

## Examination of the Ardagh Chalice—A Case History

Ardagh now is scarcely more than a placename; it is in County Limerick in Ireland. In 1868, while a peasant named Quinn was digging potatoes in an earth fort, he found at a depth of about three feet beneath a thorn-tree some bronze objects and a silver chalice. These objects were taken to the convent at Limerick, where they were examined by the Bishop and by Lord Dunraven, an amateur antiquarian. Later, these objects passed to the Royal Irish Academy in Dublin. There they were cleaned and the chalice examined by a jeweler named Johnson. Johnson's report on it was incorporated into the report that Dunraven published in 1874 in "Transactions of the Royal Irish Academy." We are greatly indebted to his account for knowledge of the condition of the chalice at the time when it was found. Illustrations for his paper were drawn by Margaret Stokes, a writer on the antiquities of this period, who used photographs as the basis for her drawings. Through the exertions of Etienne Rhyne of the National Museum her photograph album was discovered a few years ago in a local bookshop. These have helped solve a problem that had arisen from observations made in the course of the examination to be described.

In June 1961 the chalice was taken to the Research Laboratory of the British Museum for repair because it had become loose at the joint between bowl and foot. This necessary work was also to provide a convenient occasion to study the chalice, both in order to discover how reliable for modern usage Dunraven's account had been and also to analyze its materials and construction.

The work proceeded alongside the normal activities in the laboratory (including moving to a new building) but became more and more complex as it developed. Nevertheless, because at least partial completion had been promised by the end of 1962 the chalice was actually placed on exhibition in the British Museum during December 1962 after it had been reassembled temporarily especially for this purpose. After the exhibition the examination recommenced and uncovered more and more problems. Eventually, details of the final reassembly were agreed with Dublin and the chalice was returned in December 1963. The following account itemizes some of the complexities encountered and gives an insight into the problems that can arise in a museum laboratory. The illustrations are from the two hundred or so photographs taken in the course of the examination.

### Description

Fig.1 shows the chalice as received. It consisted essentially of a silver two-handled bowl joined to a silver foot through a gilt-bronze neck. The bowl is decorated with a rim, with two handle-escutcheons beneath the handles and with two roundels, one quite clearly visible at the front. It was decorated

also with a band of panels beneath the rim that is described here as the "bowl-girdle." The foot is decorated with an upper foot-girdle, in view when the chalice is at rest, and a lower foot-girdle, visible when the chalice is raised off a table.

### Objectives

The objectives of treatment were as follows: first, to secure the loose neck; second, to check the accuracy of Dunraven's account and especially to confirm the existence of an iron bolt which Dunraven wrote "holds all together"; third, to determine the nature of the various materials employed. The results should be publishable. This objective of final publication had to be borne clearly in mind if the labor of preparation for publication was to be minimized. It influenced all of the work. The task of the scientific laboratory was considered to be to provide evidence in a form that could be interpreted by later generations of archaeologists using their own conventions. Dunraven's text was already proving unreliable although it was less than a century old. For this reason as much evidence as possible was to be recorded: not only evidence that could be understood now but also evidence that would have to be interpreted in the future, for example, the shape and the markings found on the chalice. For this reason the results of the work were to be recorded in graphic form which would in some degree be independent of words, whose meanings change with the passage of time. Records made included photographs and scaled engineering drawings. This account explains the methods used to make them and some of the discoveries made solely as a result.

The problems were attacked broadly as follows. First, study of whatever could be seen in the uncleaned condition of the chalice and of its components, followed by recording, as far as possible in a form suitable for immediate publication. Second, cleaning of a particular feature, recording anything newly revealed. Third, gathering together a number of these observations and making deductions. Emergence of a theory would then necessitate re-examination of the chalice with a view to confirming the theory. An example of this will be given later.

In accordance with the enormous value of the chalice, during the whole of the work extreme precautions were taken against risk of damage. Overnight it was stored in a strong-room. During the day it rested in a tray on a sponge support beneath a transparent protective cover so that nothing could fall accidentally against it. Throughout, precautions were taken against any kind of damage to any one part of it. According to Dunraven's account there were 354 parts!

### Examination

As a preliminary, examination was directed toward discovering

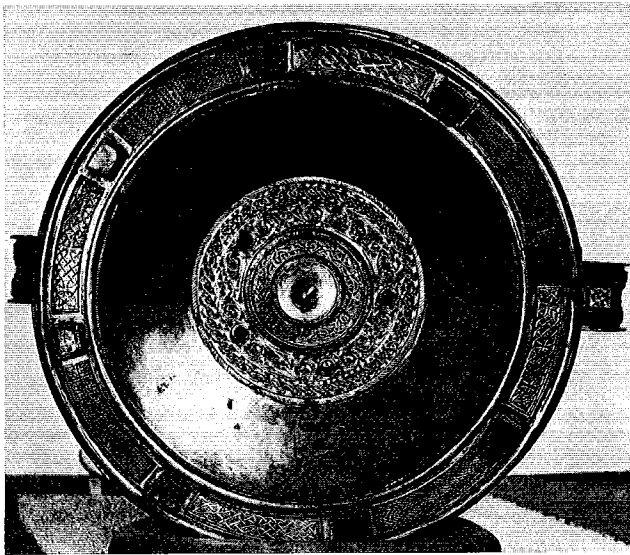


1. The Ardagh chalice as received.

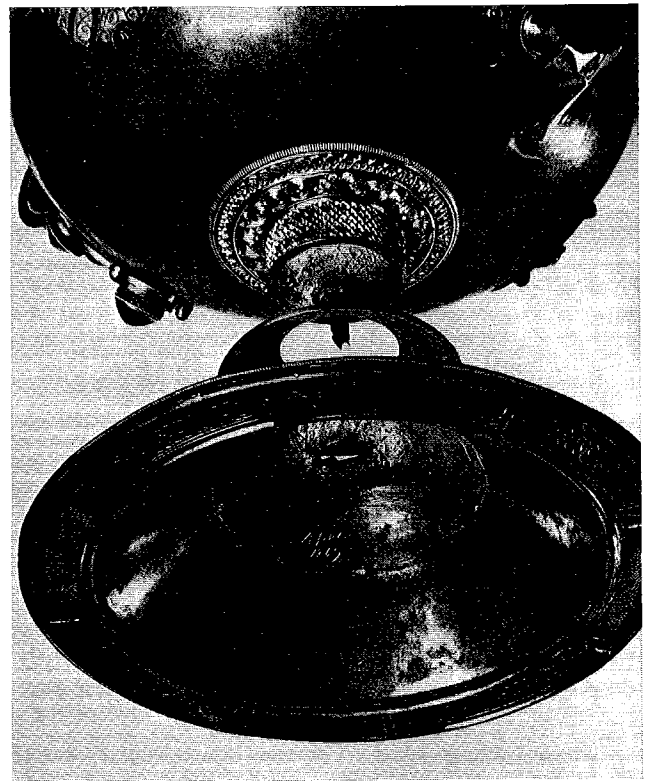
how the chalice was constructed. No single action was taken without thought. The chalice was laid on its side on its foam pad, its foot resting in a rubber ring to prevent it from rolling, as shown in fig. 2. This was one of the earliest of the photographs. Simply taken by daylight with a Leica camera, it is unclear because of the glare of light reflected from the multitudinous facets in the underfoot disc. The difficulty in taking a photograph was overcome later. Another feature of the photograph is a central dark patch in the crystal. It may be deduced from this that a reflecting surface beneath the crystal, probably metal foil, had been perforated. Perforation could have occurred at some earlier examination as a result of the

central crystal dome having been rotated carelessly in its mount against some sharp metal object lying beneath the foil.

The next stage of examination was to touch the underfoot disc, the component decorated with the five small circular studs, and to attempt to rotate it gently. The disc could rotate only through a small angle. From this it was deduced that the disc was mounted loosely upon a square bolt, or at least upon a bolt whose end was not circular in cross-section. The parts were next separated: first, the crystal was eased from its mount, shown at the bottom of the exploded view in fig. 3. Then the whole of the mount was lifted away from the under-foot disc. This then revealed inside the foot-cone the expected



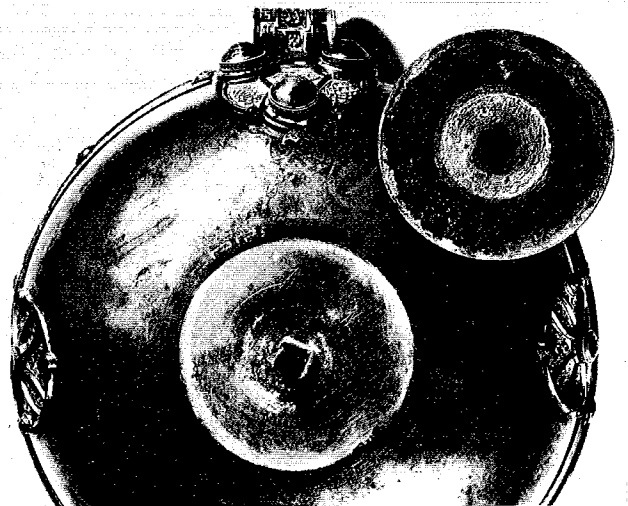
2. The chalice laid on its side for preliminary investigation of its construction exposing the foot.



4. Removal of the foot-cone and the lower neck ring to reveal a mass of lead cast into the neck.



3. Exploded view of crystal mount, under-foot disc, and the end of the central bolt.



5. The neck assembly removed from the bolt.

square bolt. It also revealed two sharp tags projecting from the end of the bolt. The earlier two deductions now stood confirmed: here were the sharp projections that had torn the silver foil and the square bolt.

The next stage of exploration was to lift away the foot-cone. This revealed the lower of the three rings of the neck assembly and also exposed a mass of lead, fig. 4, that locked the bolt into the central ring of the neck. A loose stud that fell out of the foot-girdle during this work was immediately taped on to the appropriate position of the bowl, using pressure-sensitive tape, as a short-term precaution against loss or damage (see upper right-hand corner of fig. 4).

At this stage of examination it was believed that the lead in the neck had been inserted by Johnson, the jeweler who first examined and cleaned the chalice, and that it could therefore be removed if need be because it was not original. In fact it was shown later to have been original, but removal now was essential, whatever its origin, because it was endangering the stability of the chalice: the lead had corroded — the crust of corrosion products on it is visible in the photograph — and had been forcing the foot away from the bowl. This turned out to have been the source of weakness in the neck that had initiated the work.

The lead was removed very carefully. It was first channelled annularly with a rotary file with care that the file did not approach any part of the chalice. Then the thin wall of lead that had been left against the central bolt was carefully levered back into the annular space made by the file. The neck could then be lifted away from the bowl. In fig. 5 it can be seen with its lead still within it, turned over and laid down alongside the place from which it came. Looking at the inside of the neck you may note that the lead that had lain against the silver bowl is white with corrosion products. Circular turning-marks in these suggest that a lathe had been used. In the periphery of the disc there is a greenish-white deposit that actually represents corrosion products from the bronze of which the disc was made. On the silver bowl may be seen a circle of untarnished silver. This had been protected from the tarnishing gases in the atmosphere by the seal of corrosion products around the periphery of the disc. Toward the center of the clear circle of silver one or two patches of white material adhere firmly. These provide evidence that the expanding corrosion products of lead had been forced tightly against the silver at these places.

It has now been shown that the major components of the assembly consist of a foot-cone, a neck, and a bowl held together by a bolt. Let us now consider separately the several minor components of the chalice, beginning with one of the two handles on the bowl, fig. 6.



6. One of the two handles on the bowl.

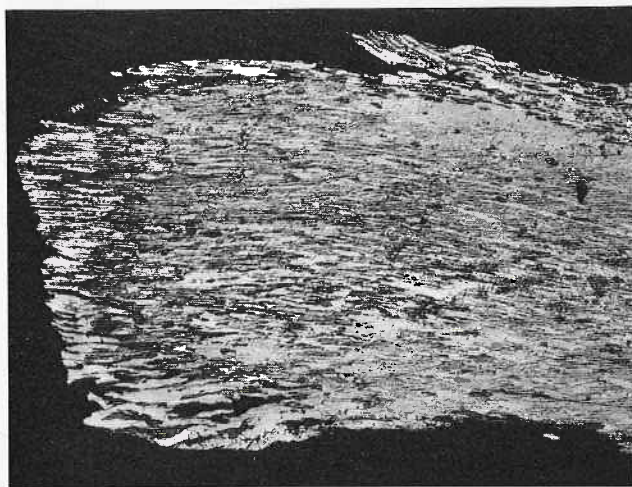
### The Handles

This handle was secured to the bowl by two rivets at the top (invisible in this photograph) and two rivets at the bottom that are covered by small glass studs. For the moment let us ignore the decoration but consider how this handle has been made. Its shape suggests a curved sheet of silver having flanges, serving as stiffeners, attached to both sides. It was a question whether this handle had been cast in one piece or whether parts had been soldered together. This question could have been answered by making a metallographic cross-section in some portion but removal for such a purpose was not permissible and preparation of a taper section in situ would have been very difficult.

Examination of the surface of the handle under a microscope at a magnification of about ten diameters suggested that the handles had been cast. This impression had to be con-



7. The side and exposed interior of one of the handles.



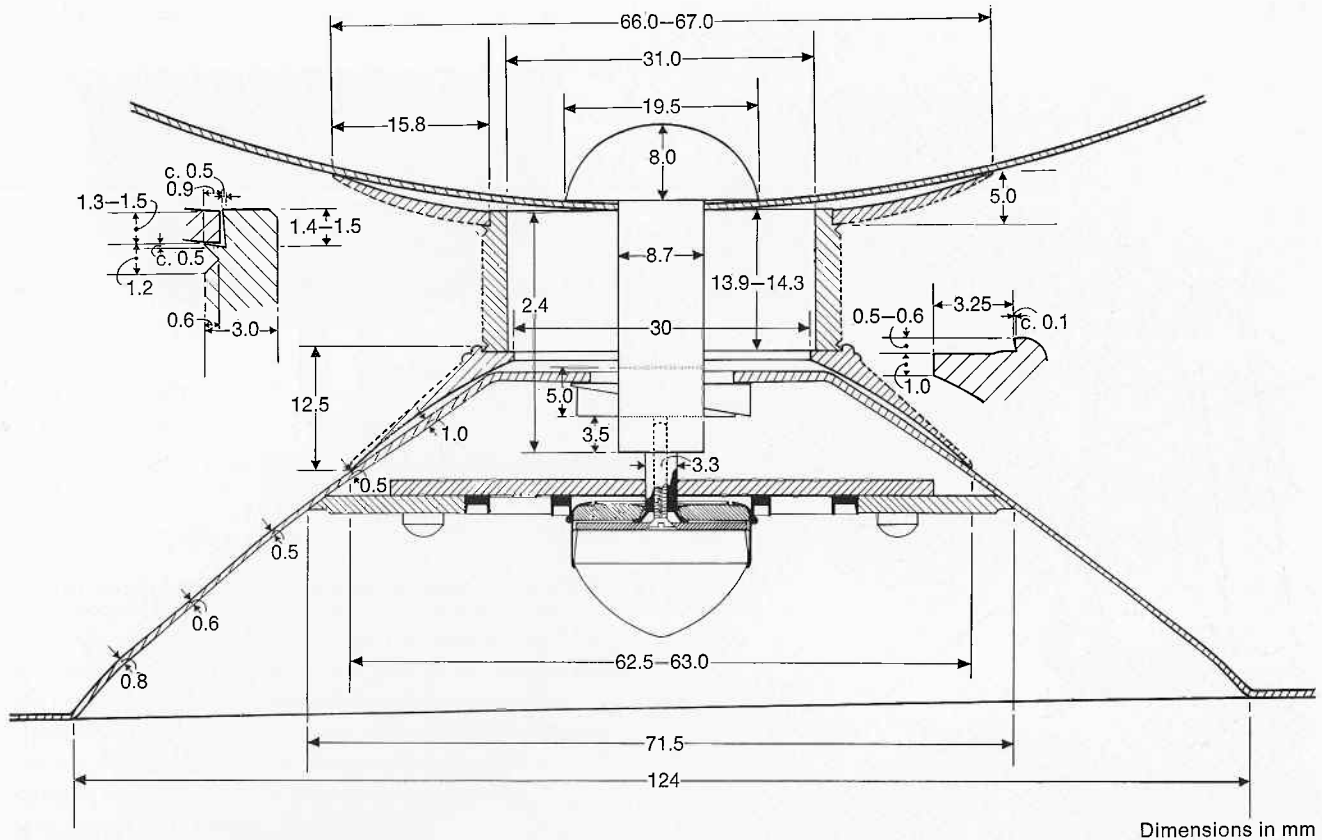
8. A prepared cross-section of a fragment of the silver liner of a handle.

firmed in some objective manner. It was confirmed by an examination of the curvature of the C-shaped flanges on the sides (see fig. 7). Here it can be seen that the "C" is not part of a circle — its radius of curvature varies from point to point. This was quite an important observation because if the handle is not circular, with a readily repeatable curvature, then there is a strong probability that one side of the handle will have a slightly different curvature from the other. It was decided to investigate this.

