THE RECONSTRUCTION OF A GREEK VASE: THE KYKNOS KRATER

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Abstract—A late sixth century BC Greek calyx krater was restored. The ancient fragments bear the signature of the noted red-figure painter Euphronios, and comprise some 25% of the original piece. Because a traditional plaster of Paris reconstruction was considered unsuitable, a new technique was developed to fabricate a shell composed of epoxy resins and acrylic paste into which the fragments could be inserted. The measurements for the reconstruction were determined from those of the original fragments. Templates of the internal and external contours of the vase were mounted on a rotating device and turned in sequence to model the various layers of the shell. The finished product is both physically and aesthetically compatible with the original.

1 Introduction

In 1979 an art collector in the United States acquired fragments from a late sixth century BC red-figure calyx krater, signed by the painter, Euphronios [1, 2]. The vase is called the 'Kyknos Krater' in reference to the predominating scene and, with the exceptional krater by the same painter located in the Metropolitan Museum, New York, ranks among the finest examples of Greek vase painting.

The Kyknos Krater fragments comprise approximately one quarter of the entire surface of the vase. Fortunately, they include the signature and a significant portion of the main panel. This is an especially vivid depiction of the battle in which Heracles (a hero favored by Euphronios) mortally wounds Kyknos in punishment for the theft of animals intended for sacrifice to Apollo. Included in the scene are the figures of Athene, Ares and Aphrodite [3]. The superbly balanced dynamic composition was executed with sure, masterful strokes, fine dilute-glaze modeling and relief accents (see Figure 11). The panel on the reverse side, as was common at the time, portrays a scene from contemporary life rather than a mythological subject. Unfortunately, very little remains of this art (see Figure 7).

The decision to attempt a reconstruction of the entire piece was made after careful consideration. Physically the fragments required only minimal conservation. If they had been judged notable solely for their historical worth, no further restoration would have been necessary. However, it was important also to evaluate this vase as a work of art. The fragments, although undeniably powerful when viewed separately, lose some of their aesthetic impact out of their proper context. The surviving pieces are so widely dispersed over the total area of the krater that it is difficult for the scholar, much less the lay person, to visualize the original form at first glance. To restore some of the artistic integrity of the vase it was decided to display the fragments within a complete reconstruction of the original shape.

2 Conservation of the fragments

Careful microscopic examination of the fragments under 2× and 10× magnification failed to reveal any processes of deterioration. However, three shards from the foot demonstrated a loss of clay when their broken edges were lightly rubbed. This fragility, and the lighter color of the black glaze on these shards, suggested that the firing temperature in this area was lower than that for the rest of the vase.

2.1 *Consolidation*

The three fragments from the foot were consolidated under vacuum in a 2·5% solution of Acryloid B-72 dissolved in diethylbenzene. The consolidation was carried out in a glass chamber at 27 × 10^2 Pa (20 torr) for six hours following a six-hour preliminary soaking at atmospheric pressure. The fragments were subsequently removed from the solution, blotted with cotton fabric, wrapped in clean fabric to absorb any excess consolidant, and placed in plastic bags.

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During the drying period of 10 weeks, they were continually turned to distribute the consolidant uniformly within the fragments. The plastic bags allowed a slow, even evaporation rate which prevented film formation. They were turned every three hours during the first day, every six hours for the following three days, and then daily for the remainder of the drying period. During the last two weeks they were dried in the open air. The drying process was considered to be complete when no solvent smell could be detected.

2.2 Salt extraction

Several small fragments were selected for immersion in distilled water for one week at a fragment/water ratio of approximately 1 : 10 w/w. The water was then tested with both a conductivity meter and a specific ion electrode to determine the concentration of salts. Since the level was quite low, below 5 ppm, the remaining fragments were not subjected to salt extraction procedures.

2.3 Cleaning

The surfaces of the fragments were relatively clean. Only a light, milky deposit and traces of insoluble salt crystallizations had to be removed. For the removal of the white deposit, which was the result of previous conservation attempts with plaster of Paris, a 10-minute application of the cleaning agent AB-57 (without EDTA) was sufficient [4]. Silicone rubber burrs in a flexible-shaft dental drill (set at a rate of 250–1000 rpm) were used to remove mechanically the insoluble salts from the surface of the black glaze. Previous experience had proven this method to be satisfactory for cleaning sound black glaze surfaces. Inorganic deposits can be removed easily in this way without the danger or length of time inherent in cleaning with a scalpel or with acid.

2.4 Reassembly

The choice of the glue was based on many years of experimentation with a number of different adhesives, many of which are discussed in the conservation literature. These include epoxies, polyesters, acrylic polymers and copolymers in solutions and emulsions, thermosetting acrylics, cyanoacrylates and epoxy-acrylics [5, 6]. A cellulose nitrate-based adhesive (Duco Cement) was selected in this case because it offered a combination of properties not found in any of the alternatives. It is fast-drying, simple to apply, relatively non-toxic, easily reversible and, most importantly, forms an extremely thin bonding film. It was used full-strength or diluted up to 50 : 50 w/w with acetone if a thinner join was needed between small fragments.

Cellulose nitrate adhesives do have some drawbacks. They are unstable when exposed to ultraviolet radiation, oxygen and elevated humidity levels and they become increasingly brittle as the plasticizer (camphor) evaporates [7, 8]. In this application, the adhesive was completely protected from UV light and partially protected from oxygen by being applied only between the fragments (deep in the cracks) and covered with light-resistant fillers on both sides. The brittleness of the glue presented only a relatively minor problem because it was applied next to the rigid terracotta. However, for additional safety, a UV-stable acrylic thermosetting adhesive (Teets Cold Cure) was applied to the backs of the joins after the initial assembly with cellulose nitrate.

