SCIENTIFIC INVESTIGATIONS
OF SOME GLASSES
FROM SEDIEINGA

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In 1973, Prof. Jean Leclant described the glass excavated at Sedeinga, a Meroitic site in Sudan. Among the objects are two extremely important footed flutes bearing elaborate "painted" and gilded polychrome decorations. Professor Leclant dated the tombs in which the glasses were uncovered to the second half of the third century A.D. One of the flutes is in Khartoum; the other is now in Pisa.

These flutes would be of extraordinary interest in any event, but the fact that they were found (along with some other luxury glasses) in an area so remote from regions where one might normally expect to encounter such glass raises the additional intriguing questions of where they were made and how they reached Nubia. Because of the specificity of the decoration, these vessels must have been commissioned by or for some very special client. It is equally certain that they were made by experienced and highly skilled glassmakers and that they were decorated by a master artist accustomed to working closely with glassmakers. This becomes all the more evident when one realizes, as is demonstrated below, that at least parts of the "painted" decoration are indeed fired onto the glass. This is not a case of an artist having simply painted a decoration onto a handy piece of glass with paints that were ordinarily used on other materials.

One of the theories advanced by Professor Leclant is that the glassmaker and/or artist actually made the flutes in Nubia. This is fine if one posits an indigenous luxury glass industry, but local manufacture, although still possible, seems less likely if it required bringing the glassmakers to Nubia. To accept the latter hypothesis, it is also necessary to accept the corollary that they brought with them, or constructed there, the necessary tools, materials, and glassmaking facilities. The alternative hypothesis is that the glasses were made at some distant glassmaking center and imported into Nubia. Professor Leclant’s first choice in this event is Alexandria, and that makes good sense, but lacking any supporting evidence for it, one cannot rule out other possible glassmaking centers. The matter of difficulty of transport, raised by Professor Leclant, may

1. J. Leclant, "Glass from the Meroitic Necropolis of Sedeinga (Sudanese Nubia)," Journal of Glass Studies, v. 15, 1973, pp. 52-68. The present study was originally intended to have accompanied Leclant’s article, but it was withdrawn from the Journal because of space limitations. It was withdrawn from the 1975 volume of the Journal, dedicated to Donald Harden, for the same reason. In its present dusted off and somewhat revised form, the paper is now doubly dedicated, belatedly but fondly, to Professor Leclant and Dr. Harden.

Leclant’s “Vetri dalla necropoli di Sedeinga nella Nubia sudanese,” in Le vie del vetro: Egitto e Sudan (Pisa: Giardini, 1988, pp. 44-57), is a translation of his paper in the Journal of Glass Studies. In the same volume, the catalog entry for the glass in Pisa (by Edda Bresciani, p. 108) is accompanied by color photographs of all the figures.
not be a deciding issue in settling on an origin, for if the glasses had to make the lengthy transit up the Nile (let us say) from Alexandria, they could just as well have made a trip of comparable difficulty beforehand from some other point of origin to Alexandria. There is ample evidence that glass—even very fragile glass—was transported over considerable distances in ancient times. The glass found at Begram comes immediately to mind.

The question of origin may ultimately be answered best on art historical or archeological grounds, but it was the above line of reasoning that prompted a scientific examination of the Sedeinga glasses. We wanted to see if any plausible places of manufacture could be either confirmed or eliminated on the basis of laboratory studies. However, there is another equally important technological question involved: was the painted decoration simply “cold-painted” on the glass with the same paints that artists used on other materials, or was it applied as an enamel? In enameling, powdered glasses of various colors are mixed with a flux, suspended in a vehicle, and painted onto the substrate, and the whole object is refired at moderate temperatures so as to fuse the enamel and fix the decoration permanently in place. The subject of cold-painting versus fired-on painting (hereafter, simply painted and enameled) deserves careful review because without a proper examination, one can easily be deceived and draw erroneous conclusions.

Our investigation so far consists of seven parts:
1. A cursory, hand examination of the flute W T8 c 14 in Khartoum.
2. A more careful examination of the flute W T8 c 13 in Pisa.
3. A microscopic examination of a small fragment of the flute W T8 c 13.
4. A non-destructive, non-sampling qualitative chemical analysis of the above fragment by X-ray fluorescence.
5. Radiography of the flute in Pisa.
6. Quantitative chemical analyses of nine fragments of other glass objects from Sedeinga.
7. A lead isotope determination of a sample of galena from one of the tombs. (While of general interest to the study of the finds from Sedeinga, this analysis did not have a direct bearing on the glasses.)