A very careful transfer was made of the curvature of the flange. The transfer was not made by tracing with a pencil: the handle was made to transfer its own curvature. This was done by placing a transparent sheet of "Kodatrace" backed with carbon-paper against the flange and then rubbing the Kodatrace in the region of the metal edge with the back of a fingernail held at a constant angle. By this means the line of the edge was transferred through the carbon-paper to the Kodatrace.

The trace was then laid against the other parallel flange of the same handle and it was observed that the two curvatures were different. In other words the handle was asymmetric. The trace from the left-hand flange of one handle was then laid against the left-hand flange of the other handle. It was found to fit perfectly throughout its whole length within the width of the traced line — within 0.1 millimeter ( $1/250$  inch). A trace from the right-hand side of one handle was similarly found to match perfectly the right-hand side of the other handle. In other words it could be shown that the two sides of one handle differed from each other but were identical with the corresponding sides of the other handle. This implied that both handles were made from a single pattern by casting. It is most improbable that identical noncircular curvatures would have been achieved so precisely by any other method of fabrication. Other observations were made that rule out other possible forms of construction.

In the photograph the interior of the handle is shown exposed rather unpleasantly because the sheet of silver that covered it had been removed. The next photograph, fig. 8, illustrates the structure of this silver liner. It represents a cross-section through a fragment that has been examined metallographically: polished and examined at high magnification. The smaller dimension of the cross-section shown represents a distance of 0.3 mm ( $1/80$  inch). The metal was examined in order to determine whether it was in fact as ancient as the chalice, about A.D. 800, or whether it represented a piece inserted by Johnson in 1869 — one of the liners appeared at first sight to be more recent than the other. The photograph shows a structure consisting of flattened dendrites. Clearly, the silver had been cast and then reduced in thickness by hammering. This is evidence for a primitive technique of fabri-



9. Dimensioned drawing of cross-section of central portion of the chalice.

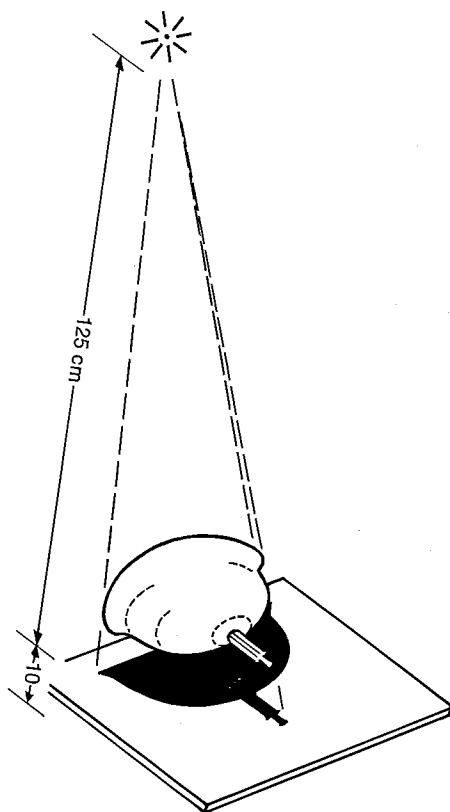
cation: modern rolled silver has a quite different structure. Furthermore the silver has become enriched at its surface: the center area of the section appeared pink, consisting of an alloy of silver with much copper, whereas the peripheries of the section are white because they have lost copper and now consist of almost pure silver. The copper-rich phase has been converted during the centuries into the lines of dark mineral that may be seen in between the white crystals of the silver-rich phase, and even these have been lost from immediately beneath the surface at the edge of the fragment, leaving only the white silver-rich metal.

**The Bowl**

Next let us examine a diagram, fig. 9. This is an engineering drawing that has been very carefully scaled. This method of drawing was adopted deliberately because it ensured that the original was studied correspondingly carefully. The upper portion of the drawing shows a part of the bowl of the chalice. The detailed shape of the whole of this bowl was determined for the sake of precision by a mechanical method.

Obviously the bowl could not be cut across in order to determine its precise cross-section. Instead, a beam of light was used to make a shadowgraph (see fig. 10). The source of light was a pointlite lamp. The bowl was inverted on a flat support immediately in front of a screen placed close against it and carrying a sheet of sensitized (bromide) paper. The essential precaution for the success of this kind of work is to position everything very carefully: the source of light has been placed exactly in the same plane as the rim of the bowl and rather far removed from it in order to cast a slightly enlarged shadow that truly represents the shape of the bowl.

Fig. 11 shows the silhouette thus obtained. Dimensions have been added to it, showing that beneath the rim the silver is about one-half millimeter ( $\frac{1}{50}$  inch) thick whereas at the center of the bowl the silver is a whole millimeter thick. From these measurements it can be deduced that the bowl was made by the process of raising. The silhouette also preserves evidence for posterity of the precision with which the light source was set in the same plane as the rim. These are in fact the four flanges, two to each handle, that appear exactly equal

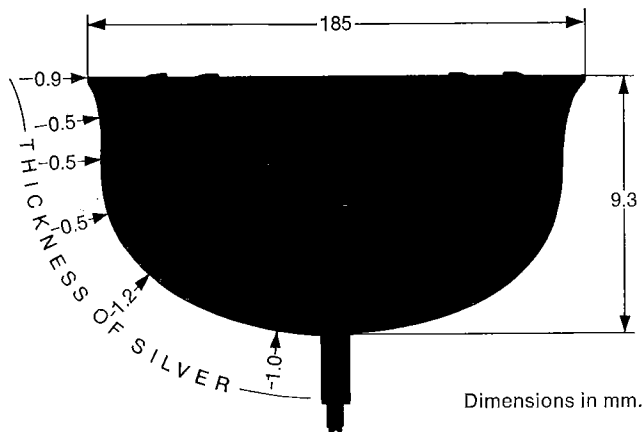


10. Arrangement of bowl and light source to yield an accurately proportioned shadow of the bowl.

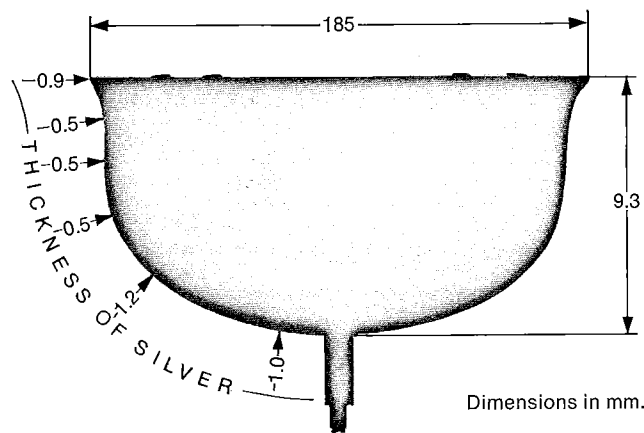
in size only because the light-source was positioned correctly. The resulting black and white silhouette was not very convenient for publication: a simple black line is preferable. How was the transfer achieved? It was produced without risk of error in manual tracing by the simple expedient of Xeroxing the silhouette. The result, fig.12, became a sharp line edged by a grey border because of the special characteristics of the electrostatic process. In this way the beautiful curvature of the bowl has been presented without the falsification that manual copying could have introduced.

**The Rim of the Bowl**

The upper edges of the outline, representing the sharp rim of the bowl, were covered in the actual object by a rim made of gilt brass. This had a rounded upper surface and a groove beneath to fit over the edge of the bowl. It was held in place

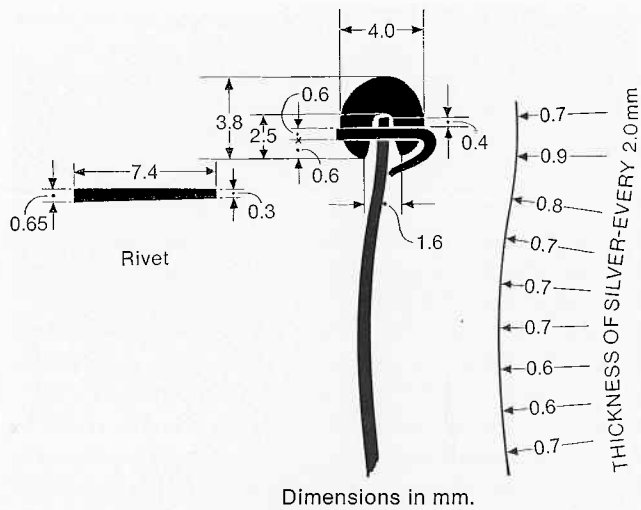


11. Silhouette of bowl and bolt with dimensions added.



12. An outline of the bowl produced nonmanually.

by three tapered pins which were spaced around and passed through the rim and were bent over on the inside. All of this detail is shown very precisely in fig. 13. Unlike the bowl, the shape of the cross-section could not be obtained by use of the point-source of light because the outside of the complete ring would have shielded light from its inner surface. Furthermore, the groove itself was quite inaccessible to light. In this case the shape was determined with certainty by making an impression. A short length of the rim was laid in a channel, its ends stopped with wax. Ready-mixed fluid cold-setting silastomer was then poured into the space and allowed to cure. When hard the rubbery impression was slit and peeled away from channel and rim. Cross-sections were then made by cutting thin slices from the impression. These were laid on a glass plate in the photographic enlarger and the image projected on to bromide paper. From the silhouette thus obtained



13. Scale drawing of cross-section of the rim of the bowl.

the dimensions could be scaled off, once the outside dimensions of the actual metal rim had been measured at the position from which the impression had been taken. The measurement of small dimensions, such as the 0.3 mm (twelve-thousandths of an inch) diameter of the end of the brass pin, was made by means of an eyepiece micrometer (a measuring graticule set in the focal plane of the objective of a low-power microscope).

**The Neck-Assembly**

Let us next return to our engineering drawing, fig. 9, and examine the neck. It can be seen to consist of three components, namely, the upper ring-mounting, lying immediately beneath the bowl; the cylindrical collar; and the lower ring-mounting sitting neatly on the foot-cone. The lower ring-mounting does not actually touch the foot-cone anywhere except along its lower border. The method of determining the dimensions of these components was quite straightforward, making use of a scale and calipers.

Fig.14 shows the details of the neck assembly. The three components have been decorated externally by the kerbschnitt technique. They fit very closely together: when properly assembled the three could be lifted together as one by grasping the upper ring-mounting alone. The black spot shown at the center of the periphery of the lower ring-mounting represents damage to the gilding. At this point the bronze has lost its protective gilding and has begun to corrode. Damage of this kind was turned to account, as will appear later.

Certain questions about this neck assembly required answers: how were the components made? How was the pattern formed?



14. The three components of the neck assembly fitted together.



15. The inner surface of the upper ring mounting.

Examination of their inner surfaces revealed that the components had been cast. Fig.15 shows the inner surface of the upper ring-mounting. At about three o'clock a casting flaw is visible, together with many blowholes. At about one o'clock there is also a tiny plug of copper metal that the bronze



founder had inserted in order to fill a particularly deep blow-hole. In fact this plug was found to pass through the entire thickness of the metal to the other side, where it was obscured from casual inspection by the overall gilding. Clearly, this one of the three components has been cast and the other two show similar features. Furthermore, the inner surface has been either turned or stoned down: the circular markings from this process are clearly visible around the rim.

These observations of the inner surfaces do not answer the question of how the outer decorative pattern was made. It could have been cast or it could have been punched or chiselled. This problem was solved by examining the structure of the metal of one of the components. Preparation of a special taper-section by metallographic methods was found to be unnecessary because an area from which gilding had been lost some time ago was discovered on the basket-weave on the collar. From this spot the corrosion products that had formed during the centuries were carefully thinned by mechanical means and the final traces obscuring the metal were removed by a gentle chemical etching reagent. The area of metal exposed is shown in fig.16. In the elongated patch on the left-hand side there is a ladder-like pattern that represents the dendritic structure of cast metal. This confirmed that the metal had been cast. This conclusion had already been reached from other considerations but, in addition, because the straight lines of the dendrites pass quite up to the surface without deformation, it is difficult to believe that the metal could have been



16. A corroded area of the basket weave on the collar, cleaned and etched to show structure of the metal.

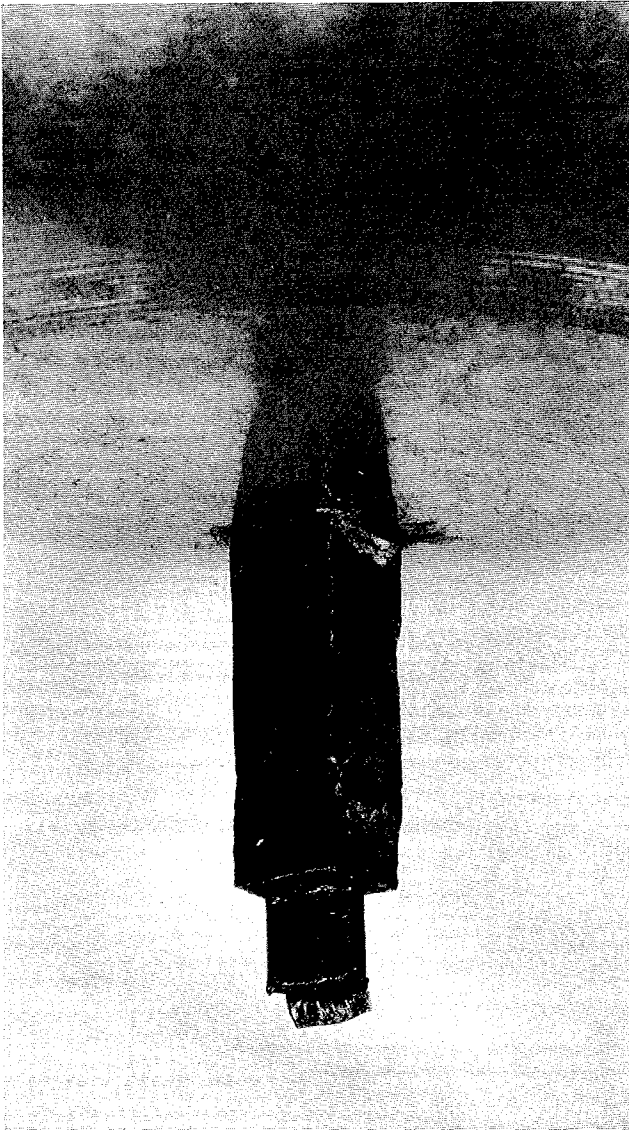
either punched or chiselled. A chisel could scarcely have failed to deform the dendrites near the surface. Quite clearly here was a pattern that had been cast into the surface and, at least at the spot examined, had suffered a minimum of subsequent correction.