The fragments were glued in an essentially traditional manner. The larger fragment (which might be a single piece or, as assembly progressed, a section comprising several joined segments) was embedded in a box filled with wooden particles. These wooden particles have an average diameter of 2–3mm and are considerably less harmful to delicate, painted surfaces than the sand which is commonly used in this procedure. The heavier fragment was positioned so that the edge to be joined was horizontal and at the top. Adhesive was then separately applied to this edge and to that of the smaller fragment. The lighter fragment was balanced on top of the one in the box until the adhesive had dried enough to provide a sufficiently strong grip.

2.5 Application of a temporary protective coating

A coat of 1·5% aqueous solution of polyvinyl alcohol (Vinol 540) was applied to the cleaned surfaces to protect them from minor damage and soil during the subsequent restoration procedures. This particular resin was chosen both for its resistance to the solvents used in the later phases of the project and because it can be removed easily with water.

3 Fabrication of the reconstruction

3.1 Selection of the method

Two factors dictated separate reconstruction of the entire form with subsequent insertions of the original fragments: the ratio of the total surface area of fragments to that of the missing areas, and the number of floating fragments.

This is not an unusual technique in ceramic restoration when simple filling of lacunae is not possible [9, 10]. However, the material traditionally used in such reconstructions is plaster of Paris. This substance was considered unsuitable for use with the Kyknos Krater for the following reasons:

1) a plaster shell could not sufficiently support and protect the relatively heavy fragments, especially during transportation, handling, etc.;
2) plaster of Paris is a potential source of soluble salts which can cause deterioration when they migrate into adjacent original fragments under conditions of elevated humidity [11];
3) a plaster surface could not be made sufficiently durable or resilient to undergo the burnishing process used to obtain the final gloss.

It was ultimately decided that a combination of thermoplastic and thermosetting resins, modified with appropriate fillers, would best produce a shell with superior mechanical strength. Because the techniques used for making plaster reconstructions could not be used with these materials, it was necessary to design new methods and equipment in order to proceed with the fabrication.

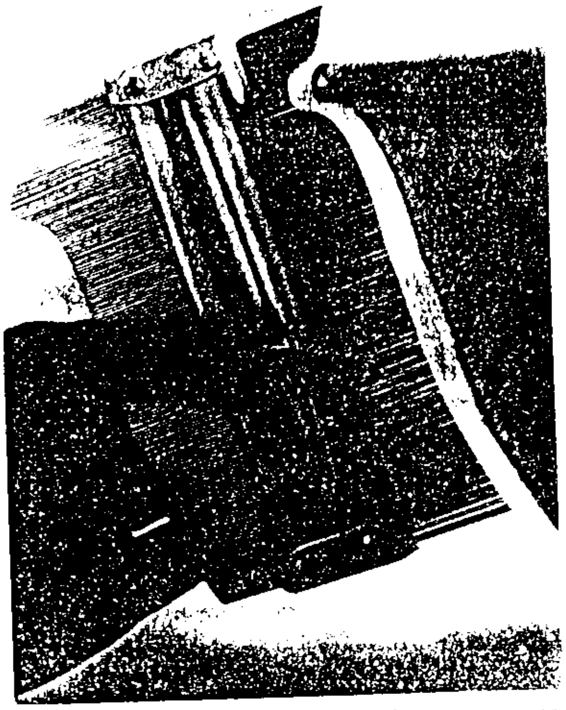

Figure 1 Contour registration with the contour gauge

3.2 Preliminary measurements

The first step was to establish the dimensions of the original krater. Fortunately, the fragments represented each of the major areas of the vase, including portions of the rim, the body and the foot. Precise measurements of the fragments were taken in order to calculate the exact size, shape and contour of the vase.

To find the various circumferences of the krater, measurements were taken from each shard complex (group of fragments glued together) with a contour gauge (Figure 1). The gauge was aligned with the turning marks of the potter's wheel visible under the glaze on the interior side. Once the curve was obtained, the gauge was locked and the contour drawn on tracing paper. The tracing was then superimposed over a piece of cardboard on which many concentric circles had been drawn 2mm apart. By moving the section in and out of the concentric circles, it was possible to match it to the circle to which it most closely corresponded, thereby determining the circumference of the vase at that point. In this manner, circumferences were obtained at 2cm intervals for the entire height of the vase.

The circumferences at the rim and foot were cross-checked with an additional method. Each fragment group was placed on cardboard and its exterior curve traced directly on the board. Two straight lines, each connecting two points on the curve, were then drawn. Perpendicular lines were drawn from the center of each chord and extended until they intersected. The point of intersection was the center of the circle, or circumference (Figure 2).

Next, the thickness of each shard was mea-

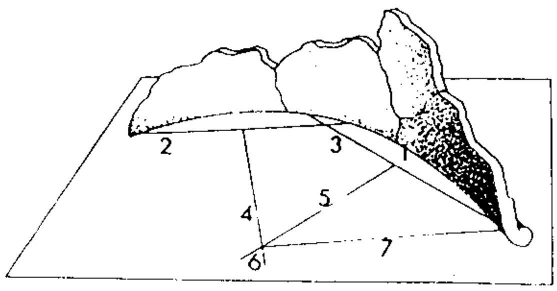

Figure 2 Method of cross-checking circumference measurements: (1) tracing of the curve of the original fragment; (2, 3) chords; (4, 5) perpendiculars to the chords; (6) center of the circle; (7) radius of the circle.

sured with a micrometer accurate to 0·01mm. These measurements indicated the thickness of the vase wall at every two centimeters along its vertical axis.