As all too often happens, however, our experiments have had certain limitations, which leave us with less information than we would like to have obtained. Nonetheless, the results are well worth reporting.2

Examination of the Flute W T8 c 14 (Khartoum, No. 20406)

This object, Leclant’s no. 5, is illustrated in the colorplate frontispiece and figures 12–15 of his article.3 It is of blue transparent glass and stands 20.3 cm high.

Because of time limitations, it was not possible to make a thorough microscopic examination of this object. However, a hand lens examination of the principal figures in the decoration was sufficient to establish without doubt that these decorations were fired into place. Because of the complexity and detail of the designs, the fused-on materials could have been applied only by “brushing” on suspensions of powdered colored glasses. These were subsequently fused into place by reheating, so this glass, consequently, is an early example of true enameling. Some other incidental observations were made during the examination. For example, through the use of a Chelsea filter, it was determined that the blue glass is colored with cobalt oxide.

Examination of the Flute W T8 c 13 in Pisa

This object, Leclant’s no. 4, is illustrated in figures 5–11 of his article and in figures 1–4 here. It is also of blue transparent glass, and it stands 20.1 cm high.

Through the courtesy of Prof. Edda Bresciani of


3. The author is very much indebted to Dr. Negm ed Din Mohammed Sharif, then director of the Antiquities Department of Sudan, for his cordial cooperation and for granting permission to handle and photograph this object. I also thank Prof. Frederick Matson, who helped in the examination, which was made on May 6, 1973.
the Archaeological Institute of the University of Pisa, the author was permitted to examine this flute at the university. The examination was made with the aid of two hand lenses, which allowed magnifications of 8x and 10x.

The construction of the foot of the vessel is of some interest. There is a clear indentation in the base of the short, solid stem, from which the foot flares out, but this is not a pontil mark or even a tool mark. It is simply the natural configuration caused by the extension of a bubble blown into the original gather from which the foot was made. Thus, while the body and rim were being formed, the vessel could not have been stuck-up on a pontil. Instead, it was supported either by the attachment of the gather (probably partially inflated) from which the foot was eventually formed or by a “clamp” holding the already finished foot.

The surfaces of the glass show no signs of weathering (which is as expected) or of wear. No devitrification could be detected at the low magnifications available.

The glass itself (as distinct from the applied decorations) is moderately bubbly. Most of the bubbles are small and either spherical or nearly so. Among the larger bubbles (equal to or greater than about 1 mm in greatest dimension), many are elongated to a ratio of about 3:1 or 2:1 or less. A few of the largest bubbles are elongated to perhaps a 6:1 ratio. The largest single bubble seen (in the body, near the bottom) was about 3.5 mm in greatest dimension.

4. The examination was made on October 2, 1974. It was hindered—indeed almost frustrated—by an unfortunate decision on the part of the restorer. In what was apparently an effort to enhance the appearance of the object, the restorer had coated the entire object with a lacquer or varnish of some sort. This coating appears never to have set completely; months later, it was still tacky to the touch, and even light handling left fingerprints on the surface. It is sad to report that during examination, several pieces of the foot separated; it could be seen that the glue had become embrittled and that it had little adherence to the fractured glass surfaces. As a side effect, the coating obscured the surface enough to make it difficult to discern many of the microscopic features that would have allowed an observer to draw conclusions as to the nature of the decoration materials.

5. This raises an interesting technological question. If, as is the case with this flute, both ends of an object were finished at the glory hole and the object does not have a pontil mark (or evidence of the removal of such a mark), then some other support would have been needed during the final finishing. Certain types of objects could conceivably have been hand-held, perhaps with the aid of some insulating material, but for the most part, it seems much more likely that simple clamping devices of some sort were used. We have made a cursory examination of some 300 ancient blown objects in The Corning Museum of Glass and have found that the numbers of glasses with pontil marks and those without pontil marks—among glasses hot-finished at both ends—are about the same. The use of a pontil versus the use of clamping devices (for lack of a better term) might help to distinguish among wares made by workmen from markedly different technological traditions or working at different periods within a given tradition, particularly during the early stages of glassblowing before the use of pontils became widespread.
sion, with an elongation ratio of about 4:1. The elongation occurs in the expected orientations. Throughout the cylindrical part of the body, even near the curved portion at the bottom, the elongation is vertical. At the very rim and at the edge of the foot, the elongation is horizontal, implying that the final finishing steps were circumferential movements.