#### The Foot-Cone And Bolt

Next let us consider in the drawing, fig. 9, the silver foot-cone that supported the neck. In order to make the drawing the shape was determined by the shadow-casting method. Notice particularly the size of the aperture in the flat top of the foot-cone. In the plane of the drawing the foot-cone does not touch the bolt anywhere, but in a plane a few millimeters behind this the aperture fits the bolt closely. Let us now consider some of the problems posed by this bolt. It has a rounded head that lies inside the bowl and has been gilded. The bolt protrudes downward from beneath the bowl and holds all of the various components together. For the moment let us ignore the modern pair of wedges shown in the drawing passing through the bolt. Dunraven stated that the chalice was fastened together by an *iron* bolt "which secured all together." The bolt actually found was made of copper, not iron (fig.17). It was square in section with a hollow tubular extension at one end and a rectangular slot passing through the copper that could serve as a key-way. Next let us examine the aperture in the flat top of the foot-cone. Seen from above, fig.18, the aperture was square, fitting closely against the bolt, with additional slots cut on two opposite sides.

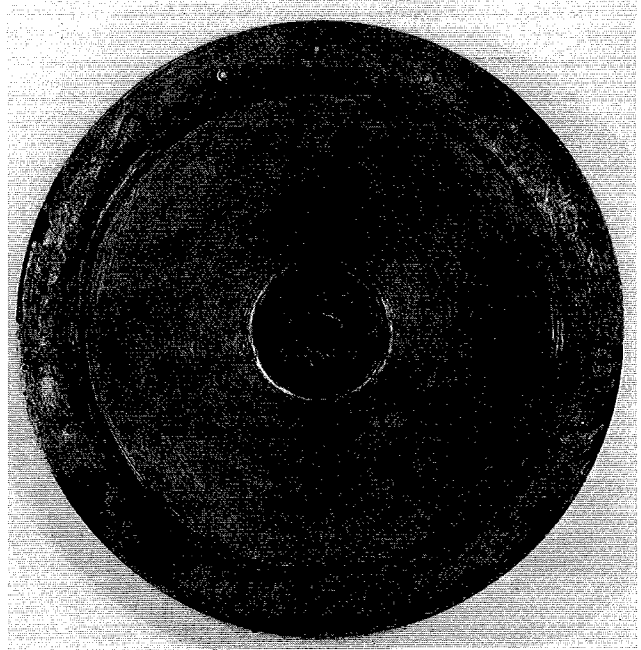
Now, although the copper bolt observed was not the iron bolt noted by Dunraven, an iron key was found that actually passed through the slot in the copper bolt and lay in the two additional slots found cut across the central square. The iron key lay there quite loose and served no useful purpose whatever. By close reasoning from a number of observations it was deduced that this was not the original key. On the bases of this theory, most important for the reassembly, a search was made for evidence that it was correct. Confirmation hinged on the fact that if the original key had been made of iron it should have rusted extensively because it would have lain underground in contact with a nobler metal, silver, for over 1000 years. The product of corrosion would have been iron oxide, of greater volume than the iron. This should have resulted in expansion of the key against the top of the foot-cone. Some evidence of such an expansion might have been preserved as a deformation of the silver at areas of contact with the key. Evidence of deformation was therefore sought on the flat top of the foot-cone. It was in fact found. We were next faced with the problem of recording this deformation in a form that would carry greater weight for posterity than mere words.

The resulting photograph is shown in fig.19, containing a grid of lines superimposed on the top of the foot-cone. The steps in

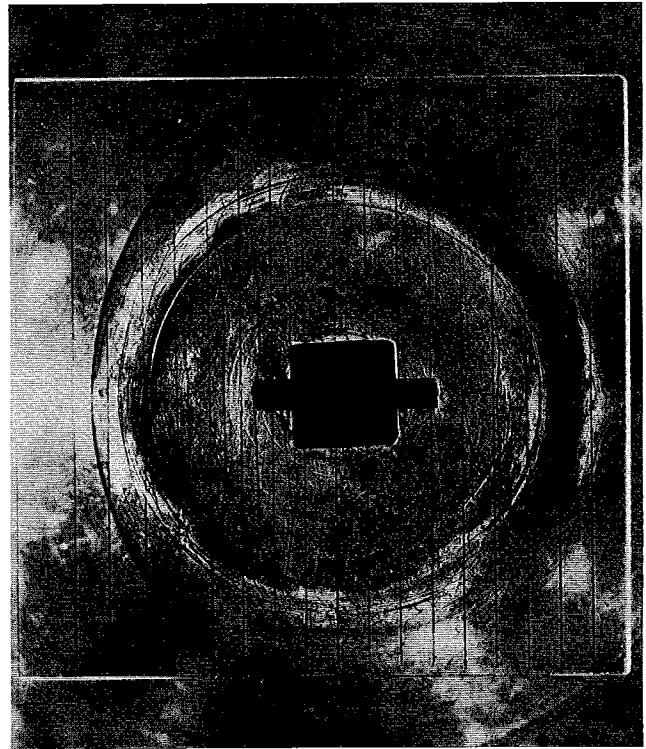


17. The copper bolt found in the neck. One of the two end tags has broken off.

producing it were as follows. Parallel lines were drawn as a grid on a glass plate (a 2 inch by 2 inch transparency cover-glass). The plate was laid on the top of the foot-cone with its lines across the axis of the deformation that had been observed. A point source of light was then set up on the left-hand side of the arrangement with the result that it cast shadows on the cone. In the photograph, on the left-hand side of the silver cone a black arc represents the shadow cast by the thick edge of the glass plate. This arc is the end member of a family of line shadows cast by the ruled grid. On the flat top can be seen



18. View of the foot-cone, decoration removed, from above.



19. The deformed flat top of the foot-cone, illustrated by a family of curved shadows cast from a grid of straight lines.

both the straight lines of the grid and, between these, their shadows. The curves of these shadows indicate quite clearly that the slightly concave top has been deformed along the axis of the two side slots in which the iron key was discovered lying loose. It was also observed, in confirmation of this finding, that the whole foot-cone had been distorted slightly along this same axis. It had been "squeezed in." In fact, at the time when the chalice was reassembled temporarily for exhibition at the British Museum, at a time when the significance of this distortion was unrecognized, a pair of tiny pads had to be inserted between foot-cone and lower ring mounting in order to compensate for the distortion and to obtain a rigid structure. Those pads may be seen in fig. 25.

It was next argued that Johnson would have had to break away the original corroded iron key in order to dismantle the chalice and that when during reassembly he came to insert a replacement, the key actually found there, he would have been unable to do so because of the unsuitable simple shape he had given to it. Then, in the last-minute flurry to get it assembled in time for collection he had to cut out the side slots in order to admit the key. This was another theory for which confirmation had to be sought. It was found!

Fig. 20 shows the inside of the foot-cone. On the axis of the side slots, at the right-hand side, is a rather ragged line. It is believed that this was made at the time when Johnson was struggling to insert his key. The key slid down the side of the foot-cone, marking it because of a rough corner at its rear edge, and was then wiggled side to side in an endeavor to force it further. The impossibility of inserting such a key was checked by making a key and attempting to insert it. The fact that this experiment was made may suggest that the test caused the mark. Actually, photographs made of the inside of the foot-cone before the time of the theory revealed the mark already present, although it had not been noticed at that time. This alone was justification of the policy of taking careful photographs at all stages of the work. To summarize: there was now evidence to support the theory that Johnson cut away the rusted original key and replaced it with a new key and that he cut out the side slots in the top of the foot-cone in order to insert this new key.

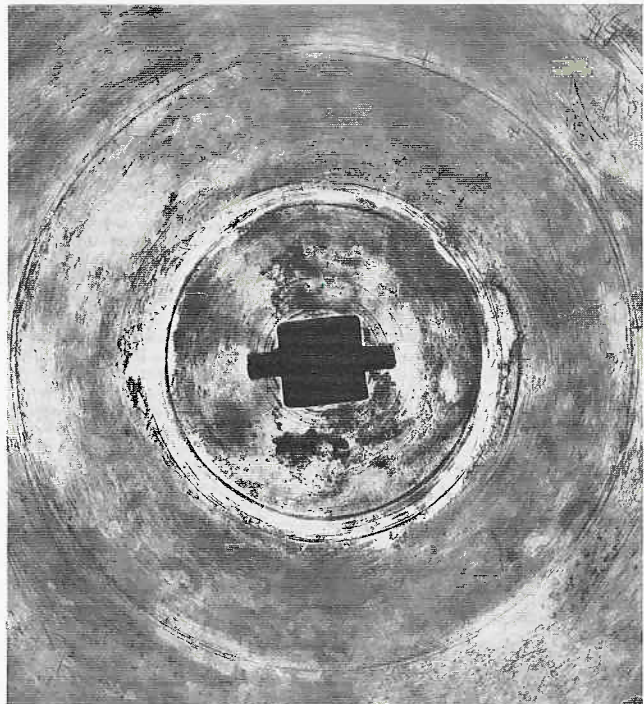
Additional evidence was found that the side slots are actually different from the central aperture. Fig. 21 shows the central square aperture outlined in white lines because there is a burr on the edges. The two side slots are not outlined in white because they were made with a different tool at a different time, in accordance with the theory.

#### The Under-Foot Mounting

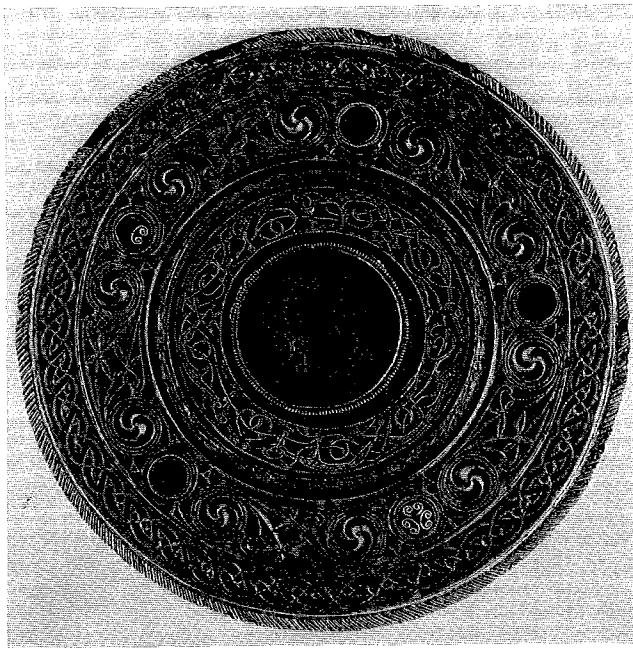
Let us turn again to the drawing, fig. 9, examining now the under-foot mounting in which the central crystal was set. Al-



20. The interior of the foot-cone. The central area, normally hidden by the under-foot disc, remains marked by the silversmith's hammer and bears the date of Johnson's examination.



21. The exterior of the foot-cone in the uncleaned condition.

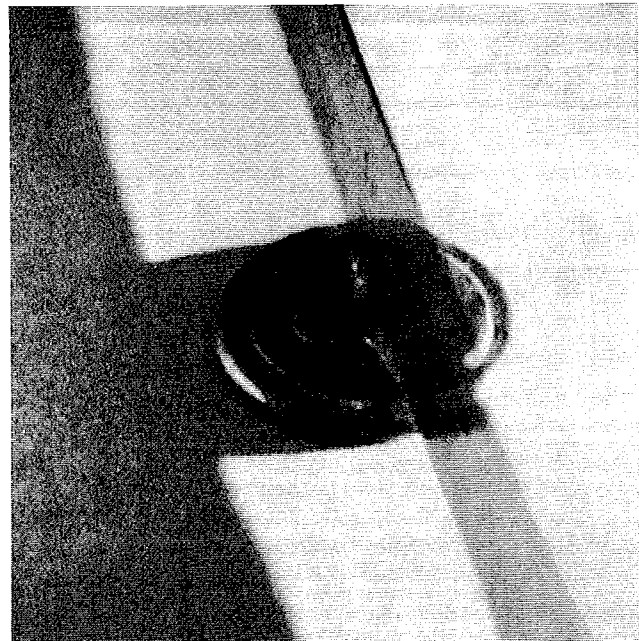


22. Detail of the under-foot disc without its central crystal.

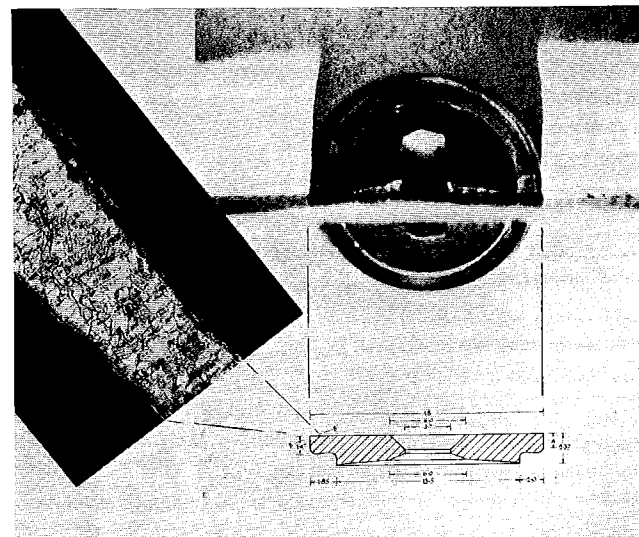
though this mounting was decorative it served to hide the central fixing-device and also served a structural purpose: it centralized the bolt on the axis of the foot-cone and made the whole structure rigid. We shall return to this point shortly. A detailed photograph of the under-foot mounting appears in fig. 22. The mounting is made of gilt bronze. In this view the crystal and reflective foil have been removed to expose the slotted so-called catch-disc in the center. The mount for the crystal itself is held against the back plate by means of this disc. Looking outward along any radius a number of features can be observed. First there is a gilt silver channel which contained fragments of malachite and amber. Outside the channel lies a circle of gold filigree interlace, zoomorphic in style. Outside this again lies another channel, silver-gilt, now empty. Beyond this is a double feature: a gilt bronze circle that contains five studs, and an outer circle of gilt bronze interlace. This outer circle is particularly important because it is evidence for a later argument.

**The Catch-Disc**

For the moment let us consider the problem presented by the central catch-disc: the one shown slotted that lay behind the crystal. This, when removed from behind the crystal, had exactly the appearance of having come from a modern clock: its back had been lathe-turned. The problem was to decide whether this disc was indeed a modern introduction or whether it was the original ancient catch-disc. In order to solve the prob-



23. The shadow cast by a steel straight-edge on the turned back surface of the catch-disc.



24. Scale drawing of cross-section of the catch-disc, derived from shadow casting, indicating the location of a metallographic section.

lem two methods of examination were used. The first was a superficial examination directed to discovering precisely the shape of the turned back of the disc. It was carried out as shown in fig. 23 by laying a straight edge along the back and then casting a shadow of this straight-edge upon the turned surface at a shallow angle. The side-view photograph shows

clearly that the shadow of the straight-edge is curved. From a vertical photograph a diagram, fig. 24 was constructed, again a detailed scaled drawing. From this it can be seen that the original back has been turned off at an angle, leaving an edge that marks the limit of travel of the tool, and that the edge of the disc has also been rounded off.