After adjoining fragments had been glued together, sections of the major areas of the vase were cast with silicone rubber (Figure 3). Each cast was a strip approximately 1cm wide which

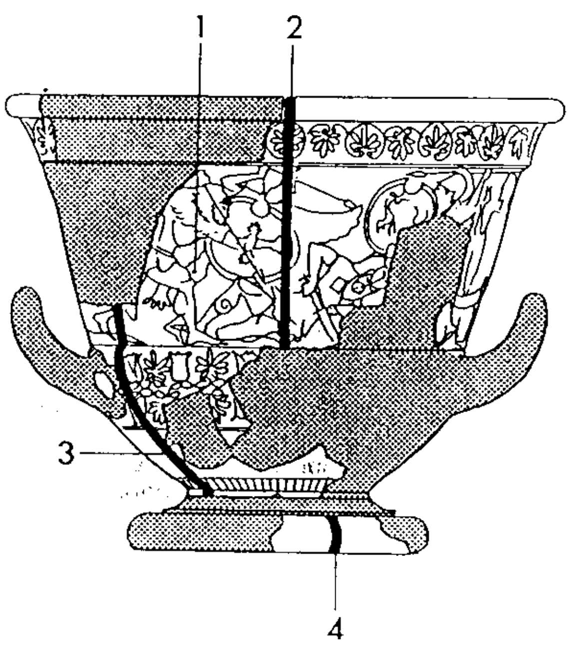

Figure 3 Locations of silicone rubber casts used to obtain interior and exterior contours for (1) rim and body, (2) cul, (3) foot.

extended from the base of the interior side of the fragment, up over the top and down the exterior side. The casts were positioned according to measurements recorded with the contour gauge. This time the gauge was pressed perpendicular to the potter's wheel marks on the front and back of each section of fragments. This placement assured that the vertical axis of the pot was accurately followed. A pair of cardboard restrictive borders (1·5cm high) was made for each side.

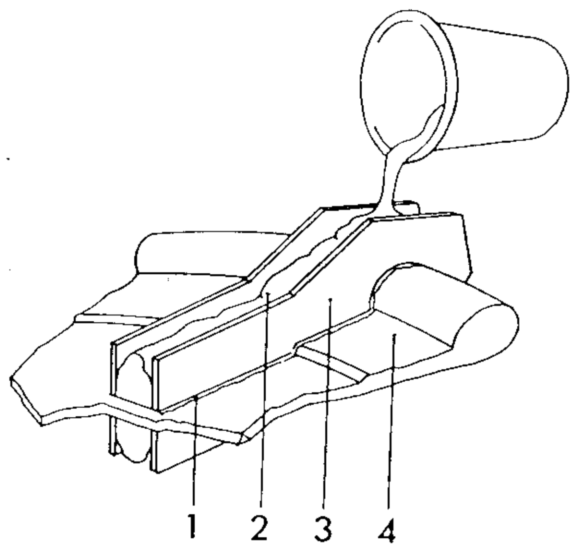

Figure 4 Casting the exterior and interior contours of the fragments: (1) rubber latex sealant; (2) RTV silicone rubber; (3) cardboard restrictive borders; (4) original fragment.

These borders were subsequently attached with rubber latex which also served as a seal. The cardboard walls were parallel to each other at a distance of 1cm and perpendicular to the surface of the fragment. To assure easy separation from the ceramic surface, Moldkote 1919 mold release agent was applied. Some of the fragments with particularly fine painted surfaces were instead covered with a 0·013mm (0·52mil) thick polyethylene film (Handiwrap) prior to the pouring of the rubber. Silicone rubber (Silastic RTV—Type E) thickened with 1% w/w fumed silica (Cab-O-Sil) was then poured into the channels (Figure 4).

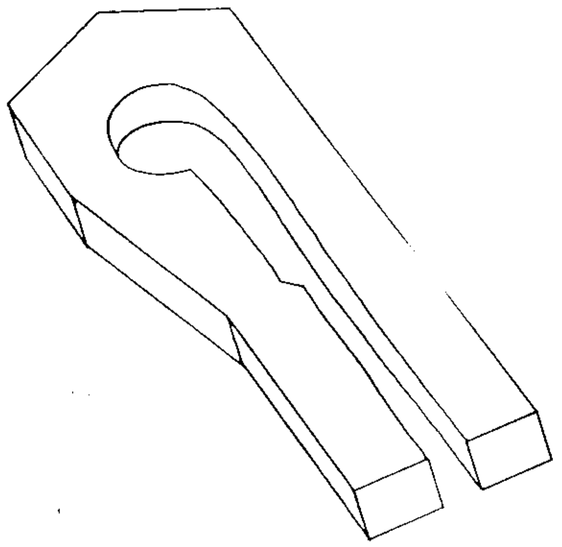

Figure 5 Silicone rubber cast removed from the fragment.

After curing, the rubber casts (Figure 5) were placed on photosensitive paper. The alignment was checked against the dimensions obtained with the micrometer. The paper was then exposed and developed. The resulting documents showed very precisely the interior and exterior contours for the entire height of the krater.