The edges of both the foot and the rim, finished by fire-polishing, were not ground afterward. The ridge near the rim was apparently formed by an applied thread, which coalesced with the body as a result of the reheating required for finishing the rim. The thread was carefully applied, with no clear-cut beginning or tail, only a general thickening in one segment.

The most intriguing parts of the object, microscopically, are the decorated regions. Examinations were made of six representative areas:

1. The four-lobed florets near the bottom (Fig. 1).
2. The stag (Fig. 2).
3. The necklace on the “gilded person” carrying an animal and standing to the left of Osiris (Fig. 4).
4. The arm of the “gilded person” (Fig. 4).
5. The head of Osiris (Leclant’s figure 5).
6. The eye of Osiris (Leclant’s figure 5).

The artist’s palette consisted of seven basic colors, with mixtures used for intermediate shades. Even though the object has been repaired, we have assumed that no repainting accompanied the repair. The basic colors were:

a. Yellow opaque (which sometimes appears green against the blue glass).
b. Turbid white (with a slightly bluish tint).
c. Red opaque (sometimes a brick red).
d. Dense white opaque.
e. Brown (probably a mixture based on red).
f. Black.
g. Light green opaque (a chalky, Paris-green color).
The first three of these colors are clearly fired-on enamels, and they appear to be based on the usual color chemistry of early glasses. The colorant-opacifier phases are lead antimonate ($\text{Pb}_2\text{Sb}_2\text{O}_7$) for the yellow, possibly calcium antimonate ($\text{Ca}_2\text{Sb}_2\text{O}_7$) for the turbid white, and cuprous oxide ($\text{Cu}_2\text{O}$) for the red opaque. The nature of the turbid white is interesting. The turbidity results not exclusively from suspended particles of a white pigment, but mainly from a bubble cloud. The enamel is filled with tiny bubbles that are barely resolvable at 10x magnification (approx. 50 microns diam.), and one senses that there is a myriad population of even smaller bubbles. Nevertheless, we have decided to associate this turbidity with calcium antimonate because that system invariably is a very bubbly phase even where the particles of white pigment themselves are abundant. Residual antimony pentoxide tends to evolve very small bubbles of oxygen in hot glasses.

The dense white opaque is entirely different from the turbid white. It has a tendency to "pile up" in relief, unlike the other three enamels, which spread out thinly on the base glass. On the basis of radiographs (discussed below), this dense white material apparently contains much lead, and one is tempted to guess that it might be a white lead pigment. The nature of the brown color is unknown to us, but the black paint is definitely a tarry or resinous substance. Finally, the green paint, which is different in character from the others, does not seem to have been fired on. It has a distinctly chalky appearance and shows cracking, which must have occurred during drying or aging.

From the overlapping of colors, it is possible to make a guess as to the general sequence in which the colors and the gilding were applied. Such a sequence is not absolute because an artist would not necessarily have created the design by applying all of one color, then all of the next color, and so on. It is more likely that he or she would have returned to the palette to draw upon different colors more than once. Nonetheless, if the sequence below was followed, it would account for all the overlapping observed.

**FIG. 4. Detail of flute in Pisa. Courtesy J. Leclant.**

Evidently, the entire design was sketched out roughly in the turbid white and thin yellow opaque enamels. These colors underlie the other colors and the gilding in the figural designs, the gilded letter-

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6. See chemical analyses below.
7. A yellow opaque enamel of a character very similar to this sketching enamel was found on a fragment of a "painted" blue bottle (more correctly an enameled blue bottle) from the medieval factory at Corinth. It was published in Gladys R. Davidson, "The Minor Objects," *Corinth*, v. 12, 1952, no. 751 (7465), p. 115 and plate 58; and *idem*, "A Mediaeval Glass-Factory at Corinth," *American Journal of Archaeology*, v. 44, 1940, nos. 56-57, p. 320 and fig. 22. Another technologically similar piece of blue glass with a thin yellow enamel is in The Corning Museum of Glass (67.1.19); see A.H.S. Megraw, "More Gilt and Enameled Glass from Cyprus," *Journal of Glass Studies*, v. 10, 1968, pp. 86-104.

ing, and the gilded bands. While abundant evidence of this can be seen microscopically, it shows especially vividly in the paintings of the unfortunate stag illustrated in Figure 2. The right ear of the creature was left unfinished by the artist. The brown, red, white, and black paints used to color the rest of the animal—including the left ear—were never applied to the right ear, so the thin yellow opaque sketching enamel is clearly visible.