The second method of examination involved making a minute metallographic cross-section along the line BB' marked on the drawing. The cross-section reveals two thin broken white lines on the two surfaces of the disc. The lines represent gilding about 0.002 mm (less than  $\frac{1}{10,000}$  inch) thick. It is believed that this gilding was applied at the time of Johnson's restoration because similarly thin gilding has been observed elsewhere on the chalice. This thin gilding was absent from the lathe-turned surfaces of the disc. From this it may be deduced that the lathe-turning followed gilding. Furthermore, the plane of turning has not been squared off nor has the tool been traversed fully before being withdrawn. This suggests that the work was being carried out in a great hurry — the ridge could have been removed in a matter of seconds by a few strokes of a file but it was not, and it may well have been carried out at the last moment of reassembly in order to make the crystal fit.

The metallographic section, viewed at a magnification of 50 diameters, contains numerous nonmetallic inclusions. This suggests that the metal is ancient. It therefore appears probable that the disc was the original catch-disc, regilded by Johnson (although it is not visible in the reassembled chalice) and altered by him at the last moment in order to allow the crystal to be fitted securely into its mount.

#### Design of the Assembly

Now let us turn our attention to fig. 9 again, in order to consider some evidence that tends to suggest that the original intention of the designer of the chalice was frustrated during actual construction. Considering the under-foot mounting as it lies within the foot-cone, it will be noticed that by raising it through a distance of about 3 mm it will lie neatly against the end of the solid bolt. This position would provide a much more rigid support than does the actual position in which it was found — part way up the hollow, thin tubular extension to the bolt. Furthermore, by raising this disc-shaped mounting by 3 mm — and to do so would involve making it smaller because it will then be seated higher up the walls of the cone — its edge would seat on the inside of the cone exactly level with the lower edge of the lower ring-mounting, which has already been noticed as the only portion of this mounting to make firm contact with the foot-cone. The disc can be reduced to the diameter needed for this arrangement, exactly, merely by taking away completely the outer element of ornament — the narrow outer interlace pattern that was mentioned above. Now, while

imagining the under-foot mounting in this new raised position, let us attempt to see the structure with the eye of an engineer. The foot-cone is made of comparatively thin sheet silver. In this new arrangement it would be clamped between a solid neck-mounting of cast bronze and a solid under-foot disc of cast bronze. The disc would be mounted very securely on the end of the stout solid copper bolt and the bolt would be located centrally in the strongest part of the foot-cone in a close-fitting square aperture. This arrangement could provide a very strong structure through which the bolt passes axially. There should have been no need for the mass of lead that was cast into the neck because a workman found himself unable to maintain the bolt in an axial position in the assembly. This and other evidence indicates that the designer of the chalice was much in advance of the means of construction that were available.

When the chalice was finally reassembled at the British Museum, the lead which, corroding, had endangered the security of the assembly was taken out of the neck and replaced by a spacer made of polymethyl methacrylate. This is obviously a 20th century fitting and could not be mistaken at some date in the future for work of the 8th or 9th century. An iron key was not replaced through the bolt because experiment had shown that one long enough to be secure beneath the slotted foot-cone could not in actuality be inserted. Instead a pair of brass wedges were inserted. These together ensured that the bolt remained perpendicular to the flat top of the foot-cone. Instead of allowing the whole weight of the under-foot mounting to be suspended on the two small tags of metal an 8 B.A. brass screw was inserted and a substantial brass disc was added beneath the crystal in order to support the load. The one completely detached tag was refitted with epoxy resin. Fig. 25 illustrates how the chalice was assembled temporarily in 1962.

The exploded view shows the crystal dome at the bottom. The silver foil is not shown here. Above this is the 8 B.A. screw centralized in the brass washer beneath the mount for the crystal. All of these were inserted into the under-foot mounting that was placed inside the foot-cone over the tubular extension to the bolt. Through the bolt passed the two new brass wedges that pulled the foot-cone tightly upward and compressed the neck-assembly rigidly against the underside of the bowl. At the neck, inside the lower ring-mounting can be distinguished a pair of white pads that at that time were inserted to compensate for the distortion of the foot-cone. In the final reassembly these were omitted because another method of insuring rigidity was found. The polymethyl methacrylate spacer is visible within the neck-collar.

#### The Decorative Plates beneath the Foot

The various decorative plates on the underside of the flange of



25. An exploded view to show how the components of the chalice were reassembled temporarily in 1962.

the foot-cone include one of silver, one of copper, and another made of woven wire (fig. 25). A combination of such plates made up the whole decorative scheme. Next, consider some interesting features of these panels. Fig. 26 shows the silver plate in detail. It was made of very thin silver, embossed into a pattern, supposedly, by the "pressblech" process, in which the silver was beaten down against a shaped die. Evidence was

found that the four plates of silver had indeed been made in this manner. Of the four plates, all have patterns that are identical in shape. They were shown to be identical by a number of methods. First of all they were compared visually side by side. Next, photographs were made of all of them under identical conditions of lighting and distance. The negative from one of them was laid in turn on contact prints made from the others. In each case the print was cancelled out — it became uniformly grey. This procedure yielded evidence that the negative of one was identical with positives of the other three. Finally, in order to confirm these findings an instrument called a synchriscope was applied. This instrument is used by ballistic experts for comparing the marks on pairs of expended bullets. Again, it was found that all four silver "pressblech" plates were identical, all except the corner of one plate, on which a second misplaced impression of the pattern appeared, perhaps because the workman had mis-struck on the first occasion.

Next, in fig. 27, we see a small part of one of the copper plates, only 9 mm wide, that is patterned with swastikas. The pattern appears to have been formed by tracing with a punch. Quite clearly it has not been engraved. The line is shown partly filled with green material. This may consist of corrosion products or it may possibly be the remains of an original inlay. The evidence was uncertain, although the material has been examined by X-ray diffraction analysis.

Next let us consider the panels beneath the foot made of woven wire (fig. 28). The upper panel has a square pattern and the lower one has a herringbone pattern. Fig. 29 shows these same two panels turned over. It will be seen that the upper panel now has the herringbone pattern and the lower panel has a similar but rather rounded pattern. Fig. 28 represents the upper woven-wire panel as received in the chalice (square pattern). Fig. 29 shows the lower panel in the as-received aspect (rounded herringbone). In the final reassembly the sides to be exposed were selected so that both of them would exhibit the herringbone pattern. These photographs were made while the panels rested on a illuminated sheet of translucent glass in order to remove distracting shadows from between the finely spaced wires. As a result the photograph indicates clearly that two different kinds of wire are present. One was made of silver and the other of bronze.

Fig. 30 represents the inside of the lower foot-girdle after examination. At the stage shown it had been reassembled and the various components had been fixed permanently in position ready for replacement on the foot-cone. After replacement was complete, from stylistic arguments Etienne Rhyne raised certain questions concerning the arrangement of these panels. By this time it would have been exceedingly difficult to open up the girdle for reexamination. Nevertheless, it was possible to look at this photograph, examine it under the microscope



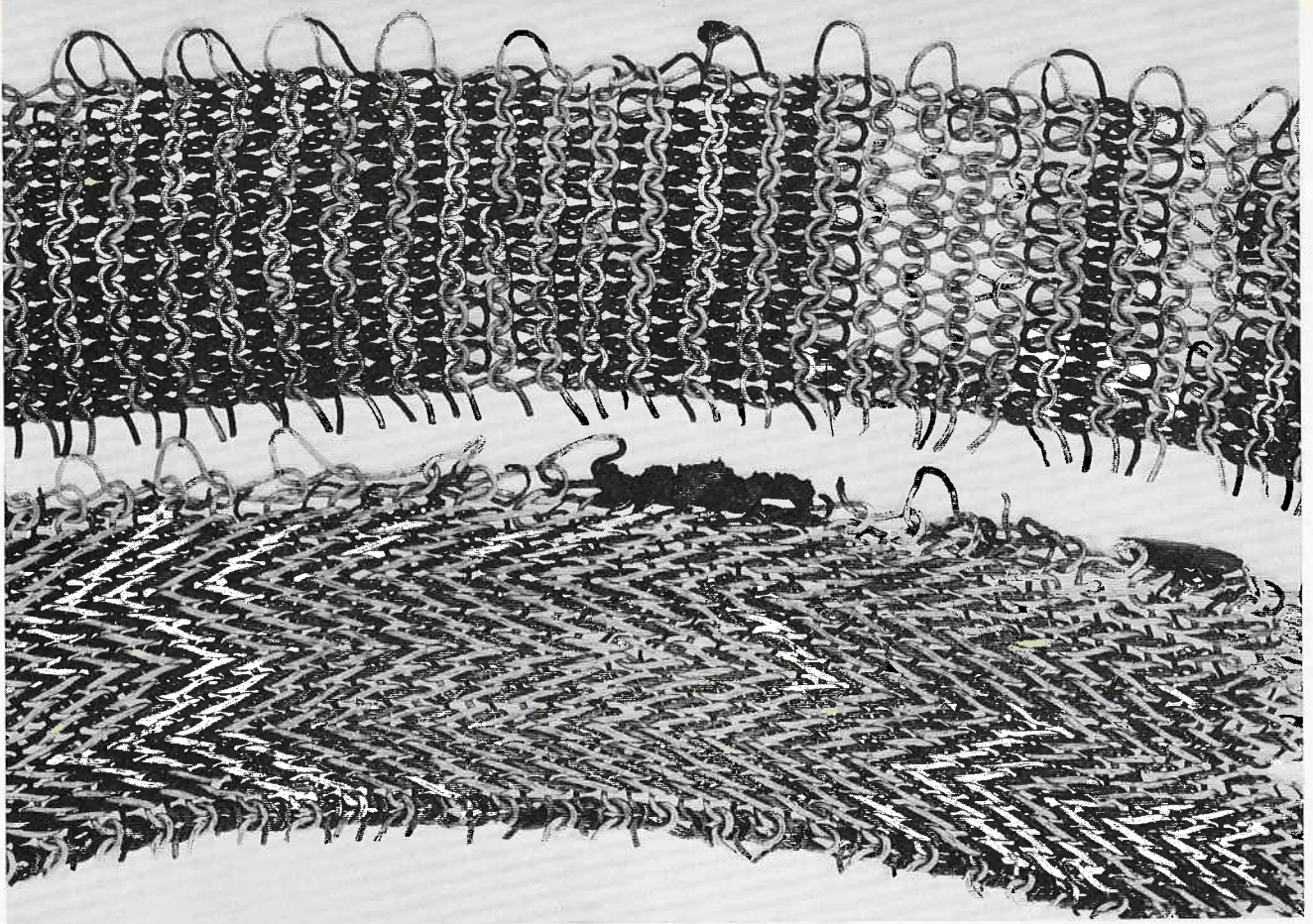
26. One of the silver plates decorating the underside of the foot-cone.



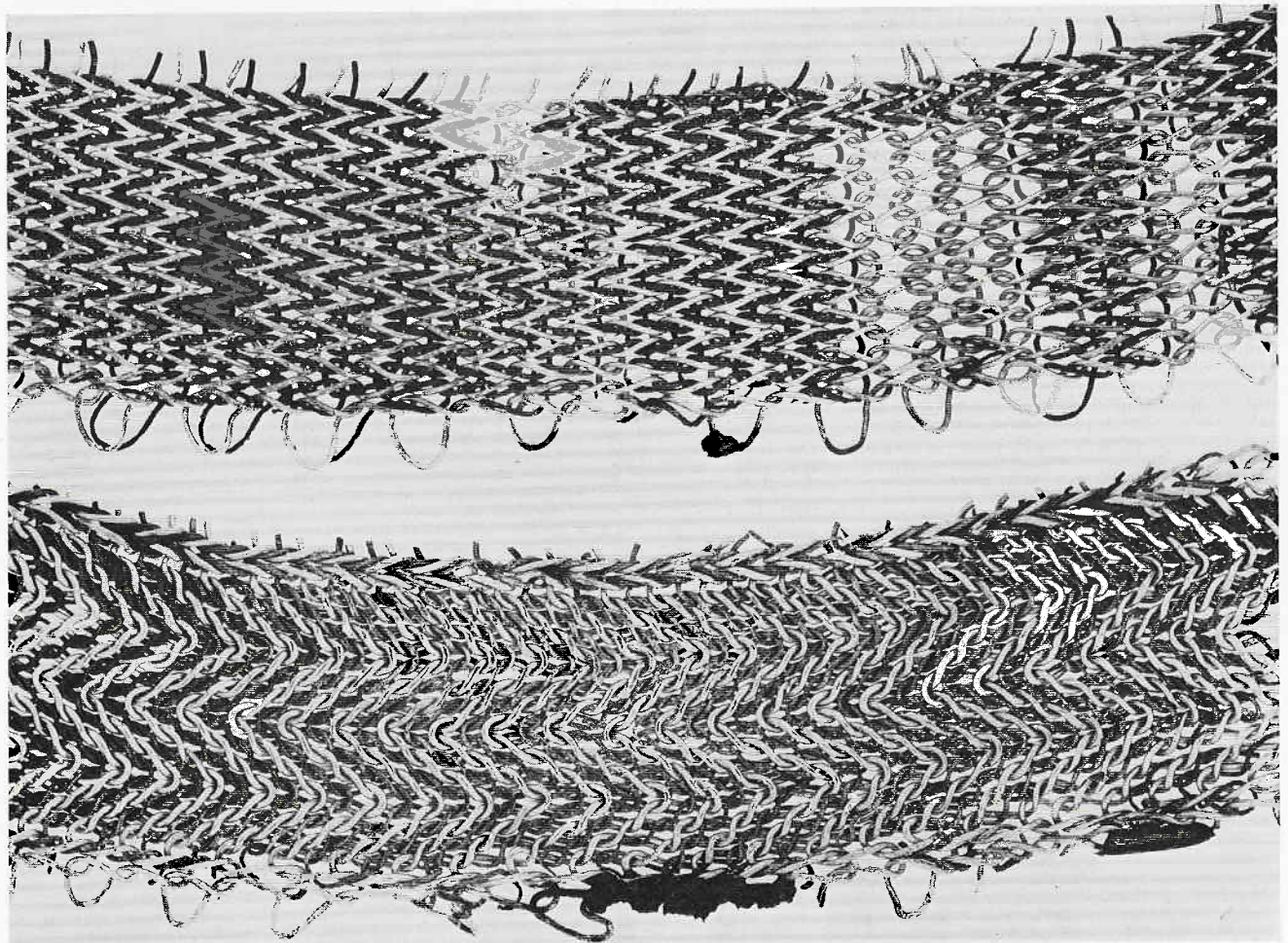
27. A part of one of the copper plates decorating the underside of the foot-cone.