Comparison with the Metropolitan Krater revealed a remarkable similarity in size and shape [12]. The heights of the two kraters differed by a mere 7mm and the diameters of the rims by only 0·5mm. The only portions of the Kyknos Krater which could not be directly determined were the missing handles and a small section on the foot between the base ring and the base of the cul. The latter dimension was extrapolated following a proportional study of all of the Euphronios kraters extant, most particularly the Metropolitan Krater. The handles were cast after those of the Metropolitan Krater (Figures 6, 7).

Figure 6 The Euphronios Krater from the Metropolitan Museum, New York (purchase, bequest of Joseph H. Durkee, gift of Darius Ogden Mills and gift of C. Ruxton Love, by exchange, [illegible]). Dimensions: height 45·7cm; diameter of the rim [illegible]5cm. (Photo: Metropolitan Museum of Art.)

Figure 7 The back of the Kyknos Krater after restoration. Dimensions: height 45·0cm; diameter of the rim 55·10cm. (Photo: M. Bodycomb, Kimbell Museum.)

3.3 *Fabrication of the templates*

Two templates were built utilizing the measurements for the interior and exterior vertical contours They were fabricated from sheet acrylic (Plexiglas) with a thickness of 0·95cm. This material was chosen for its rigidity and transparency, and because it is very easy to process. Mounting holes were drilled on both templates to correspond to holes in the frame of a forming device. The cutting edge was beveled to make it sharp.

3.4 *Construction of the forming device*

A forming device was constructed with a 60 × 60 × 10cm square maplewood base to which a frame supporting the central rod and template was attached. The maple frame consisted of four vertical members (10 × 10 × 60cm) fastened to the center of each side of the base and two horizontal members (10 × 10 × 80cm) joined to the tops of the vertical ones at a 90° angle above the center of the base. One of the vertical members, and half of the horizontal one attached to the top of it, were channeled and drilled in order to mount the templates. A brass rod was placed vertically from the center of the base to the center of the horizontal members crossing above it, with ball-bearings at both points of attachment. A round acrylic sheet (59cm in diameter and 0·95cm thick) was placed over the wooden base and connected to the brass rod which passed through its center. This acrylic circle turned with the rod over eight acrylic spacers (8 × 15 × 0·95cm) mounted in a circle on the surface of the base to facilitate rotation.

3.5 *Fabrication of the support shape*

A circle of silicone release paper was placed over the round acrylic sheet on the forming device. Its diameter was 54cm, which was 6cm smaller than the interior diameter of the rim of the krater. The central rod was coated with a silicone release agent and a two-component rigid polyurethane foam base (Isonate) was cast around it on top of the silicone release paper. The resultant irregular form was then shaped with a hand saw and a rasp. Next, the space between the edge of the template and the polyurethane foam (approximately 1-4cm) was gradually filled with modeling clay. By hand-turning the base supporting the foam shape, the excess clay was cut off as it passed under the sharp edge of the template. In this way, a smooth-surfaced, accurate shape of the interior void was obtained.

3.6 *Fabrication of the shell*

The first template was replaced by the template of the exterior contour. The distance between its cutting edge and the clay-covered foam shape was precisely the thickness of the projected reconstruction.

The clay shape was sprayed with a thin layer of Liquitex Modeling Paste tinted with acrylic colors to match the terracotta of the original. It was sprayed several times until a thickness of 1mm was obtained. This layer served two purposes: it separated the epoxy layer from the clay so that the clay could not inhibit the curing of the resin, and it provided a smooth surface on the interior of the reconstruction which could be easily sanded.

When the modeling paste had dried, a thixotropic epoxy paste was applied with a large palette knife. It was composed of the epoxy resin Araldite 502, 100 parts by weight; Araldite hardener HY 956, 25 parts by weight; Fillite ceramic microspheres (inert filler), 300 parts by weight; and Cab-O-Sil fumed silica (thixotropic agent), 2·5 parts by weight. The thickness of this layer was between 2 and 3mm. This assured a rigid support for the application of the next layer which had to be applied by exerting considerable pressure.

The distance between the Araldite layer and the template edge was then filled with Pliacre epoxy resin. This is a material with the consistency and the working characteristics of modeling clay. Because there is virtually no shrinkage upon curing, the final product is free of deformation. It was applied in small areas of no more than 50cm^2 at a time. After initial general hand-modeling, a more refined surface was obtained by rotating the base and allowing the template to shape and smooth the resin. This was greatly facilitated by moistening the resin with water.

After the Pliacre had cured, a thin layer of colored acrylic paste was applied and again rotated under the edge of the template. This paste can be worked more easily than the epoxies and was excellent for filling the small remaining irregularities to produce a smooth, color-stable surface (Figures 8, 9).

The whole shape was pulled up and off the central rod after the horizontal cross-members were removed. The polyurethane foam and modeling clay were separated mechanically from the resin shell and the interior and exterior surfaces of the shell were finished by wet-sanding them first with 400 and then with 600-grit sandpaper.

The foot was prepared separately using the same technique.

The two handles were cast in silicone rubber molds using Araldite 502 epoxy filled with ceramic microspheres. The ratio of epoxy/hardener/filler was 100:25:200 by weight. For added strength, a 3mm-diameter brass wire was embedded in both handles. It was later used to reinforce the connection between the handles and the body by inserting the ends protruding out of the handles into special holes drilled in the body. Epoxy resin was used to connect both the handles and the foot to the body.

