The leads from the LEDs are run through holes drilled in the bottom of each LED socket and are shown in an expanded view in Table 1.

Table 1. Materials List for the Macrotube and Brief Instructions on Its Fabrication

Item and Use	Possible Source	Task
4-inch-inner-diameter PVC pipe cap with a wall thickness of $\frac{1}{4}$ inch. Serves as the macrotube body. 	Hardware store	Set the pipe cap in the wooden jig centered beneath the drill press. Cut a $1\frac{1}{2}$-inch-diameter hole in the top. Use the hole-cutting bit to cut two shallow grooves in the top of the pipe cap. The diameters should be $2\frac{5}{8}$ and $3\frac{1}{16}$ inch, at a depth of $\frac{2}{100}$ inch. Drill six $\frac{1}{8}$-inch-diameter holes spaced 60 degrees apart between the two shallow grooves. Drill two 0.089 inch holes with a #43 drill bit in the side of the macrotube body and $\frac{1}{2}$ inch from the open end. Drill two 0.089 inch holes in the bottom of the macrotube body. These holes must be located on the diameter of the pipe cap. Cut a rectangular hole in the side of the macrotube body a little less than $\frac{1}{2}$ inch wide and $1\frac{1}{2}$ inches long. The bottom side of this rectangular hole should be approximately $\frac{7}{16}$ inch from the open end of the macrotube body.
$\frac{1}{4}$-inch-thick HDPE. Used to fabricate the camera collar and surface-contact ring.  	Plastic-supply store	Cut the camera collar and surface-contact ring from the HDPE using a hole saw. The HDPE must be attached to the drill-press base with clamps. The camera collar has an outer diameter of $2\frac{7}{16}$ inches and an inner diameter of $1\frac{1}{2}$ inches, which accommodates the Olympus Stylus camera shown in Figure 5. This dimension is specific to the camera chosen to use with the macrotube. Space holes for attaching the camera collar to the macrotube body 120 degrees apart. Use two 4-40 flat-head screws to attach the collar to the macrotube body.
$\frac{1}{4}$-inch-thick HDPE. Used to fabricate the camera collar and surface-contact ring. 	Plastic-supply store	The surface-contact ring has an inner diameter of $3\frac{3}{16}$ inches and an outer diameter of $4\frac{1}{4}$ inches. Drill shallow "pivot holes" for the macrotube feet in the surface contact ring. Cut diamond-shaped holes into the surface-contact ring with an X-Acto blade to allow the macrotube body to slide relative to the ring if the user needs to eliminate "keystoning" distortion.
$\frac{1}{2}$-inch-thick HDPE. Used to fabricate the low-angle light bar. 	Plastic-supply store	Cut the HDPE so that the light bar measures $\frac{1}{2}$ inch by $\frac{7}{8}$ inch by $3\frac{1}{2}$ inches. Drill eight 4 mm-diameter holes spaced 5 mm on center in a line. These holes, which serve as sockets to hold the LEDs, must be 3 mm deep. Drill two 0.048-inch holes in the bottom of the sockets to allow the LED leads to pass through the light bar. Make the parallel circuit connections to the LEDs on the back of the light bar. Attach the battery holder to one end of the light bar, and wire it to the tact switch and LEDs. Two CR2016 batteries that supply 6 volts to the circuit are used to power the LEDs.
Opaque white paper, black plastic tape, and double-sided tape. Used to fabricate the light shroud. 	Office-supply store	On bright days the light shroud can be used to block ambient light from the surface of interest. Ambient light can reduce the ability of the light bar to provide uniform low-angle lighting.
Three 4-40 flat-head screws (left) Two 4-40 set screws (center) Four 4-40 slotted round-head screws (right) 	Hardware store	Use to attach the camera collar to the macrotube body. Use to provide pivot action for the macrotube relative to the surface-contact ring. Use to attach the surface-contact ring to the macrotube body.
Fourteen 3 mm LEDs with 8000 mcd intensity 	Electronics store	Insert six of the LEDs into the top of the macrotube body to allow overhead illumination of the surface of interest. These LEDs are powered by a separate 6-volt circuit using two CR2016 batteries that are held by a CR2032 battery holder attached to the camera body. Use additional LEDs for low-angle lighting.
0.005-inch-diameter copper wire	Electronics store	Use to connect the LEDs to the power source and switch.
Two CR2032 battery holders 	Electronics store	Attach one holder to the light bar and the other to the macrotube body. Two 3-volt CR2016 batteries can be accommodated in series in the holder to provide 6 volts. A single 6-volt circuit can power all 14 LEDs and, with appropriate wiring, overhead, low-angle, or a combination of the two can be obtained.
5 mm tact switch (normally open) 	Electronics store	Causes the LED circuit to break when not depressed, saving battery life.

two images (Fig. 8). This change gives the device the potential to document relief changes on a surface of interest, for example, to document the effects caused by a facade-cleaning system.