30. The inside of the lower foot-girdle after the panels were reassembled.



28. The two woven-wire panels decorating the underside of the foot-cone, arranged as received.



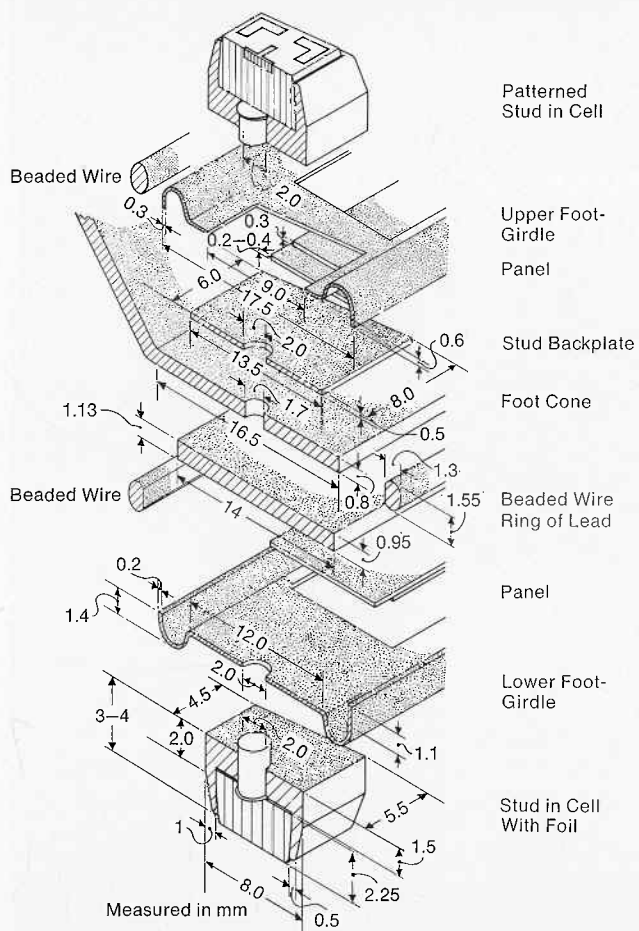
29. The two woven-wire panels shown in fig. 28, turned over to show their alternative patterns.



and to find at the ends of certain panels minute identification scratches, hitherto unsuspected, that ran off the ends of the panels onto the adjacent silver of the foot-girdle. In this way it could be shown quite conclusively that these panels had been in these particular positions at the time when someone else, perhaps Johnson, marked and dismantled it. This demonstration was further justification for the policy of making detailed photographic records of parts of the structure that would be hidden after reassembly.

**Assembly of Decorative Elements around the Foot**

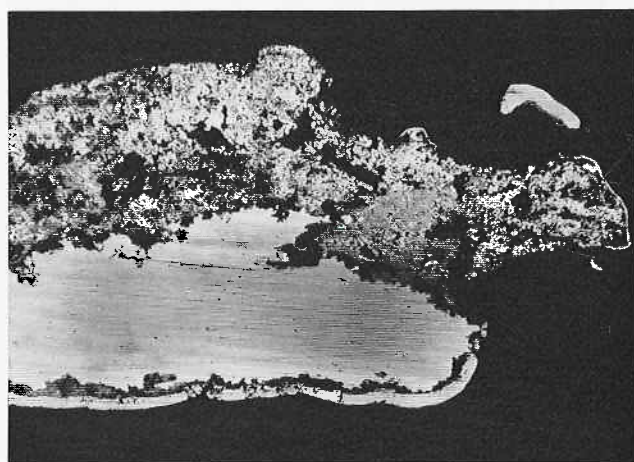
Fig. 31 shows the assembly of the foot-girdles, of which the lower is shown in fig. 30. Above the lower girdle is shown a panel about to drop into place. A tiny flange had been formed on its two ends so that it could not drop quite through. Above lies a ring of lead and then the flange of the foot-cone. Fig. 32 shows the foot-cone itself viewed from above. The upper girdle



31. How the various components were assembled above and below the flange of the foot-cone.



32. The foot-cone, complete with upper foot-girdle, viewed from above.



33. A cross-section of a fragment of one of the gilt openwork bronze panels in the upper foot girdle, unetched. The length of the part of the fragment shown was about 0.9 mm.

lies around the flange. It is pierced by apertures for eight square studs and for eight intervening panels, of which four remain. These panels were made of cast bronze with openwork patterns that were gilded. They were backed with plates of mica, presumably with the object of making the panels gleam but in fact to little practical effect. The holes that are visible here through the apertures that lack panels were of



34. View of the interior of the upper foot-girdle after reassembly.

some interest. They were quite large, about 2 mm in diameter. They did not lie on the exact center-line of the panel apertures. In contrast the hole shown at four o'clock, at the center of the square aperture for a stud, is different in size from the others and lies exactly in the center of the square aperture. In fact there were eight of these smaller holes set on a circle of large radius, and there are eight of the 2 mm holes set on a circle of smaller radius. This observation proved valuable later. Let us return now to the open work panels. Had they been shaped by tooling or had they been cast?

Fig. 33 represents a cross-section of a fragment of one of the panels, a fragment found attached only by a thread of metal. The white area of the picture represents unetched polished metal. The upper area of darker material contains mineral corrosion products. These minerals no longer have the usual appearance of such corrosion crusts. The panel appears to have been cleaned by dipping in acid, presumably by Johnson, and to have been altered by this. Other points of interest are, first, the thick white line on the surface that appears at the bottom of the photograph — this is original gilding about 0.02 mm thick (less than  $\frac{1}{1000}$  inch); second, a thin white line on the right hand side. This is newer gilding, perhaps by Johnson, 0.002 mm thick, similar in thickness to the gilding found on the catch-disc beneath the crystal shown in fig. 24.

#### The Plate of Lead in the Foot

Next let us turn back for a moment to fig. 31 and examine the

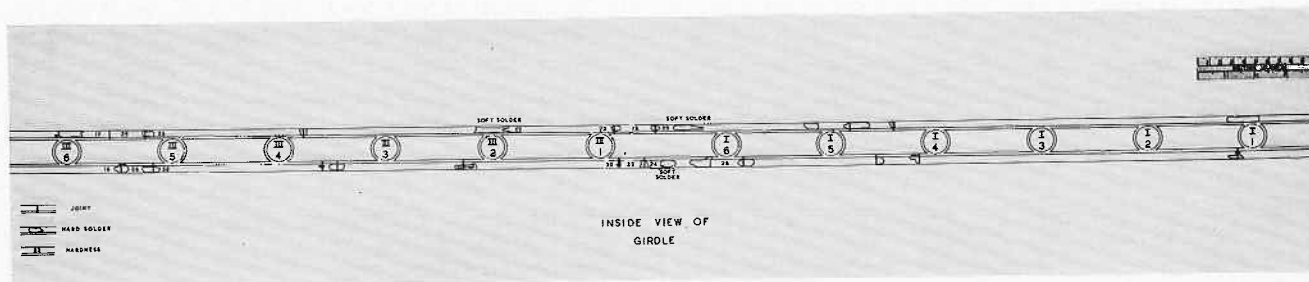
arrangement of the girdles above and below the flange of the foot-cone. This had presented a problem ever since the foot was dismantled. At that time it was discovered that the various components had been tacked together and onto a flat lead ring, which had been incorporated into the foot assembly, by means of lead-tin solder. Now the presence of this lead ring was not an essential feature of the design. It should have been quite unnecessary and probably had not been intended by the original designer. Again his design had been frustrated. He probably intended to rivet the lower studs directly on to the lower foot-girdle through the small holes made for this purpose on the circle of larger radius. The upper studs would have been riveted to the square back plates that appear just beneath them in fig. 31. These plates would have served as flanges to prevent the studs from leaving the apertures in the upper foot-girdle, through which they protruded. This was a general principle of the design. All the panels had flanges of corresponding purpose. He probably intended that the two girdles would be held together above and below the foot-cone flange by soldering along their outer edges. In this way they would secure the studs and panels.

Nevertheless, Dunraven's account refers to "plates of lead" in the foot — not to a single ring of lead such as was found but to multiple plates of lead. It seems likely that the designer's intentions had been frustrated by lack of skill on the part of the worker. He had had to insert lead packing plates into the foot because he had been unable to make his foot-girdles lie flat and sufficiently closely against the flange of the foot-cone to hold the various panels securely in position. When Johnson carried out his restoration he in turn made a whole ring instead of separate plates, and he tacked all his panels on to it by means of lead-tin solder. Nevertheless, it is probable that the chalice gained in stability as a result of the addition of weight to the foot.

In the British Museum reassembly, fig. 34, the foot was arranged more or less as the designer must have intended. The missing rivets were replaced by epoxy resin and the stud back-plates that were lacking were replaced by obviously modern transparent plates of cellulose acetate of similar thickness. In the photograph, at 12 o'clock and 3 o'clock, there can be seen all that remains of the original plates. A modern transparent replacement can be seen clearly at about 1:30 o'clock.

#### Construction of the Decorative Panels beneath the Rim

Next let us pass to the bowl girdle, the circle of panels below the rim. Fig. 35 is a drawing of its full length without either decorative panels or studs. It consists of an open-work silver frame passing around the bowl inside the handles. It is pierced alternately with circles for the studs to protrude through and



35. Drawing of the bowl girdle viewed from inside.



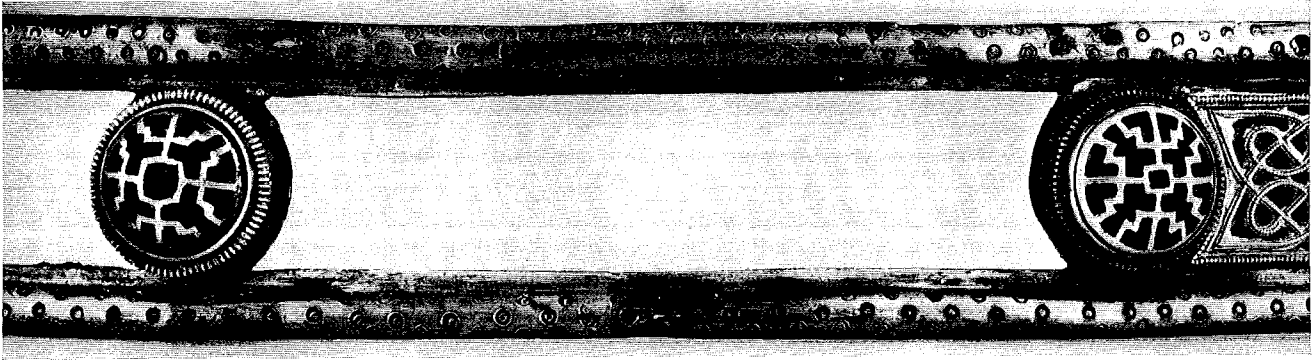
36. The ends of the bowl girdle, which do not meet, secured by means of soft solder beneath handle I.

with long apertures to display the panels. The numbers visible at certain positions represent the measured Brinell hardness of the silver. At the upper right-hand side of stud III 1 a particular short length of girdle is marked "18." This length is flanked on the left by a section of Brinell Hardness 32 and on the right by

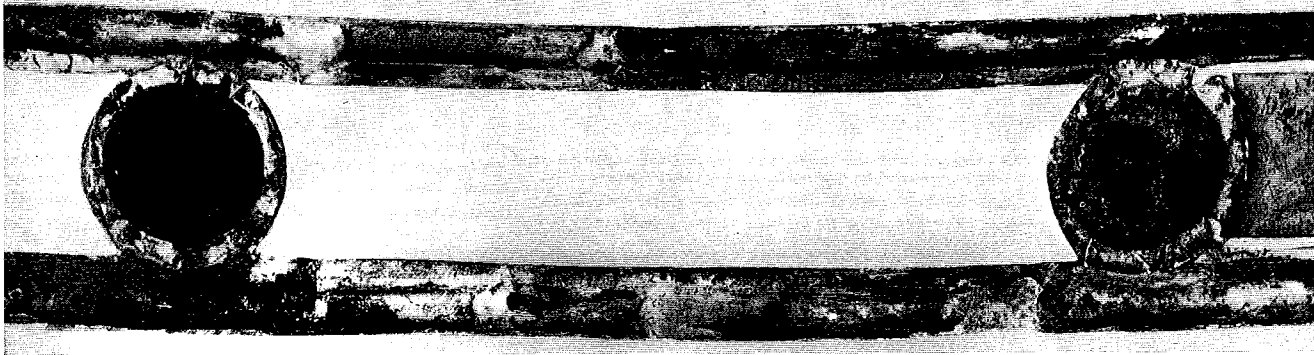
a section of hardness 29. It would appear safe to assume that the short length of silver, so much softer than the silver on both sides, is an insertion. Further evidence to support this belief will be presented later. One of the questions asked about the girdle was whether it was made of solid silver. This was easily and early answered by pointing a camera into the space beneath a handle. Fig. 36 reveals clearly that the girdle was made of sheet silver that had been formed to the required hollow shape.

In fig. 37, in the upper length of a short portion of the girdle, there can be seen to the right of the left-hand stud, a length of inserted silver that is very much whiter than neighboring metal. In fig. 38 the same length of silver and its parallel fellow when seen from the back have clearly been soldered into place with hard solder. Next, consider the panels that were set in the long apertures in the girdle. They consisted of three types; one, shown here (fig. 39) and later described as of "C-pattern," was zoomorphic. The panel was made up in three layers, first the lines of the design ridged up in gold in the pressblech manner with the intervening background cut away; second, lying along the top of the ridges, soldered on, was a treble layer of beaded wires, only the top row being visible in the photograph at first sight but all three being clearly present on close examination; third, backing the open-work pattern was a plate of gilt copper, taken away for the purpose of making this photograph. Of especial interest in fig. 39, in the lower left hand quadrant, are two cones of twisted wires, the left-hand one broken off. Details of their method of construction will be presented later. Around the panel, beyond the bordering beaded wire, was left a narrow flange that would have prevented the panel from falling through the containing aperture in the original design. Although beaded wire was mostly used, certain details of the design have been filled in with twisted wire.

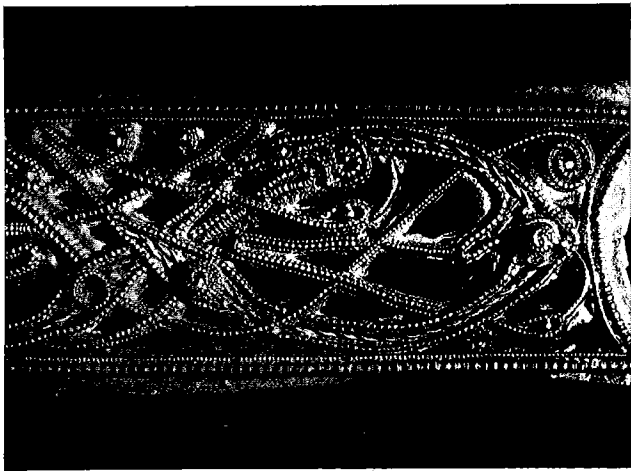
Fig. 40 present a view of part of the back of this same panel that supports the belief in a pressblech manner of construction. Even the sharp edges of the die against which the gold sheet was pressed can be discerned here along the lengths of the hollows. There is also visible a numeral, X, scratched at the top. This and similar numerals caused much perplexity, as



37. Frontal view of a short length of the curved bowl girdle between studs known as III 1 and I 6.



38. Interior view of same length as shown in fig. 37.



39. Detail of portion of zoomorphic panel from bowl girdle, type C.



40. Detail of the back of the panel shown in fig. 39.



41. Close-up view of the pair of cones shown in fig. 39.

will be discussed later. Fig. 41 is a close-up view of the pair of cones made of twisted wire described above. They have clearly been made by coiling up a pair of beaded wires. Fig. 42 shows another pattern of panel, one that has been described as type A — an ornithomorphic design. This is fabricated in a manner identical with that of the other panels. Notice also that the overall visual effect is very similar to that of the preceding panel, type C. This observation became of considerable importance when the question of arranging the panels arose at the time of reassembly. The third design of panel, fig. 43, type B, consisting of knot-work, has a quite different visual effect and stands out quite clearly from a group of all three types.