Apparently, the gilding—in the form of gold leaf—was applied next and trimmed. Because the trimming does not seem to have removed any of the underlying sketching enamel, it is possible that this enamel had been fired to fix it before the gold leaf was applied. The red enamel and the brown and dense white highlights were added next and fired permanently into place. In all cases, the black seems to have been applied after the gold leaf and other colors to add emphasis. It shows no obvious frothing or other evidence of having been strongly heated, so it must have been applied after the enamels were fired. Moreover, after the black was applied, the glass was not reheated again.

The green paint poses a special problem. It always seems to have been the last color applied, and as noted above, it is a paint, not an enamel. (It could not have been fired on, because it overlaps the black paint in places.) The green may have been applied as an afterthought or to correct something that had gone wrong in the firing.

In several areas, the different colored features tend to withdraw neatly from one another, leaving microscopic rims of glass exposed between them. Evidently, the vehicles used for the respective colors were not miscible. Some may have been suspended in oily vehicles and others in aqueous vehicles. The effect is especially noticeable between the red opaque and the dense white and between the black and the chalky green.

The possible identification of the dense white pigment as white lead raises the question of whether white lead could have been used as an enamel or whether it would have decomposed either upon heating or by reaction with the enamel flux. We have done several experiments in an effort to answer this question, and we have also speculated about the enameling process itself. These studies consisted of heat-treating samples of white lead, monitoring thermal changes by X-ray diffraction, conducting various gradient-furnace experiments, and considering bubble sphericalization and viscosity-temperature relationships.

From the observation of elongated bubbles in the blue glass of the body, it was inferred that after the vessel was formed, it was never again heated—more than momentarily—to a temperature in excess of about 650°C. If it had been heated longer, the bubbles would have become sphericalized and the vessel would have been in danger of sagging. From gradient-furnace experiments in which powdered glass was mixed with white lead and/or soda to simulate ancient enamels, it was concluded that soda alone is not very effective as a flux for making low-firing enamels, but that white lead is a very effective flux. It was also estimated that ancient glass objects probably could have been enameled in the temperature range of about 515°C to 600°C, a range compatible with the 650°C upper limit mentioned above.


10. This experiment was carried out by Cindy Mosch of Corning Glass Works under the supervision of John Wosinski. The synthetic enamel was prepared by mixing a crushed glass having a typical ancient soda-lime composition (CMG-TNH) with white lead and anhydrous sodium carbonate. The composition of the resulting enamel is SiO2, 34.6 wt. %; PbO, 41.7; Na2O, 17.5; CaO, 2.8; K2O, 1.5; MgO, 1.4; Al2O3, 0.6. For information on the gradient furnace, see Robert H. Brill, “Ancient Glass,” Scientific American, v. 209, no. 5, November 1963, p. 122; and Robert H. Brill and J. F. Wosinski, “A Huge Slab of Glass in the Ancient Necropolis of Beth She’arim,” Proceedings of the VIIIth International Congress on Glass, Brussels, Section B, paper no. 219, 1965.
In the heat-treatment experiment, separate samples of a modern white lead pigment were heated to various temperatures in a kiln, and it was found that if the enameling process required a temperature much in excess of about 450°C (for approximately one hour), the white lead would begin to discolor to a yellow or tan shade.

From all of the above, we finally concluded that a heat treatment for up to a few hours in the range of 515° to 625°C would be sufficient to fuse enamels in place (using a lead compound as a flux) without sphericalizing the bubbles in the body of the glass. White lead alone could not have been used for the dense white pigment because it would have become discolored, but if it was mixed with a powdered glass and heated for 10–20 minutes, it could have formed a white opaque enamel.

Microscopic Examination of a Fragment from Flute W T8 c13 (Pisa, No. 230)

At the suggestion of Professor Leclant, a small fragment of the flute W T8 c13 was lent to The Corning Museum of Glass for laboratory examination. Because of the importance of the object, however, the University of Pisa requested that our studies be strictly limited to non-destructive and non-sampling processes. This request was complied with rigorously, and the fragment was returned to Pisa in exactly the same condition as it was when received.

The fragment, which measures approximately 4.0 cm in greatest dimension, is illustrated in Figure 5. It can be seen, after having been incorporated in the fully restored flute, at the top of Figure 1 and in the radiograph reproduced here (Fig. 6). There was one circumstance that hindered us somewhat. As can be seen from the illustration, the fragment submitted for examination contained only elements of the border decoration, so we were unable to learn anything more about the principal design elements by our direct, high-powered microscopic observation.

The fragment is of medium blue transparent glass and includes arcs of both the rim and the exterior horizontal ridge below the rim of the vessel.