4 Attachment of the original fragments

The shapes of the original fragments were traced onto the surface of the reconstruction in their appropriate places. Leaving a margin 5–6mm larger than the pieces themselves, the sites were cut out with an electric jig-saw and carbide blade. Interestingly, the initial attempt to insert the fragments revealed that the cold-cured synthetic shape was too uniform to correspond everywhere to the shape of the original vase. Hand-throwing, uneven clay composition and drying and firing at high temperatures had all combined to produce variations and irregularities in the shape of the original krater. The necessary corrections of the epoxy shell were made by local heat applications with a hot air blower at temperatures of about 70°C. At this temperature, the epoxy becomes pliable and moderate pressure applied during the cooling process will easily change the shape without disfiguring the surface. Heat-protective gloves (Zetex) made from silica fibers were worn during this operation.

The original fragments were then placed in the corresponding holes and secured with small balsawood wedges. By adjusting the wedges, it was possible to position the fragments accu-

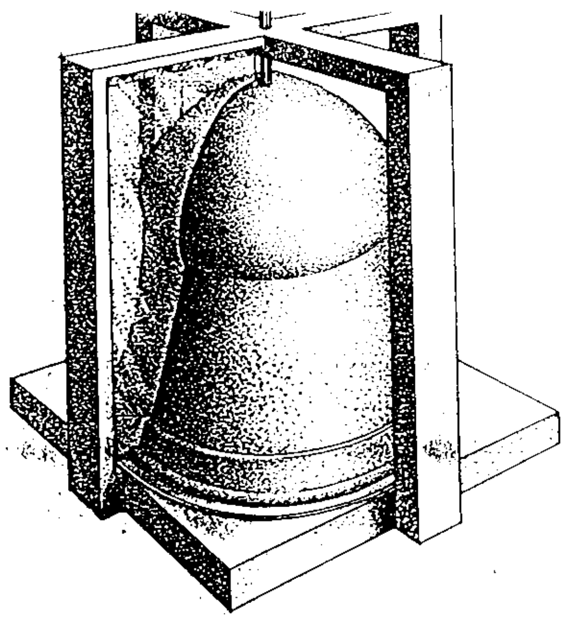

Figure 9 Rendering of the forming device with the reconstruction as it appeared in the final stages of fabrication.

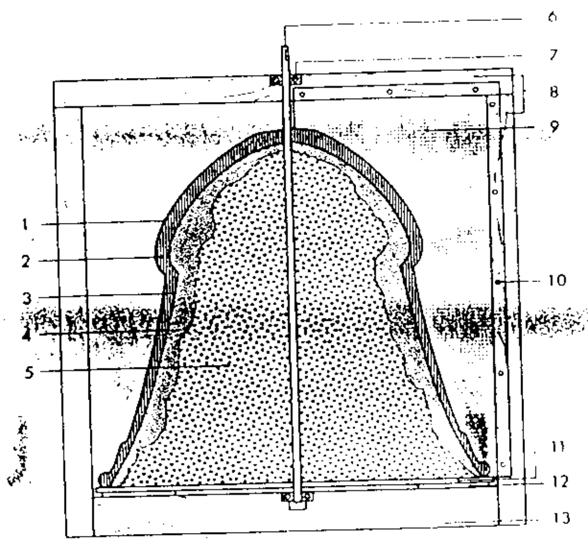

Figure 8 Cross-section of the forming device with the reconstructed form: (1) external acrylic paste layer of the model; (2) epoxy core; (3) inner acrylic paste layer; (4) modeling clay layer; (5) rigid polyurethane support core; (6) brass rod (axle of rotation); (7) axle ball-bearings; (8) wooden crosspieces holding the brass axle and acrylic template; (9) acrylic template; (10) bolts attaching template to the wooden framework; (11) rotating circular acrylic base connected to brass rod; (12) acrylic spacers, fixed to the wooden base; (13) wood base.

Figure 10 (left): The Kyknos Krater after restoration. (Photo: M. Bodycomb, Kimbell Museum.)

Figure 11 (below) Detail of the main scene. (Photo: M. Bodycomb, Kimbell Museum.)

rately and keep them in place during the application of the permanent adhesive.

The glueing was undertaken in two stages. Several spot joins were made with Teets Cold Cure acrylic polymer-monomer system. The gaps between the fragments and the shell were then gradually filled with terracotta-colored modeling paste. The number of spot joins was kept to the minimum required to fix the fragments until the paste was applied. Tests showed the modeling paste to be the most appropriate substance for the permanent adhesion of the fragments to the epoxy shell. It combines good adhesive properties with excellent resilience and reversibility. It can also absorb and buffer the different linear expansion movements of two materials with very different coefficients of thermal expansion such as the epoxy shell ($44 \times 10^{-6}\,°C^{-1}$) and the ceramic fragments ($2 \times 10^{-6}\,°C^{-1}$) [13].

After the gaps were filled, some additional fine level adjustments had to be made. These adjustments were of no more than 0·5mm and unfortunately could not be seen prior to insertion of the fragments. Several points on the shell were ground down. This was initially accomplished, where possible, with a small orbital sander. Subsequently, small round files were used, and finally 600-grit wet sandpaper mounted on a small (2 × 2 × 1cm) neoprene block. Extreme caution had to be exercised while working next to the original. The shell was built up where necessary with additional modeling paste.