Fig. 44 illustrates the back of the panel with its gilt back-panel in place. This particular back panel was gilded on its front face only. Clearly it has been held in place by tags, formed from the flange of the panel proper by snipping through and turning over. This is a simple but aesthetically unsatisfactory method of fixing that has been used extensively in making children's toys in recent times. Its use is not at all in keeping with the general concept of the design, and it is unlikely that the original designer intended to use it. He designed the

panels with end flanges to terminate behind the flanges of the two neighboring studs. These would secure it adequately. Notice also that the back of the left-hand stud is closed by a lead plug that is bordered by a row of punch-marks. These would serve to expand the plug into the inside of the cylindrical stud-mount and thus secure the mount tightly within its aperture in the girdle.

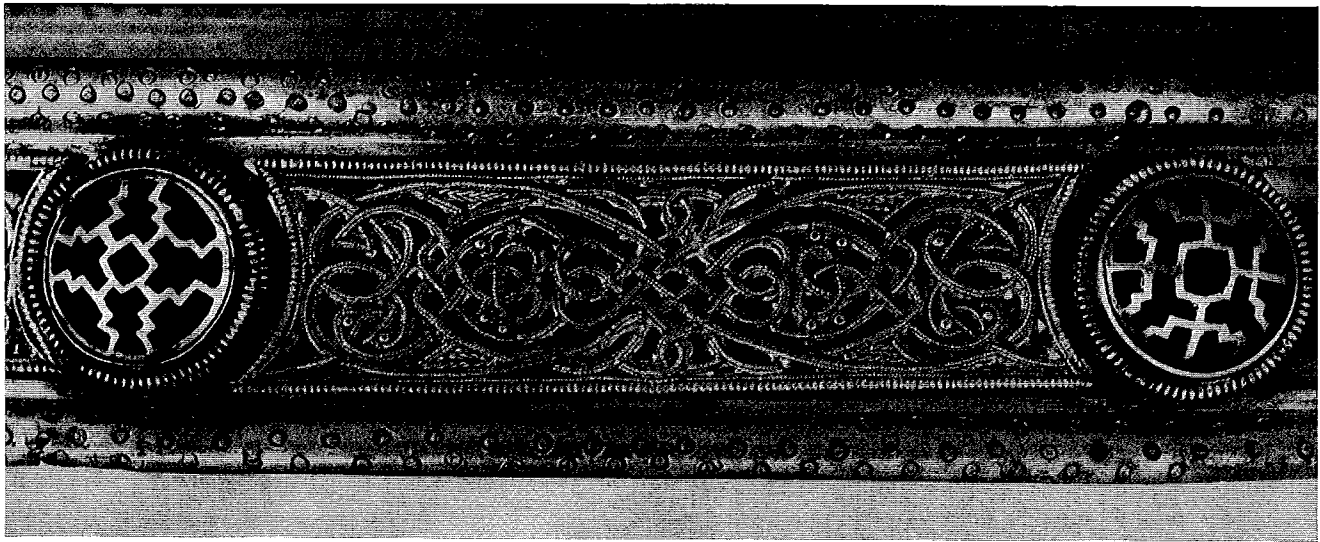
#### The Inscription around the Bowl

Next let us pass on to the inscription that runs around the bowl just beneath the girdle. Fig. 45 shows the one of the four quadrants that contains the names of Bartholomew, Thomas, and Matthew, three of the disciples. The clarity of the inscription as shown is solely the result of good photography. On the uncleaned chalice the inscription was almost invisible. Fig. 46 is a detail selected to illustrate how the inscription was made: freehand, scribed with a point, and the dotted background also impressed by a point applied almost vertically. In addition to inscribed names the bowl is decorated (fig. 47), with a set of four animals inscribed in the same manner. The illustration has been rendered so very clearly by the use of high-contrast photography. Indeed, it is more convenient to study this photograph than the bowl itself because the curved bowl has to be rotated to various angles in the available light in order to build up a mental impression of the whole animal, whereas here the image lies in a single plane.

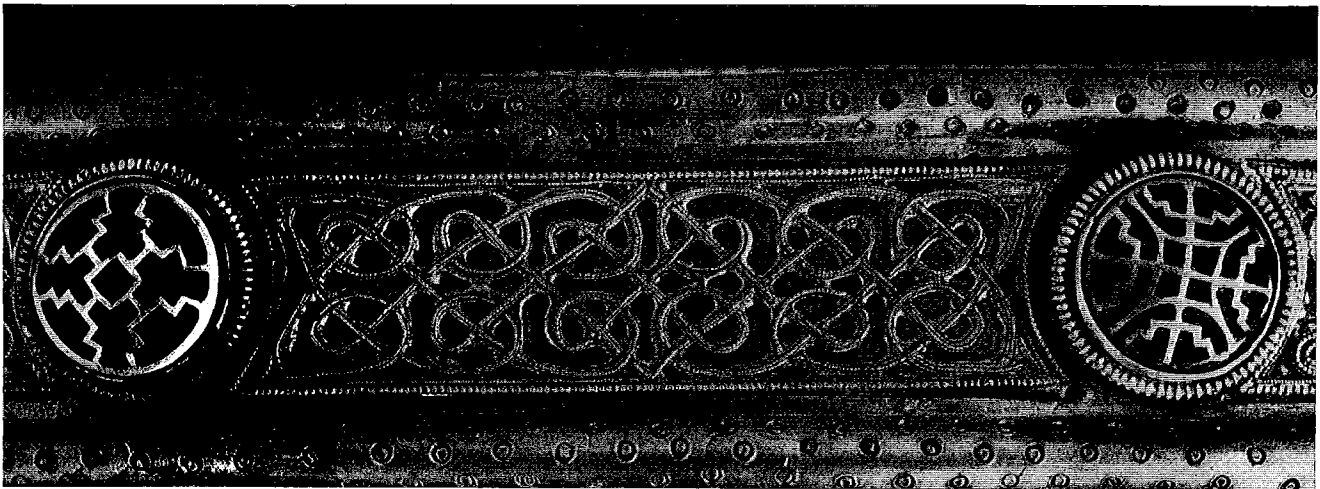
#### The Two Roundels

Next let us examine the two roundels, which are located on the bowl between the handles. Fig. 48 shows that thick silver has been formed into an eight-lobed open frame. Within each aperture is a gold panel decorated with beaded wire and also faced with a decorative surface. These gold panels differ from the smooth gilded back plates in the bowl girdle by having a textured surface. The method of fabrication has not been discovered.

The roundel shown has four studs around its periphery. The two at 3 o'clock and 9 o'clock are made of blue glass and the two at 12 o'clock and 6 o'clock are made of red material that in fact now consists of wax. According to Dunraven this was originally amber, but no trace of amber was found remaining. These four studs hide the four rivets that attach the roundel to the bowl. One of these rivets, illustrated in fig. 49 and typical of all, is very interesting. The hidden interior end is shown. It is hollow and was made by folding copper sheet into a tube and then soldering it to the head of the rivet, a tiny convex disc made of silver in order to blend visually with the interior surface of the silver bowl on which it lay. This suggests that at the period in which the rivet was made labor was cheap and material was expensive, because a great deal of effort is re-

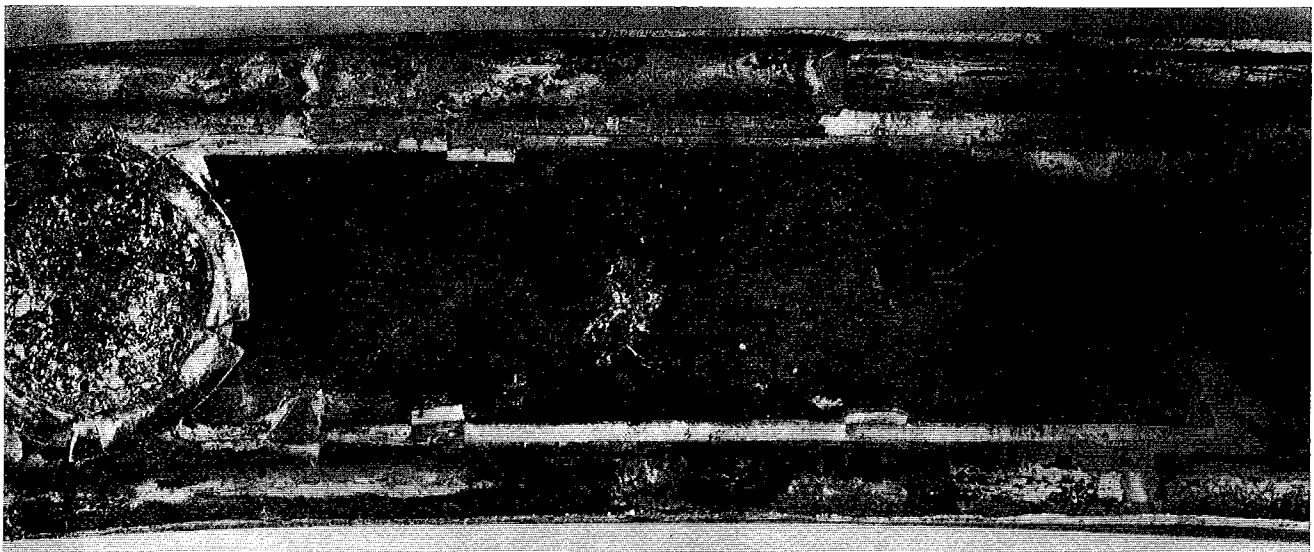


42. One of the ornithomorphic panels, type A, from the bowl girdle.



43. One of the knot-work panels, type B, from the bowl girdle.

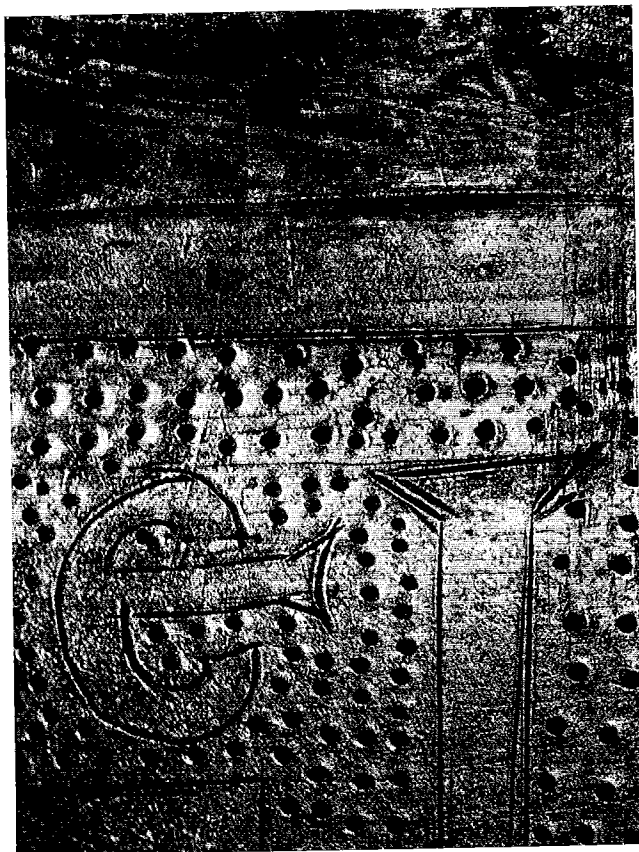
44. The back of the open-work pressblech panel showing the plate that covered the back.



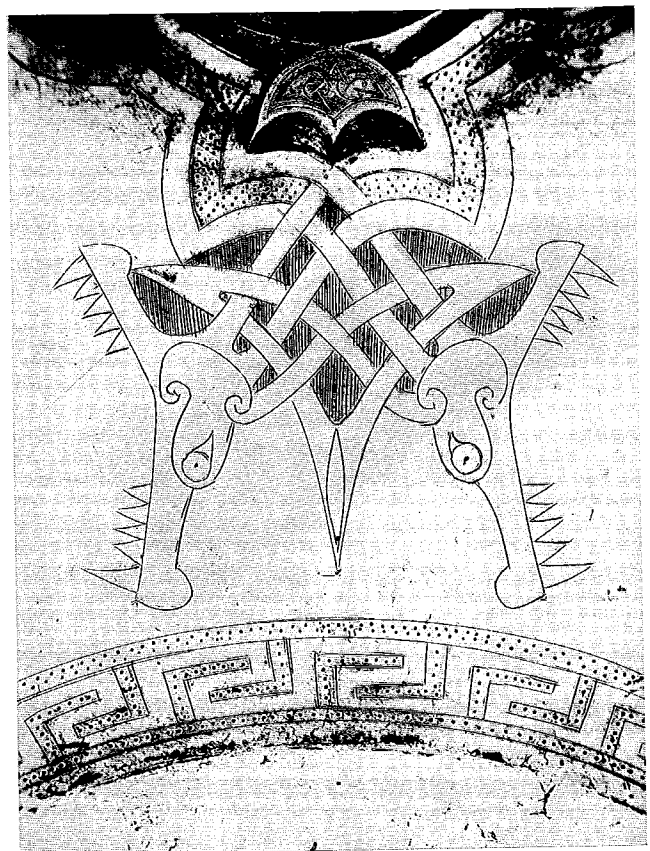


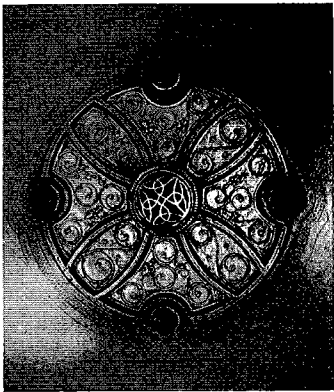
45. One quadrant of the inscription around the bowl.