The border decoration consists of a gilded design applied in the form of gold leaf and outlined with the black tarry or resinous substance described above. The black paint laps over the gold in some places, as was also noted above. Another part of the gilded design outlined with black paint is included on the fragment. This is the upper left corner of the...
letter “C” in the inscription, just above the head of the standing figure of the woman in Figure 1. That the gold was applied as leaf is evident from the appearance of the edges and corners, the frequent tears, and the wrinkled contour, all of which show up unmistakably on a microscopic scale. The gold leaf is very thin, and we could not see, on this fragment, any evidence of a sizing or of an encasing layer of any sort. If either existed, it must have been extremely thin; otherwise, in the case of a sizing, it must have burned away during the firing of the enamels.

The horizontal gold-leaf decoration and its black outline cover a thin band of the yellowish green enamel. The yellowish green band is flanked by two thinner bands of brick red opaque enamel. Microscopic examination of the fractured edges of the fragment shows that the exterior surface of the yellowish green band is perfectly flush with the surface of the blue body glass. It does not protrude at all above the surface; instead, it extends down into the blue glass. The same is true of the red bands. The wall of the vessel, the blue glass, is only a little greater than 1 mm thick at this point, and the colored bands extend down into it to a depth of 0.07–0.12 mm. Heavy enamels, such as those on Islamic glasses, invariably protrude somewhat above the surfaces of the glass substrates; that is to say, they stand in relief. But we have seen other examples of thin enamels, like the bands on the Sedeinga flutes, that are nearly flush with and penetrate the surfaces. The effect probably stems from differences between the surface tensions of the softened enamels and the glass, the viscosity-temperature characteristics of the glasses and enamels, and the fluxing action of the enamel of the base glass. (The bands, incidentally, are definitely not marvered-in applied threads.)

Under magnification, the yellowish green band can be seen actually to be a thin yellow opaque. Its greenish cast is caused by the predominantly blue environment. The red bands are rather thin red opaques. A small spot of a thin white opaque enamel (having a bluish cast) appears near the bottom of the fragment. It also seems to penetrate somewhat the surface of the blue body glass.

The blue glass itself is quite bubbly. Most of the larger bubbles in the fragment are slightly elongated horizontally. (The maximum elongation seems to be in about a 2:1 ratio.) This elongation resulted from the last stages of tooling, which shaped the ridge or the open end as a whole. A notable exception is the largest bubble (measuring approximately 1 mm in maximum length). Although now nearly spherical, it had been elongated vertically when the hot glass was extended into its final cylindrical shape.

There is little or no evidence of weathering on this fragment, in keeping with its having been excavated in Nubia. However, there are some signs of wear or erosion on the glass and possibly some devitrification on a microscopic level. This is an expected consequence of the heat treatment accompanying the enameling process.

Radiography

At the request of the author and Professor Bre- sciani, Dr. Carletti of the Ospedale Tisiopneumo- logico Provinciale di Carignano (Lucca) made several small radiographs of the flute. Dr. Carletti placed strips of film inside the vessel and made one-second exposures at 100 ma and 40 kv (Fig. 6).

The radiographs clearly delineate certain parts of the decoration and lettering. Some pigments stand out much more boldly than others because of their greater opacity to X-rays; this results from differences in chemical composition. Much of the radiographic image is attributable to the yellow opaque enamel used to sketch the design and—to a lesser extent—the gold leaf. The yellow ankh, for

14. The term devitrification is used here in its strictest sense. Devitrification is a process whereby glass becomes partially crystallized due to its being maintained for some time at an elevated temperature—a temperature sufficient to allow atomic rearrangement into a crystalline phase to occur, but not sufficient to cause a large-scale deformation of the shape of the glass. The term is not synonymous with weathering, decomposition, or corrosion.

15. We are very grateful to Dr. Carletti and his staff for their assistance and to Prof. Ubaldo Caccarelli, chief of the hospital, for providing these radiographs.
FIG. 6. Negative prints of radiographs of flute in Pisa. Fragment in Figure 5 is above woman holding tray. It extends from second band of gilded decoration up to rim and clips off the upper left corner of the letter “C”.Courtesy Drs. Carletti and Caccarelli.
example, stands out prominently, as do the other yellow parts of the designs. One of the white enamels, the dense white used for highlights (d, above), has a high opacity, consistent with the supposition that it is a form of white lead. This is especially evident in the tiny white spots of the collar and the white highlights of the stag. In marked contrast, the turbid white (b), appearing in the applied blobs and used for the other two animals, is perfectly transparent to these X-rays and casts no visible image whatever. This confirms its identification as the calcium antimonate or an antimony white producing turbidity through bubble clouds. The ducks also cast no image. The chalky green pigment (g) shows some image, but only a weak one, even though it is thicker than the other pigments. The black pigment casts no image, which is consistent with its identification as a tar or resin.