The pivot action introduces some distortion in the pictures. This is called "keystoning," and it occurs along the left and right edges of the images. Centrally, the image remains relatively distortion free. Keystoning can be eliminated by sliding the macrotube body from left to right between photographs rather than pivoting it from left to right. The diamond-shaped depressions located adjacent to the pivot points are used in conjunction with the set-screw feet to allow for a uniform shift between images. This method allows collection of stereo images without the problem of keystoning but results in no change in shadow length for a pair of stereo images. The change in shadow length between left and right images can be obtained only using the pivot-action mechanism. Both the shifting and pivoting methods for collection of stereo images may be useful. It should be noted that some distortion along the edges of the images is associated with the particular camera used with the macrotube.

Selecting a Digital Camera

A digital camera that has the capability to focus on an object a minimum distance of about 1¹/₈ in. (3 cm) in front of the lens is adequate for use with the macrotube. These cameras typically alert the user with an audio cue when the surface of interest is in focus. The lens systems of some digital cameras may introduce significant image distortion. Not all low-cost digital cameras exhibit the same amount of distortion when used in macro mode. Furthermore, both the type and level of distortion may vary across the zoom range of the camera. Distortion can be estimated by taking a picture of graph paper. It is also possible to compensate for this distortion by modifying the image once captured in an editing program such as Photoshop that provides tools for lens-defect correction.

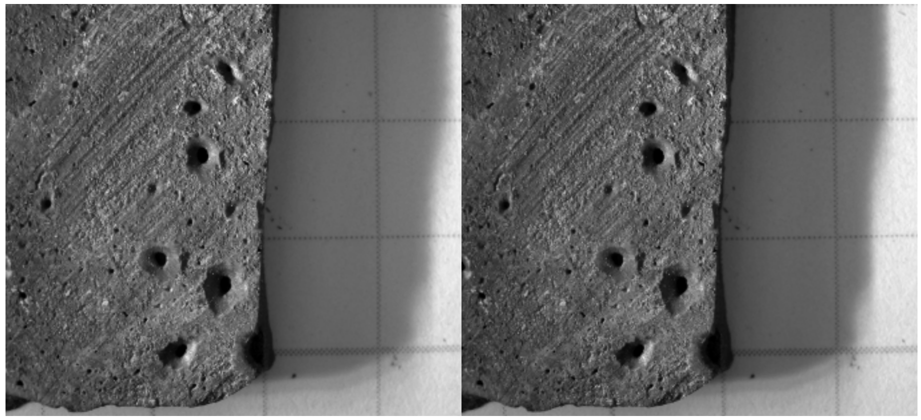


Fig. 8. Stereo images of a capping-compound fragment. Note the difference in shadow length on the right side of the fragment shown in each image, which makes it possible to determine the thickness of the fragment.

Using the Macrotube

To use the macrotube for photographic documentation, the surface-contact ring attached to the macrotube is placed or held against the surface of interest. The surface is then illuminated by either the overhead or low-angle LEDs in the unit. By taking advantage of the audio cue that alerts the user when the surface is in focus, photographs can be taken in difficult field conditions without actually being able to see the view screen. By convention the left-hand stereo image is taken first. The body of the macrotube is then either rotated to the right relative to the surface-contact ring (pivot method) or shifted right (slide method), and the right-hand image is taken. If pairs of stereo images are not desired, the set-screw feet may be taken out of the system by placing them in diamond-shaped holes.