46. Detail of the inscription around the bowl beneath the bowl girdle, removed at the time of this photograph.



47. One of the four inscribed animals.

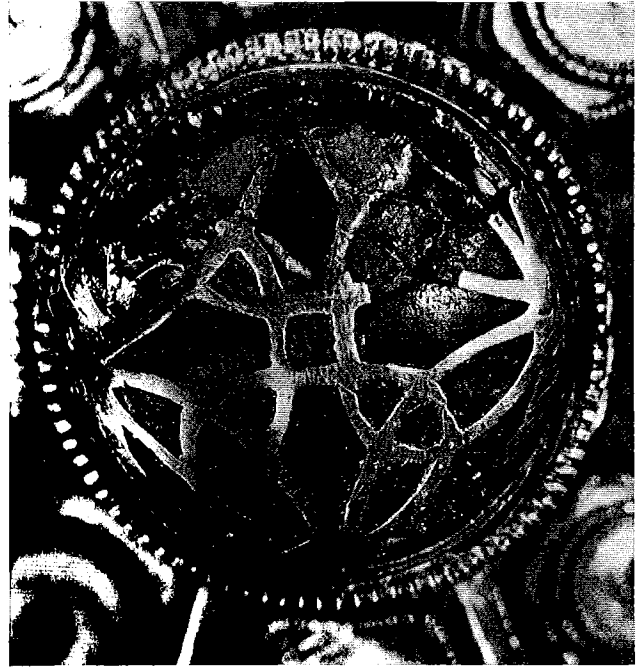




48. One of the two roundels.

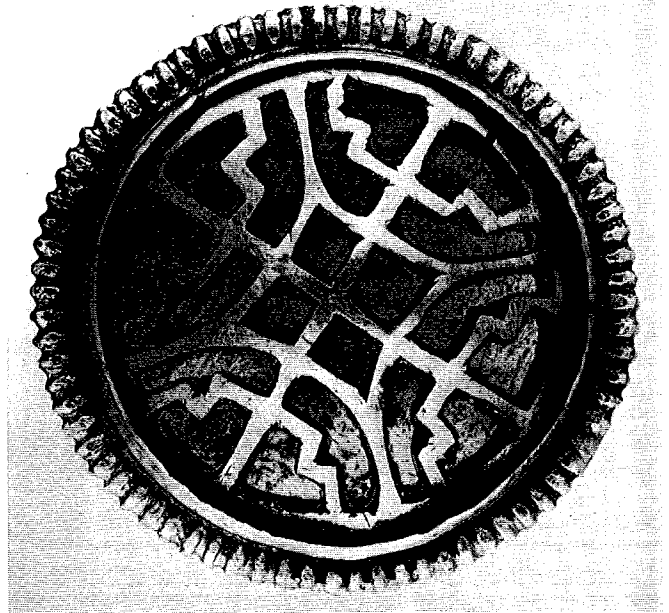


49. The end of one of the rivets hidden behind a stud in the roundel.



50. The central stud in the other one of the two roundels.

51. One of the blue glass studs from the bowl girdle viewed through toluene to eliminate surface scratches.

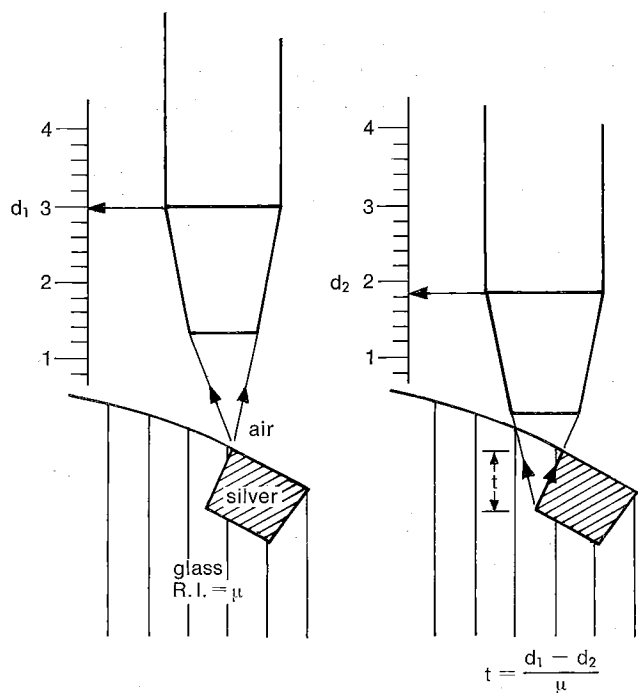




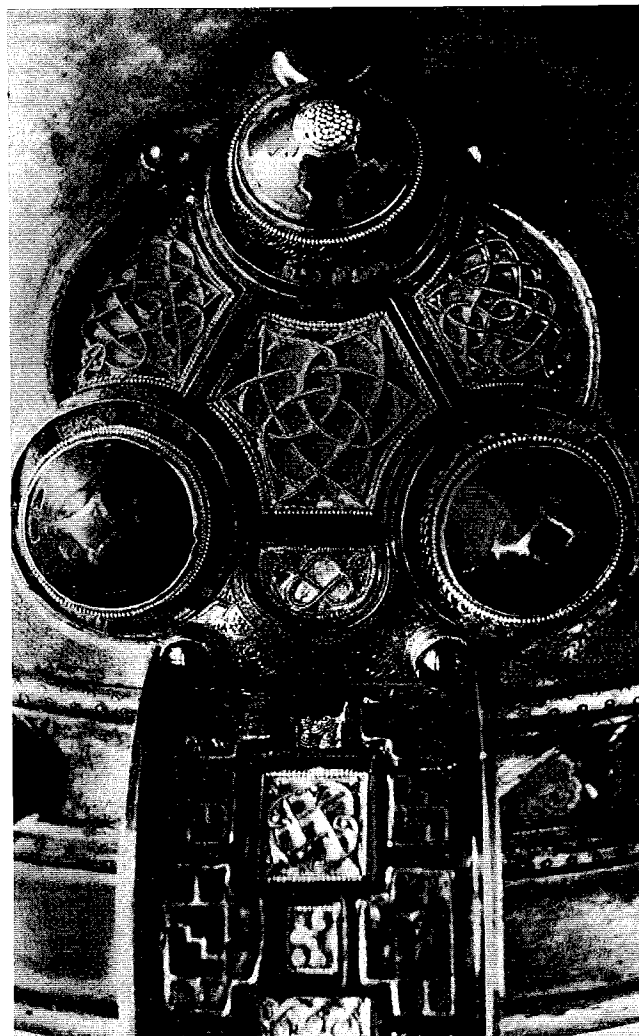
quired to make up a tiny rivet out of fragments of silver and of copper sheet.

Fig. 50 illustrates the central stud in the roundel on the other side of the bowl. A certain amount of damage had been done here, with the result that where the central silver grille had been torn away the glass of the stud had been exposed. The stud contains both red and blue glass. It could be seen that the red glass has been inserted into spaces in the grille and that the blue glass in a plastic condition has been pressed in behind it in order to fill all of the remaining cavities.

The damage here appears to have been done by someone in search of information. A less destructive method of examining a stud would have been to push it slightly forward in its mount so that the edge of the silver grille was exposed. The thickness of the exposed edge could then have been measured by means of a microscope. In fact, on preliminary examination a stud was found that had been pressed forward in this manner. Advantage was taken of this to measure the thickness of the grille, 0.1 mm ( $1/250$  inch). There does exist, however, a general method of examination that is completely nondestructive. The next photograph, fig. 51, illustrates another stud, photographed while it was immersed in toluene so that the glass can be seen clearly without the confusion introduced by surface scratches. Here the actual thickness of the peripheral



52 Method of measuring the approximate thickness of the silver grille without damage to the stud.

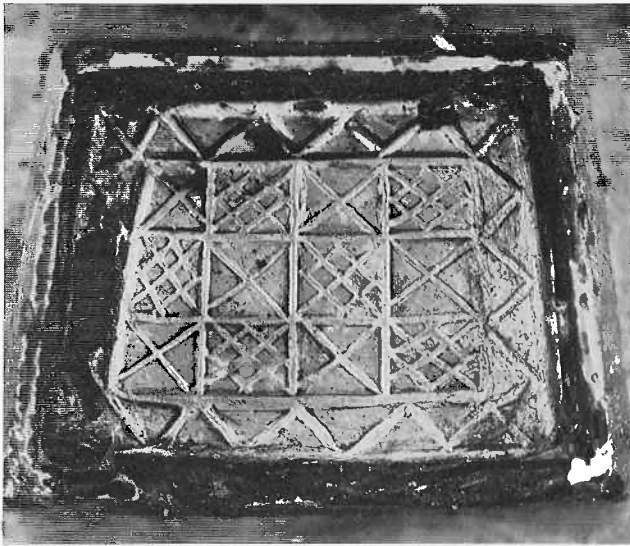


53. One of the two escutcheons beneath a handle, before cleaning.

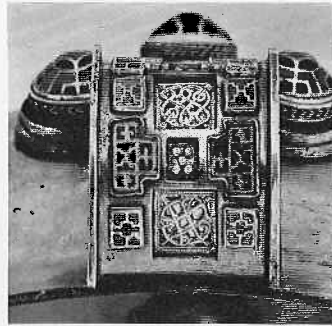
edge of the silver grille can be seen. In these circumstances it was not difficult to focus a suitable microscope first of all on the upper edge of the grille and then on the lower edge (fig. 52). By measuring the travel of the microscope between these two positions the thickness of the silver may be estimated. Details of the method are indicated in the illustration. A suitable factor has to be applied to compensate for the refractive index of the glass, but this need not be known very precisely.

**The Handle Escutcheons**

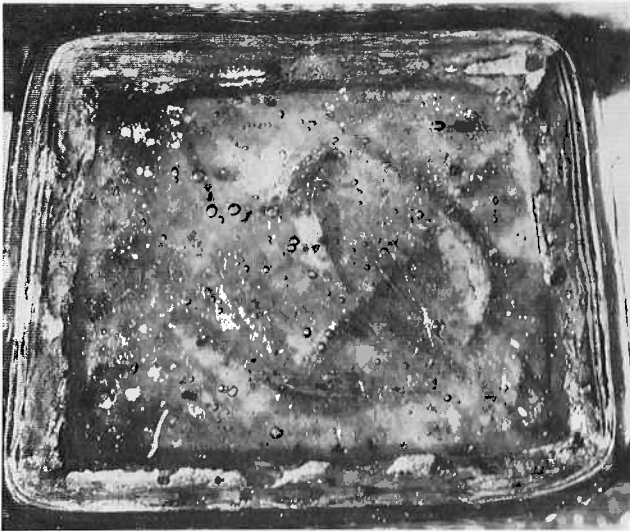
Next let us examine the handle escutcheons which provided some features of interest (fig. 53). The design is very elegant. It incorporates three subconical studs. The lowest stud has a central area decorated with gold granulation. Around its base



54. Patterned silver foil for the underside of a stud in the under-foot girdle.

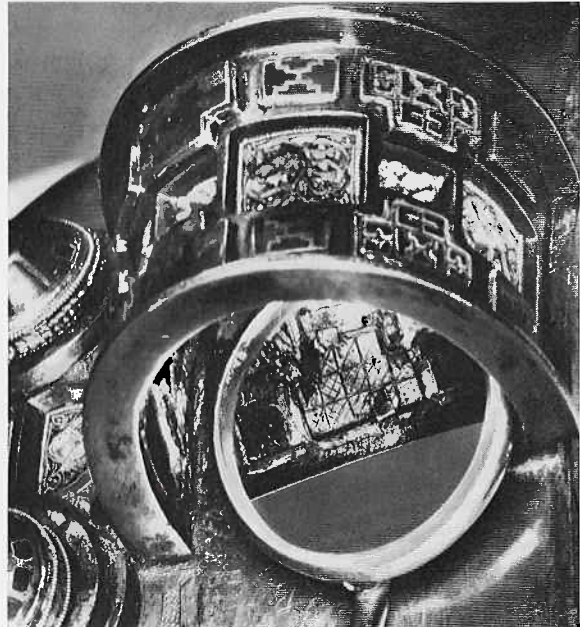


57. Some of the decorative studs in one of the handles.

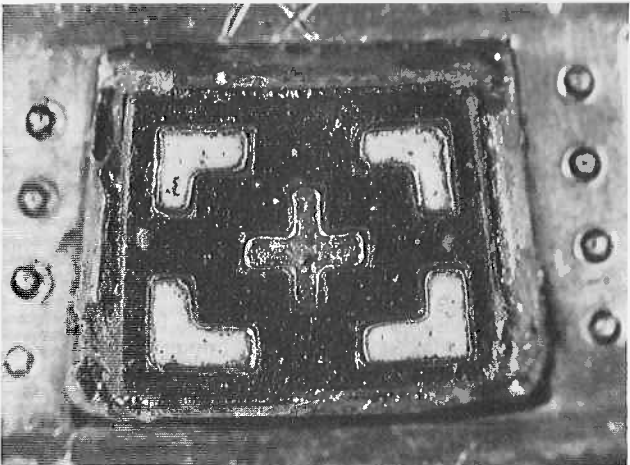


55. A stud in the under-foot girdle photographed through immersion liquid in order to reveal bubbles and striae in the glass and the pattern of the foil beneath.

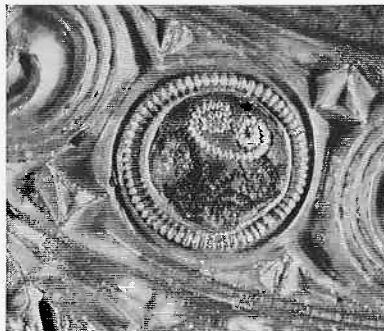
56. One of the four glass studs in the upper foot girdle.



58. The silver foil backing of one of the transparent glass studs in a handle, and the method of attachment, photographed through a dental mirror.



59. A blue glass stud from the under-foot disc that retains only one of its three gold beaded-wire decorations.



is a partitioned ring filled now with malachite and originally decorated with roughly plano-convex cylindrical amber beads set upon the malachite. Before returning to this feature let us consider the studs generally.

#### The Studs in the Foot-Girdles

In the lower foot girdle there were eight studs of almost rectangular shape that supported the whole weight of the chalice on the table and were in consequence very much scratched. They were made of pale blue transparent material. One of the studs was missing, and a backing of patterned silver foil was in consequence exposed (fig. 54). We wanted to discover whether all of the studs were backed by similar silver foil. In order to establish this and to discover the pattern on the foil it became necessary to take photographs through the almost opaque scratched surface of each stud. To do this the stud was coated with an oil of suitable refractive index that would fill the scratches and give them optical properties similar to those of the mass of the material. Fig. 55 illustrates the result. Bubbles in the stud provide clear evidence that the stud was made of glass and not of some semi-precious stone. This photograph offers additional evidence that the stud is made of glass by showing the presence of striae. These are evidence of inadequate mixing of the molten glass. The pattern on the embossed foil is also visible. Not all of the foils had the same pattern. The one shown in fig. 55 is different from that in fig. 54.

The studs on the upper foot-girdle, of which fig. 56 presents an example, were never hidden by the foot while the chalice was standing: they were always in full view and were therefore made more ornate. The mass of the stud shown consisted of blue opaque glass. In its center was a red cross, and in each corner a yellow angle. Two of the four studs had this particular arrangement of colors. The other two had the colors reversed: yellow in the center and red in the corners. The various fields of color were separated by, not cloisons proper, but narrow strips of silver sheet that had been bent to shape and set on edge.

Fig. 57 presents the decorative studs set in one of the handles. Here a central vertical row of gold filigree panels is flanked on two sides by mirror-twin pairs of rectangular studs. All of the studs except those two across the middle of the field of view have silver grilles in their faces. The two exceptions have grilles made of red glass. Unfortunately the red has corroded extensively. Certain of the studs were made of pale blue transparent glass (two of these may be seen on edge on the curve of the handle). These were both backed by silver foil, but only one of the two foils was embossed. It was necessary to photograph this from inside the handle, for the benefit of posterity, while the silver liner of the handle that normally ob-

scured it had been removed. The photograph, fig. 58, was taken as shown here through a carefully aligned dental mirror.

#### The Studs in the Under-Foot Mounting

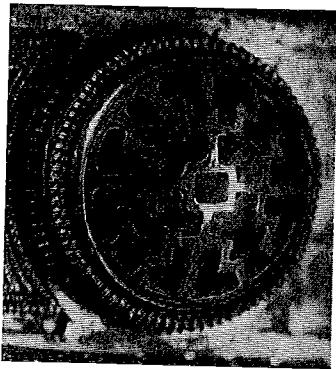
Fig. 59 shows yet another kind of stud: one of the five found in the underfoot mounting. Only two of the five still retained any of the gold beaded-wire decoration, and in this photograph only one of the coiled wires remains, but the shapes of the other two are retained in the glass stud. These indicate conclusively that the glass was pressed around the beaded wires while it was in a viscous condition. A little thought about this design will indicate that the shapes of these three coiled beaded wires were perfectly adapted to the method of construction of the stud. Placed back to back inside a hemispherical mold the three would slide to the bottom and align themselves symmetrically in contact while the viscous glass could be pressed in to fix them in place.