### Chemical Analysis of the Flute W T8 c13

At present, there is only one method for the chemical analysis of glass objects that can truly be considered non-destructive and non-sampling. This is X-ray fluorescence. Consequently, we had such an analysis carried out on the fragment while it was on loan, but with the a priori realization that the technique was not an ideal one for what we were trying to learn. In the first place, this method did not (at the time) yield data for some of the major and minor components that are most likely to aid in classifying glasses according to probable loca-

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16. Conventional X-ray fluorescence cannot be regarded as non-destructive because there is a possibility of producing discoloration due to solarization of manganese-containing glasses. Methods that utilize radiation from radioactive isotope sources, instead of X-ray tubes for excitation, do not present this hazard.
tions of manufacture. Also, the technique did not provide data of sufficient accuracy on some elements because of experimental complications.

The analysis, carried out at the Winterthur Museum Laboratory by Victor Hanson and George Reilly, was done with a KeVex-Packard X-Ray Fluorescence Analyzer on June 17, 1971.

Three different areas of the fragment were masked off from one another so that independent analyses of the areas of most interest could be obtained one at a time. These regions, which can be seen in Figure 5, were:
1. The underside (or undecorated interior side), which represented the blue glass alone.
2. The region containing the gold leaf over the yellowish green band.
3. The bluish white spot.

The results, which are summarized in Table 1, are consistent with Professor Leclant’s dating and offer no special surprises. Unfortunately, however, because of the limitations alluded to above, we cannot even attempt to draw a conclusion concerning the region of manufacture. Nonetheless, a few useful comments can be made. If we later obtain supporting information, it should be possible to interpret these data more fully.

a. The analyses are consistent with the assumption that the base glass is of the soda-lime-silica type, as anticipated.

b. The analyses are insufficient for deciding whether or not the glass is of the high K2O-high MgO type because they gave no information on MgO (magnesium oxide), and the results on K2O (potassium oxide) may not be reliable. (The level estimated is about 0.01½-0.02½, which is unusually low for an ancient glass.)

c. All three areas analyzed are rich in antimony (Sb). This can be taken as evidence that the vessel dates from no later than about A.D. 350. The antimony in the yellowish green band (beneath the gilded area) is most likely in the form of the yellow pigment Pb2Sb2O7; that in the bluish white spot is probably present as the white pigment Ca2Sb2O7.

In the main blue glass, the antimony is in solution.

d. The fact that manganese (Mn) seems quite low (approximately 0.02½ if the analysis is reliable) may suggest a date prior to about A.D. 300, when manganese began to be widely used as a decolorizer. However, colored glasses often did not contain decolorizers, because they would have served no practical purpose.

e. The gold (Au) in the gilded region is obviously associated with the gold-leaf decoration. Arsenic (As) and selenium (Se), the latter of which seems surprisingly high, may offer clues as to the origin of the gold. This is a matter we have encountered in other connections, and it is worth pursuing.

f. The prime colorant of the transparent blue glass is cobalt oxide (CoO). The estimated concentration of 0.01½-0.05½ cobalt oxide is sufficient to confer the observed blue color. The presence of cobalt oxide in the glasses was confirmed by a transmission spectrum also run by Dr. Reilly at the Winterthur Museum Laboratory. Secondary transmission peaks were located at 555 and 615 millimicrons and above. This transmission is characteristic of glasses colored with cobalt, and it indicates, moreover, that the glass contains relatively little copper oxide (CuO), which would have reduced the red transmission considerably if it was present to greater than about 0.5%. The transmission spectrum represents a verification of what had been observed visually with the Chelsea filter for the companion flute in Khartoum.

g. Lead (Pb) appears in all three areas, but it is especially rich in the gilded area; this is undoubtedly due to the presence of the Pb2Sb2O7 colorant-opacifier in the yellowish green band beneath the gold leaf. Its presence in the other areas is not unexpected in strongly colored glasses. If a lead isotope determination could be made on glass from the vessel, useful evidence might be uncovered relative to the origin of the glass.

h. The tin (Sn), zinc (Zn), and silver (Ag) are all probably associated with the introduction of colorants. Silver, in particular, probably accompanied the lead, as it does in most lead-containing ancient glasses.