5 Final finishing

The surface of the reconstruction was sprayed with a thin layer of Flashe matt vinyl paint, and sanded with 600-grit wet/dry sandpaper in order to make the surface perfectly smooth. The original pieces were protected during this process with a layer of rubber latex (White Plastico). Red areas were sprayed first and then masked with latex during the spraying of the black areas. The black surfaces were covered with a thin layer of Renaissance microcrystalline wax and then burnished with an agate burnisher to give the effect of the original black glaze. Earlier attempts to obtain glossy surfaces with materials such as high-gloss automobile paint or clear varnish coats produced only lifeless results. Burnishing was far more time-consuming but considerably more rewarding aesthetically (Figures 9, 10, 12 and 13).

Following the completion of this stage, the latex protective film was softened with toluene and carefully removed. The polyvinyl alcohol was also removed with wet cotton swabs.

6 Inpainting

6.1 Preparation of the surface

Cracks and small lacunae in the original fragments were filled with a mixture composed of Liquitex modeling paste and Fine Polyfilla (in the ratio of 2 : 5) colored with Flashe vinyl colors to match the terracotta background of the original. The addition of Polyfilla was necessary to obtain even-colored fills. The modeling paste alone, although providing a superior surface, produced a mottled effect. The fills were leveled by the use of micro-scalpels and, wherever possible, 600-grit sandpaper.

Because the value of the original terracotta color varied within the fragments, the fills were first matched to the lightest color of the surrounding original ceramic. Precise adjustments were made with the additional application of washes with Flashe vinyl colors.

6.2 Ethical considerations

The reconstruction of the missing parts of the drawings posed the most complex ethical and technical problems of the entire restoration. All decisions were made in accordance with Article 9 of the Charter of Venice which states that '... restoration ends where hypothesis begins' [14]. Reconstruction of the drawings was limited to only small sections of primarily straight lines where there was no doubt regarding the thickness, direction and shape. All other missing portions of drawings, regardless of size, were left as blank terracotta-colored areas if there was any ambiguity of interpretation (Figure 11).

6.3 Technique

The exceptionally high artistic quality of this piece demanded a rigorous effort from the conservator. This was particularly apparent in those areas where existing lines were reconnected. There are several hypotheses regarding the techniques used by ancient Greek vase painters [15]. After trying all of the methods cited in the available literature on the subject, as well as several other techniques, the author is of the opinion that the only way to have achieved the very long lines of varying thickness was with a small quill. However, as this technique is successful only for fast freehand drawings and is thus unsuitable for restorations, the reconstruction was done with black ink, fine pens and brushes, most often under a microscope (5–10 × magnification). In order to connect the new lines very precisely with the original, without wavy edges or varying width, even the thinnest line was painted twice. This was accomplished by painting one side of the line and then turning the vase through 180° to paint the opposite edge of the same line. Ink proved superior to acrylics, vinyls and watercolors because of its density and fluidity. A water-soluble type was employed to allow for corrections. In some places as many as 40 attempts were made before a satisfactory result was obtained. The ink was fixed by covering the lines with diluted acrylic emulsion (Rhoplex AC-33).

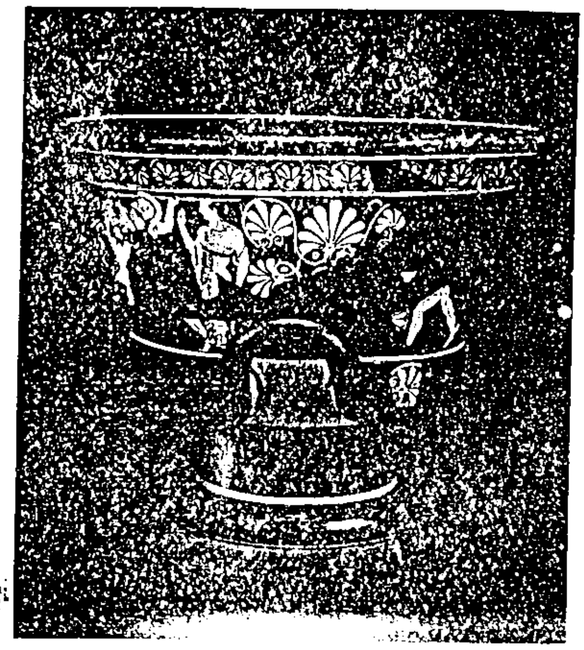

Figure 12 Side view of the Kyknos Krater after restoration. (Photo: M. Bodycomb, Kimbell Museum.)

Acknowledgements

The author gratefully acknowledges the following people: Dr Jiri Frel for his generous and valuable assistance during the placement of the fragments and discussions regarding the reconstruction and the inpainting; Nelson Bunker Hunt, owner of the krater, for permission to publish; Dr Dietrich von Bothmer, for permission to publish the photograph of the Euphronios Krater from the Metropolitan Museum.

Appendix 1: Material information and suppliers

Acryloid B-72: An ethyl methacrylate/methyl acrylate copolymer made by Rohm and Haas, used for consolidation of some of the fragments. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

AB-57: An aqueous solution containing (by weight) 3% ammonium bicarbonate; 5% sodium bicarbonate; 1·5% high-viscosity carboxymethyl cellulose (gel-forming agent), and 2·5% of a 10% solution of quaternary ammonium compound (biocide and surfactant).

Duco Cement: A [illegible] nitrate [illegible] manufactured by Devcon Co., used for the reassembly of the fragments. Typical formulation is cellulose nitrate, camphor (hardener and plasticizer), ethanol, butan[illegible] [illegible] acetone. Tensile strength 450kg/cm². Compressive strength 1500kg/cm². It is reversible in

Figure 13 Side view of the Kyknos Krater after restoration. (Photo: M. Bodycomb, Kimbell Museum.)

alcohol, esters, ketones and aromatic hydrocarbons. Available in hardware stores.