The device has proved useful in rapidly documenting surface-relief conditions on historic dimension stone and brick masonry. If the camera is set to collect the highest resolution data file for the image, then significant digital magnification is also possible. Two sets of stereo images, one of an eroded surface of Indiana limestone and one of a mortar joint on a historic building, are pictured in Figures 9 and 10. A set of stereo images is placed with the images about 6 cm apart, and the three-dimensionality of the image becomes apparent when observed using a stereo viewer. A simple way to align images is to place them side by side in a presentation program such as PowerPoint. If hard copies of the images are prepared with a good-quality laser printer, they can be examined using a stereo viewer.

Building the Macrotube

A list of materials needed to build the macrotube and a brief description of the steps required to build and assemble the individual parts are given in Table 1. The tools needed to fabricate the parts include a drill press; various twist drill bits; a hole-cutting bit; a small, high-speed handheld grinder; and a band saw. C-clamps and a wooden jig are useful to hold the stock pieces in place during machining. The jig has a circular groove that matches the thickness of the macrotube body. A soldering iron is also needed to make electrical connections.

Summary

The macrotube is a simple device that can be built without special facilities. Its use makes it possible to take full advantage of the macro capability available on many of today's compact digital cameras. When a digital camera is used in conjunction with a macrotube, difficulty in focusing, poor lighting, and camera shake are eliminated. The result is a field-documentation system that provides high-quality images taken under repeatable conditions. Stereo images can be obtained rapidly using this system. When illuminated with low-angle light, stereo images may potentially be used to quantify surface-relief changes that may occur during facade-cleaning trials.

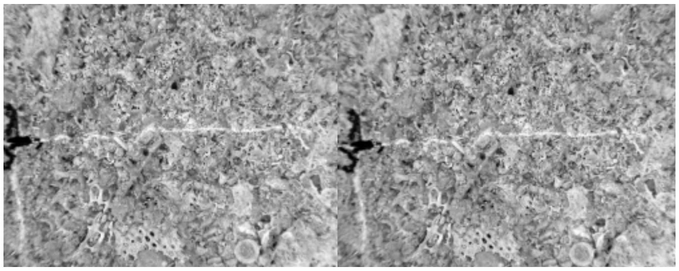


Fig. 9. Stereo images of the eroded Indiana limestone, with visible fossil fragments.

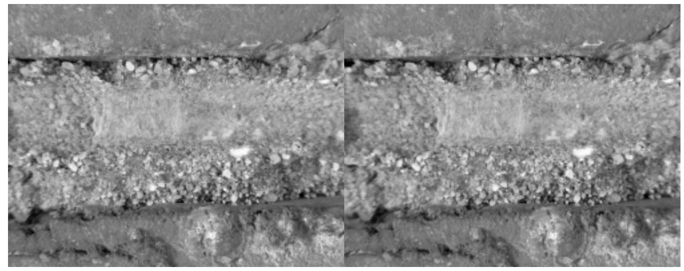


Fig. 10. Stereo images of an eroded mortar joint.

A camera with a macrotube attachment can collect images at a very fast rate, a situation that can lead to confusion if field locations for each image are not properly recorded. The authors have not explored computer-assisted methods to catalog multiple images and tie them to specific locations on a building facade. However, the camera chosen for development of the macrotube also has the capability to capture video and record sound. This feature makes it possible to document a specific location and record macroscope image numbers for later transcription.

L. BRAD SHOTWELL is an associate principal and petrographer assigned to the Cleveland office of Wiss, Janney, Elstner. His primary focus is the petrography of concrete and dimension stone. He has collaborated with Joshua Freedland on a number of preservation projects throughout the U.S.

JOSHUA FREEDLAND is an architectural conservator in the Chicago office of Wiss Janney Elstner. During his nine years at WJE, he has worked on numerous significant preservation projects throughout the U.S.

DAVID A. WAUGH has recently completed PhD studies in paleontology at Kent State University. He has an interest in historic-mortar analysis.

Notes

1. D. A. Waugh and L. B. Shotwell, "SEM-Scale Replication of a Wide Variety of Geologic Materials: Case Studies in Decapod Cuticle Microstructure and Building Dimension Stones," *Geological Society of America Abstracts with Programs* 38, no. 4 (2006): 75.

2. M. Mudge, T. Malzbender, C. Schroer, and M. Lum, "New RTI Methods for Rock Art and Multiple-Viewpoint Display," in *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, ed. M. Ioannides, D. Arnold, F. Niccolucci, and K. Mania (Aire-la-Ville, Switzerland: Eurographics Association, 2006), 195–200.