i. The other elements are all expected trace ele-
# Table 2

Analyses of Some Glasses from Sedeinga

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<td>Fe₂O₃</td>
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<td>1.8</td>
<td>1.8</td>
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<td>0.18</td>
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</tr>
<tr>
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<td>0.07</td>
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<tr>
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<td>0.4</td>
<td>0.4</td>
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<td>0.00X</td>
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<tr>
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<td>0.000X</td>
<td>0.000X</td>
<td>0.000X</td>
<td>0.000X</td>
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<tr>
<td>Li₂O</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
</tr>
<tr>
<td>B₂O₃</td>
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<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
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<td>0.96</td>
<td>1.31</td>
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<tr>
<td>SiO₂*</td>
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<td>2.86</td>
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<td>1.69</td>
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<tr>
<td>Fe₂O₃*</td>
<td>1.53</td>
<td>2.55</td>
<td>2.55</td>
<td>2.56</td>
<td>2.54</td>
<td>0.38</td>
</tr>
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</table>

Major and minor oxides by atomic absorption; P₂O₅ by colorimetry; SiO₂ estimated by difference. All other values by emission spectrography.

Sought but not found: CoO, SnO₂, Rb₂O, V₂O₅, Cr₂O₃, NiO, ZnO, ZrO₂, Bi₂O₃.

No. 1730 also contains 0.00X V₂O₅ and 0.02 ZrO₂.
No. 353 also contains 0.01 V₂O₅ and 0.03 ZrO₂.
Nos. 352-355 contain approx. 0.00X SnO₂.

(?) Doubtful value, but repeat determination checked original value.

All analyses by Robert H. Bell and colleagues of Lucius Pitkin Laboratories, New York City. (LP 688122)
<table>
<thead>
<tr>
<th>Vessel (cut)</th>
<th>Gaming piece</th>
<th>Vessel</th>
<th>Vessel</th>
</tr>
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<tbody>
<tr>
<td>Colorless Wht. Op.</td>
<td>1729</td>
<td>1732</td>
<td>Purple 1730</td>
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<table>
<thead>
<tr>
<th>Oxide</th>
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<th>1732</th>
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<tr>
<td>SiO₂</td>
<td>~70</td>
<td>~71</td>
<td>~75 (?)</td>
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<td>15.1</td>
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<tr>
<td>CaO</td>
<td>5.95</td>
<td>5.30</td>
<td>3.10 (?)</td>
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<td>K₂O</td>
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<td>0.38</td>
</tr>
<tr>
<td>MgO</td>
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<td>0.70</td>
<td>0.72</td>
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<td>1.95</td>
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</tr>
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<td>2.0</td>
</tr>
<tr>
<td>CuO</td>
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<td>0.000x</td>
<td>0.00x</td>
</tr>
<tr>
<td>Ag₂O</td>
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<tr>
<td>PbO</td>
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<td>0.00x</td>
</tr>
<tr>
<td>SrO</td>
<td>0.03</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Li₂O</td>
<td>0.000x</td>
<td>0.000x</td>
<td>0.000x</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>0.04</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>P₂O₅</td>
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<td>SiO₂*</td>
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<tr>
<td>CaO*</td>
<td>6.01</td>
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<td>3.16</td>
</tr>
<tr>
<td>K₂O*</td>
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<td>0.43</td>
<td>0.39</td>
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<tr>
<td>MgO*</td>
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<td>0.74</td>
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<tr>
<td>Al₂O₃*</td>
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<tr>
<td>Fe₂O₃*</td>
<td>0.30</td>
<td>0.51</td>
<td>0.72</td>
</tr>
</tbody>
</table>

*Elements in early glasses and appear to be present at the usual concentrations.

j. We have unpublished analyses of the painted and enameled areas of other Roman glasses and of Islamic enamels and luster-decorated glasses. Unfortunately, however, these analyses cannot be related directly to those reported here because the Sedeinga fragment lent for analysis did not contain enameled areas.

**Analyses of Some Other Glasses from Sedeinga**

Samples of nine other glasses excavated at Sedeinga were also submitted by Professor Leclant. Because they were not useful for restoration, small portions were sacrificed for quantitative atomic absorption analyses and qualitative emission spectrography.

The analyses, reported in Table 2,17 are especially interesting in that the glasses fall into two distinct compositional groups. The first five glasses (nos. 1726, 1727, 1728, 1731, and 1733) are typical of high K₂O-high MgO glasses made with soda derived from plant ashes. They also have high manganese (MnO) contents corresponding to levels of an intentional additive. The other four glasses (nos. 1725, 1729, 1732, and 1730) are of the low K₂O-low MgO type, and they are typical of glasses made with natron. They contain antimony at levels of an intentional additive, but manganese only as an impurity. (No. 1730, a purple glass, contains manganese as a colorant, and it consequently would not be expected to contain antimony.)