Teets Denture Material: An acrylic adhesive and filler made by Co-Oral-ite Manufacturing Co., used as an adhesive for reassembly of the fragments and attachment to the model. It is a two-component methyl methacrylate, polymer-monomer system [6, 13]. The mixing ratio is 2 : 1, non-critical. Pot life is 10min. at 25°C. Complete curing time: 4hrs. Coefficient of thermal expansion: 97×10^{-6} °C^{-1}. It is non-yellowing and reversible in ketones, esters and aromatic hydrocarbons. Supplier: Healthco, Woodland Hills, CA 91311, USA.

Vinol 540: Polyvinyl alcohol made by Air Research and Chemicals, Inc. A water-soluble resin which is insoluble in most common solvents. Used as a temporary, protective coat on the fragments. Viscosity of a 4% solution at 20°C is 35–45cP. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

White Plastico No. 10: This is a white, natural rubber latex liquid masking substance made by Douglas and Sturgess. It was used to attach the restrictive cardboard borders to the fragments during casting and to seal the gaps at the line of attachment. It was also used to mask the original fragments during spraying of the reconstruction. One-component, air-drying. It may require 2–3 coats if applied by brush. Available in art supply stores.

Moldkote 1919: A Teflon mold-coat made by Hastings Plastics Co., Santa Monica, CA 90404, USA. Used as a release agent to separate the RTV Silicone Rubber from the polyvinyl alcohol-coated surface of the original. Active ingredient is a fluorocarbon dispersion. Available through the manufacturer.

Handiwrap: 0·52mil (0·013mm) thick polyethylene food-wrap manufactured by Dow Chemical.

Silastic RTV, Type E: A mold-making silicone rubber made by Dow Corning, used for casting the internal and external contours of the fragments. It is a two-component, white, high-elongation rubber with very good tear resistance and no shrinkage upon curing. The rubber/catalyst ratio is 10:1. Pot life is 2hrs. Curing time: 24hrs at 25°C. It will not cure next to any materials which contain sulfur. For best results, it should be placed under vacuum immediately after mixing the two components and held until it returns to its initial level after rising. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

Dow Corning No. 7 Silicone Release Agent: Used to coat the brass rod before application of the rigid foam. Supplier: Fisher Scientific, Springfield, NJ 07081, USA.

Silicone release paper: Coated paper used to separate the rigid polyurethane foam from the acrylic base. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

Isonate System CPR 837 8 Rigid Polyurethane Foam: Made by the CPR Division of the Upjohn Co. Used to form the support core when building up the model. A two-component CO_2-blown system with a Part A and Part B mixing ratio of 1:1. Cream time is 37sec. Rise time: 2·5min. Cure time: 25hrs. Density: 128kg/m^3. Skin, eye and respiratory irritant. Excessive inhalation of the vapors of the uncured components can produce serious, and possibly irreversible, pulmonary injury [16]. Manufacturer's safety recommendations must be strictly followed. Available in plastic materials stores.

Klean Klay No. 20: A sulfur-free modeling clay made by Art Chemical Products, used to build the surface layer of the support shape. Available in art supply stores.

Liquitex Acrylic Modeling Paste: Manufactured by Binney and Smith, Inc. Used as a gap-filler alone or in combination with Polyfilla (Fine), colored with Flashe vinyl colors. The paste is a one-component, air-drying, non-yellowing acrylic polymer emulsion filled with calcium carbonate. Initial pH is 8·0. Water content: 25%. It can be mixed with acrylic colors, watercolors and dry pigments. It becomes, after drying, a hard, off-white substance which is easily tooled, sanded and polished. Coefficient of thermal expansion: 21 $\times 10^{-6}$ °C^{-1} [13]. Reversible in ketones, esters and aromatic hydrocarbons. Available in art supply stores.

Araldite 502, with hardener Araldite HY 956: A modified epoxy resin made by Ciba Geigy. Used to build one of the layers of the model. Made thixotropic with the addition of Cab-O-Sil. The resin is based on bisphenol-A and epichlorohydrin modified with dibutyl phthalate. The hardener is dioxylated triethylene tetramine. Resin/hardener mixing ratio is 4:1w/w. Mixture viscosity: 2000–2200cP at 25°C. Pot life for 100g at 25°C: 35–45min. Cure time: 24hrs. Complete curing: 7 days at 25°C. Properties after curing: tensile strength 580kg/cm^2; compressive strength 1125kg/cm^2 [17, 18]; thermal expansion coefficient 67 $\times 10^{-6}$ °C^{-1} [13]. Supplier: Dorsett & Jackson Inc., Los Angeles, CA 90093, USA.

Fillite PFA SS20 Ceramic Microspheres: An inert filler made by Fillite USA. Used as a fill material for the Araldite 502 epoxy resin. Particle size: 20 microns and below. Specific gravity: 2·4. A dust mask, capable of filtering fine particles, must be worn when the dry powder is handled. Supplier: Hastings Plastics, Santa Monica, CA 90404, USA.