#### The Studs in the Bowl Girdle

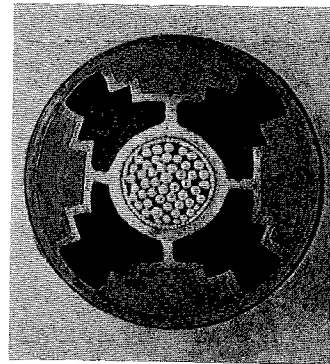
Fig. 60 shows the silver grille and the blue-glass backing as seen by the naked eye. In fig. 61 all of the physical data concerning this stud have been incorporated in a single dimensioned drawing. It shows a cross-section through the stud accompanied by an exploded drawing that indicates how the panels and panel back plates were assembled in the bowl girdle. The mounted stud *B* was passed from the front into the hole in the girdle marked *C*. A lead plug marked *F* in the cross-sectional drawing was pushed into the back of the mount and was expanded by a series of punchings around its periphery. The adjacent panels with back plates, *D* and *E*, were dropped into place in the apertures in the girdle and the slit edges of the stud mount were turned over to hold them in position. The drawing shows the condition of the girdle as received. It would have been more in accordance with the concept of the design if the edge of the back plate, *E*, cut back by someone — possibly Johnson — had been left equal in length with the panel, *D*, and the two components had then been held together by the turned-over edge of the stud mount. All this and additional information is presented in this single drawing.

#### The Stud in the Handle Escutcheon

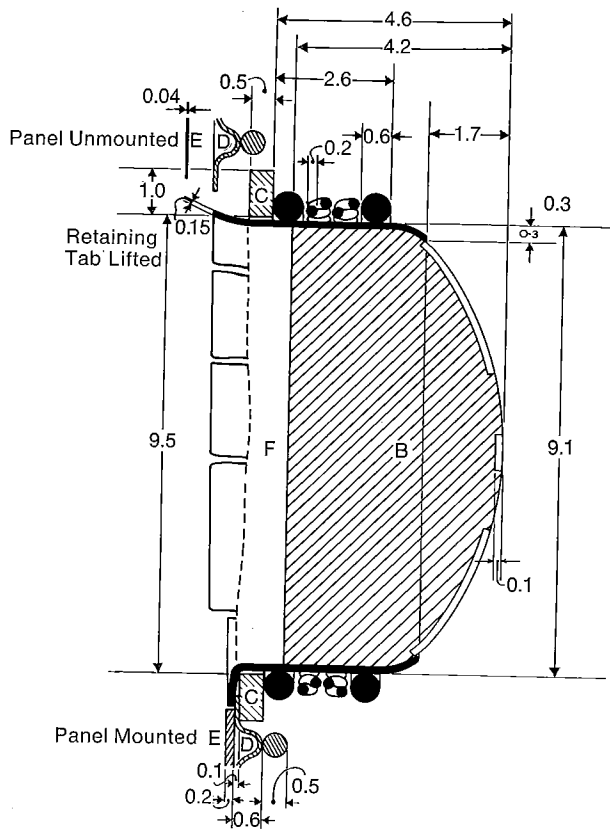
In fig. 62, the great subconical stud that was seen in the photograph of the handle escutcheon is shown illuminated with both frontal and back lighting while it was immersed in toluene. This illumination gave an impression of the transparency of the glass. As seen when mounted the glass appears to be opaque because no provision could be made in the design of the escutcheon for light to pass through it. The same stud is shown in the sectioned drawing, fig. 63, which was made to illustrate the details of construction of the mount.



60. A view of one of the blue glass studs in the bowl girdle that illustrates the beaded wire around it.

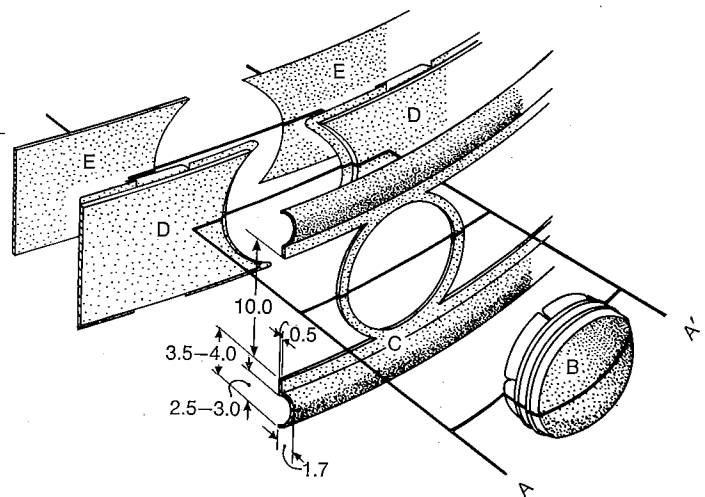


62. One of the subconical studs from a handle escutcheon photographed while it was immersed in toluene.



Section A A'

- B Glass Stud in Silver Mount
- C Girdle
- D Panel
- E Panel Backplates (thick and thin)
- F Lead (in some cases)



Measured in mm

61. Cross-section and exploded view of a glass stud in the bowl girdle.

Beneath the stud can be seen three packing pieces made of cardboard. These pieces of card are part of a photographic print, possibly from the early 20th century, that must have been inserted at the time of some earlier examination.

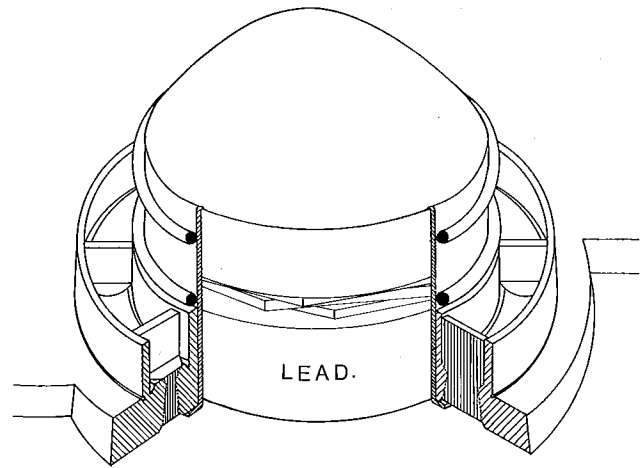
**The Malachite Paste beneath Inlays of Amber**

The channel around the stud contained residues of green material that presented a problem. X-ray diffraction analysis indicated that it was made of malachite, but the shape of the filling indicated that it had been inserted while it was of a pasty consistency. If this were the case then the malachite may have been used in powder form, ground up with a medium such as glue, and inserted into the mounting to serve as a temporary packing and adhesive for the amber inlay. The fragments of amber inlay still remaining are plano-convex and are adequately held in position between the walls of the channel, under constraint by the lower beaded wire on the stud mount. It is suggested that the malachite mixture was applied as a temporary adhesive until such time as the stud mount should have been inserted as the final fixing device.

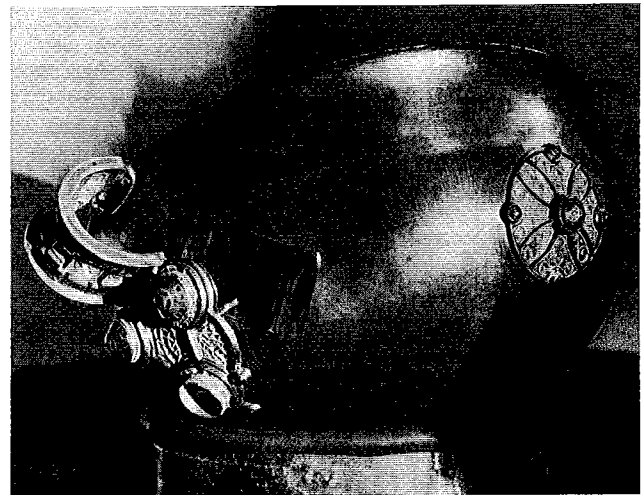
A question immediately arose from this study: why was a mixture of malachite employed? Why not make use of a gesso? A possible answer is that the particular mixture was already in use about the 9th century workshop for some other purpose and that it was pressed into service on this particular occasion. The mixture could have been in use for soldering fine granulation work (Maryon, H., *Metalwork and Enamelling*, London, Chapman and Hall, 1954, p.10). The partitions across the outer channel are secured in conical holes (fig. 63). The size of these holes was determined, even though they were on the back of an escutcheon that was firmly attached to the bowl, by a method shown in fig. 64. One of the two escutcheons was found to be separated from the bowl by a distance of about 1 mm. A piece of reflective metallized cellulose adhesive tape was inserted into the gap and made to serve as a mirror in which the back of the escutcheon that contained the holes could be photographed. The diameter of the holes was measured by means of a microscope.

**The Arrangement of Panels in the Bowl Girdle**

The problem of the arrangement of the ten decorative panels in the bowl girdle may next be considered briefly. Their arrangement as received, unsymmetrical on both sides, had always worried the stylistic experts because it was said to be "aesthetically impossible" for the Irish craftsman. While sympathetic toward our colleagues of a different discipline, as scientists we were constrained to seek some objective evidence to justify some other arrangement of the panels. Etienne Rhyne of Dublin after considerable study proposed an arrangement that was based on aesthetic reasoning and that yielded a symmetri-



63. The construction of the subconical stud.



64. The use of reflective tape to view through a narrow gap details of the back of an escutcheon.

cal arrangement of the three types of panel. With the aid of this basic concept he was able to rationalize a number of difficulties that had arisen concerning the arrangement of several sequences of numerals that had been scratched on the backs of the panels. One of these, an "X," appears here in fig. 40. However, in search of additional objective evidence all of the data were now reviewed. First, the earliest documentary evidence that was available was examined. This was the photograph found in Margaret Stokes' album, fig. 65. After much study it became possible actually to identify the various panels not only by type — A, ornithomorphic; B, knotwork; C, zoomorphic — but individually. As a result it appeared certain that the



65. The photograph found in Margaret Stokes' album.

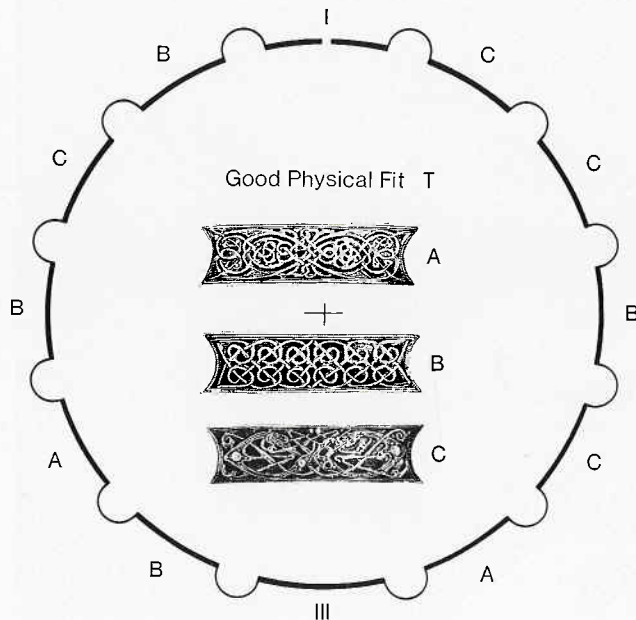
arrangement of panels shown in the photograph really belonged to the opposite side of the bowl as shown and had also been moved round by about the width of a panel. It could never have been actually as shown! The conclusion reached was that the girdle with its panels had been replaced temporarily during restoration only for the purpose of taking a photograph and it therefore did not provide evidence of much value for the purpose in view.

Another possible and historical arrangement for the panels was as they were received in the laboratory. This had in fact never been very satisfactory because as received the two ends of the bowl girdle, expanded by ill-fitting panels, had not come together as they should. The ends had been secured by solder to the bowl, with a gap between them, at a position obscured behind one of the handles.

Yet another historical arrangement of panels was found in a representation of the chalice that had been made by Johnson and was in the collections of the Victoria and Albert Museum in London. This arrangement was very close indeed to Etienne Rhyne's arrangement. It was so much more symmetrical than

the arrangement "as received" that it seemed rather odd that Johnson had not employed it when he himself replaced the panels in the chalice in 1869: he clearly held the same belief in aesthetically satisfactory arrangement as did the Early-Christian Irish!

The next attempt to resolve the difficulty ignored history: the actual physical fit of the various panels in the apertures in the bowl girdle was examined. Certain well-defined criteria that could be applied without any uncertainty in the answer were used. About a hundred trials were made of the fit of each panel into every aperture, extending over several days. The results were categorized in lists. They revealed that Rhyne's beautiful symmetrical arrangement was quite impossible in practice because all of the necessary panels just could not be inserted mechanically into the required apertures. It also showed that Johnson's arrangement as used in the representation in the Victoria and Albert Museum was not mechanically feasible in the present condition of the girdle. This explained why he had not used the arrangement in his own restoration. The result also showed that even the unsatisfactory arrangement in the



66. The arrangement of three types of panel between the studs in the bowl girdle.

chalice as received had only become possible because he had forced two panels into place. The question that then arose concerned what arrangement would be acceptable to Dublin, since neither perfect symmetry nor the Rhyne arrangement was physically feasible. From the new data it was discovered that there were two arrangements of panels that were physically possible and that contained maximum symmetry. Agreement on one of these was eventually reached and the panels were replaced as shown in fig. 66. Here the arrangements of panels are different on the two sides, but visually they appear symmetrical because panels of types C and A have similar visual impact although actually different in pattern. It is only fair to add here that some other arrangement was probably physically possible before the original restoration, at which time the bowl girdle was repaired by inserting silver and at least one panel aperture might have been shortened slightly during this operation. Finally, fig. 67 illustrates the chalice as received, grey and dull, with most of its detail invisible, and insecure at the neck. In contrast, fig. 68 shows one side of the chalice after the work and fig. 69 shows the other side, both views fully detailed and colorful and the chalice completely rigid to the touch.

### Summary

The methods of observation used included the following: directly, by sense of touch; measurement with a scale, with

calipers, with a slide gauge, by micrometer, by micrometer eyepiece in a microscope, by traveling microscope; direct visual observation; and microscope-assisted observation through air, through oil-films, and through immersion liquids. Observations have been made indirectly via silastomer molds, wax impressions, silhouettes, shadows cast by straight edges, and by grids of lines. Detailed comparisons were made visually, by superimposition of negative images from one component on positive images of another component, or by means of a synchriscope. Other comparisons of an essentially non-destructive nature have been made by measurements of Brinell Hardness. Metallographic observations have been made on naturally etched surfaces and on prepared and polished surfaces. Analyses on minute samples, barely mentioned above, were performed by spectrography and by X-ray diffraction analysis.

The recording of details, by no means the easiest part of the work, was carried out largely by photographic methods, lighting the subjects by daylight, by special arrangements of artificial light, by diffuse illumination, or using lighted backgrounds and supports in order to eliminate confusing shadows. A variety of cameras were used according to need:  $3\frac{1}{4}$  by  $4\frac{1}{4}$ ,  $4\frac{3}{4}$  by  $6\frac{1}{2}$  inch, 35 mm, ancient mahogany cameras, a modern all-movement Sinar, a Leica, and several models of single-lens reflex. In photomicrography a Vickers projection microscope was used. Objects were viewed either directly or through mirrors, even into crevices 1 mm wide. In order to yield a good record, exploded views were made and Xerography was pressed into service to achieve a particular result. Pressure to record so precisely has been generated by the desire to produce detailed schematic drawings in which the objective data could be preserved precisely for the benefit of posterity. Preparation of these drawings often exposed our ignorance of some detail of the chalice and drove us continually to devise some means of recording features that were barely perceptible. The completed drawings brought to our attention certain formal relationships between components that would otherwise have escaped notice.

In conclusion it must be abundantly clear that no one person could have carried out all of the examination, recording, and reconstruction that has been outlined here. In fact eight or nine members of the staff of the Research Laboratory of the British Museum shared in the work in varying degrees. I served in the laboratory at that time, and this account is published with the permission of the Keeper of the Research Laboratory, Dr. A. E. Werner.



67. The other side of the chalice as it was received.





68. One side of the cleaned and reassembled chalice.



69. The other side of the cleaned and reassembled chalice.

Application of Science  
in Examination  
of Works of Art

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