Cab-O-Sil: Pyrogenic colloidal silica made by Cabot Corporation, used to thicken the RTV silicone rubber and as a thixotropic agent for the Araldite 502 epoxy resin. Extremely fine silica powder with a particle size of seven nanometers. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

Pliacre: Epoxy putty made by Philadelphia Resins, used as a main constituent of the model. A two-component system: resin and polyamide amine hardener, both filled with talc. Mixing ratio is 1:1w/w or v/v. The system is compatible with water added during the preparation stage. Simply dipping the separate lumps of hardener and resin in water before combining prevents the resin from sticking to the fingers. The mixed resin has the consistency and working characteristics of modeling clay. Pot life is 35min at 25°C. Curing time: 16hrs at 25°C. Can be colored with dry pigments, acrylic colors or watercolors. The cured product has an off-white color and is resistant to most acids, alkalis and solvents. Yellows when exposed to UV light. Insoluble in common solvents. Can be broken down to small particles in methylene chloride. The best way to remove it following curing is to heat it to 60–70°C until it softens sufficiently to be cut with a knife. If this temperature is unacceptable, cold grinding is recommended. Properties: compression strength 1000kg/cm^2; tensile strength 112kg/cm^2; shrinkage upon curing 0·0001% in volume; coefficient of thermal expansion 44 × 10^{-6}°C^{-1} [13]. Because of the type of hardener used, the health hazard is very low, which is an important consideration in cases where hand-modeling is inevitable. However, sensitive people should use protective gloves or a protective chemical film to prevent irritation. Because the manufacturer did not disclose the type of filler used, we analyzed the product microscopically and with X-ray fluorescence since we suspected that hazardous fibers might be present. The examinations, however, showed only magnesium silicate. Supplier: Philadelphia Resins Inc., Montgomeryville, PA 18936, USA.

Polyfilla (Fine Surface): Fill material made by Polycell Products, Ltd. Used as a fill material in combination with the Liquitex modeling paste. Available in UK hardware stores.

Flashe Vinyl Artistic Colors: Made by Lefranc et Bourgeois. Used for the inpaintings and for painting the surface of the model. These are opaque, light-resistant colors which create a stable, matt surface. Only those colors designated by the manufacturer as permanent (made with light-resistant pigments) were used. Available in art supply stores.

Pelikan Black Ink, 4001: Used for the inpainting of the black lines, manufactured by Pelikan, W. Germany. Available in art supply stores.

Renaissance Microcrystalline Wax: Manufactured by Picreator Enterprises Ltd. Used as a coating over the black paint of the model to facilitate the burnishing process. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

Rhoplex AC-33: Acrylic polymer dispersion made by Rohm and Haas. Used over the black ink to make it water-resistant. Non-yellowing. Soluble in esters, ketones and aromatic hydrocarbons. Supplier: Conservation Materials Ltd, Sparks, NV 89431, USA.

Appendix 2: Equipment

Ceramiste Silicone Points: Silicone rubber polishing burrs made by Shofu Dental Corporation. Used for cleaning of sound black glaze. Supplier: Healthco, Woodland Hills, CA 91311, USA.

Contour gauge: Made by Preservation Research Products, Springfield, VA. This device consists of a row of aligned wires, each suspended in a uniform magnetic field on its own individual track. Profiles are recorded by pressing the wires against a curve. Used to record the curves of the fragments in order to determine the dimensions of the original krater. Supplier: McMaster-Carr Co., Los Angeles, CA 90054, USA.

Digital Comparison Micrometer: McMaster-Carr, Los Angeles, CA 90054, USA. Used to measure the thicknesses of the fragments. Accurate to 0·01mm. Available through the manufacturer.

Black and Decker Orbital Sander: Used to finish the surface of the model. 1500 orbits/min. Sanding pad size: 5 × 7cm. Supplier: Sears, Roebuck and Co., Chicago, IL 60607, USA.

CC-30 Flexible Shaft Drill: Made by the Foredom Electric Co., Bethel, CT, USA. 1/10hp motor. Speed range: 0–14,000rpm. EC-1 electronic foot control. Handpiece No. 30. Supplier: Bourget Brothers, Santa Monica, CA 90404, USA.

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Résumé—Il s'agit de la restauration d'un calice grec datant de la fin du 6e siècle avant J.C. dont les fragments anciens—qui comprennent 25% de la pièce originale—porte la signature du célèbre peintre de figures rouges Euphronios. Le restauration au plâtre de Paris s'avérant inutilisable, on fabrique par une nouvelle technique une coquille en résine époxy et pâte acrylique dans laquelle les fragments pouvaient être inclus. Les dimensions de la reconstitution furent déterminées par celles des fragments originaux. Des patrons des contours externe et interne du vase furent montés sur un dispositif rotatif et tournés successivement pour former les différentes couches de la coque. L'objet terminé est au plan de son aspect physique et esthétique comparable à l'original.

Zusammenfassung—Ein griechischer, kelchförmiger Krater aus dem späten 6. Jh. v. Chr. wurde restauriert. Die überkommenen ca. 25% des originalen Mischkruges tragen die Signatur des berühmten Rotfigurenmalers Euphronios. Weil eine traditionelle Rekonstruktion aus Gips als ungeeignet erachtet wurde, wurde eine neue Methode entwickelt: Sie gestattet es, eine aus Epoxidharzen und Acrylkleber gefertigte Form herzustellen, in die die Keramikfragmente eingesetzt werden. Die Maße für die Rekonstruktion wurden dabei von den überkommenen Fragmenten abgenommen. Schablonen der inneren und äußeren Umrißlinien der Vase wurden auf eine Drehscheibe montiert und der Reihe nach eingesetzt, um die Form aufzubauen. Die Ergänzungen werden insgesamt als mit dem Original verträglich empfunden.