Besides their differences in potash and magnesia, the two groups have different levels of the major ingredients, soda (Na₂O) and lime (CaO). Moreover, the high K₂O-high MgO glasses are much richer

---

Fig. 7. Sedeinga glasses, % Na₂O* vs. % CaO*. Circles = natron-type glasses; squares = plant ash-type glasses; shaded square = no. 1733.

Fig. 8. Sedeinga glasses, % K₂O* vs. % MgO*.

Fig. 9. Sedeinga glasses, % Al₂O₃* vs. % SiO₂*.

Fig. 10. Sedeinga glasses, % P₂O₅ vs. % MgO.

in phosphorus (P₂O₅) than are the natron-type glasses. This further substantiates that the soda used in making the high K₂O-high MgO glasses had been derived from plant ashes.¹⁸ All of these differences are readily apparent in the graphs shown in Figures 7–10. The differences can also be seen in Table 3, which reports the mean compositions of the two groups, along with 90% confidence limits.

The compositional differences separating the glasses from Sedeinga represent two distinctly different glassmaking traditions and/or regions. The first group, made from plant ash, relates geographically to Sasanian and Islamic glasses and to their Near Eastern forerunners; the other group relates

TABLE 3

Mean Compositions of Sedeinga and Begram Glasses

<table>
<thead>
<tr>
<th></th>
<th>Sedeinga Plant Ash (n = 4)††</th>
<th>Sedeinga Natron (n = 3)†††</th>
<th>Begram† (n = 5) ± 90% Conf.limits</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>± 90% Conf.limits</td>
<td>± 90% Conf.limits</td>
<td>± 90% Conf.limits</td>
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<tr>
<td>SiO₂*</td>
<td>62.7</td>
<td>64.16</td>
<td>65.6</td>
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<td>65.6</td>
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<td>71.8</td>
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<td>Na₂O*</td>
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<td>15.9</td>
<td>17.3</td>
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<tr>
<td></td>
<td>16.6</td>
<td>19.3</td>
<td>22.0</td>
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<tr>
<td>CaO*</td>
<td>9.9</td>
<td>10.2</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>5.57</td>
<td>6.2</td>
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<tr>
<td>K₂O</td>
<td>2.1</td>
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<td>3.2</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>0.42</td>
<td>0.49</td>
</tr>
<tr>
<td>MgO*</td>
<td>2.6</td>
<td>2.73</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>0.27</td>
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<td>0.79</td>
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<tr>
<td>Al₂O₃*</td>
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</tr>
<tr>
<td></td>
<td>1.8</td>
<td>1.93</td>
<td>2.1</td>
</tr>
<tr>
<td>Fe₂O₃*</td>
<td>1.5</td>
<td>2.30</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>0.40</td>
<td>0.57</td>
</tr>
</tbody>
</table>

† Electron microprobe analyses by Stephen S. C. Tong of Corning Glass Works.
†† Excludes no. 1733.
††† Excludes no. 1730.

geographically to some Syro-Palestinian and some Egyptian glasses and to many glasses found in Italy and the Rhineland.

The four natron-type glasses came from the same tomb (W T8) as the two blue flutes. In comparing the qualitative analysis of the blue flute (Table 1) with the quantitative analyses of the other glasses, one cannot go much beyond noting that all contain antimony and that none contains additive manganese. However, one of the natron-type glasses, no. 1725, is also a thin-walled flute—a colorless glass with lightly cut horizontal bands of decoration, a raised threaded band below the rim, and no painting or enameling. It is, in fact, one of two similar colorless flutes from Tomb W T8 (Leclant’s figures 2-4). They are about half again the diameter of the blue flutes and nearly twice as tall, but in their methods of construction and their overall appearance, they bear a marked resemblance to the blue flutes. It seems likely that both the colorless and blue flutes were made in the same place at about the same time. If we knew where the colorless flutes were made, we could guess where the blue flutes were made. The other three natron-type glasses, obviously companion pieces to the colorless flutes on a compositional basis, are no. 1729, a bowl with deep-cut, rounded, and slightly elliptical facets; no. 1730, a purple bowl or cup; and no. 1732, a small white opaque gaming piece. The other two pieces from Tomb W T8 are plant-ash glasses: no. 1731, a thin-walled, aqua fragment of blown glass; and no. 1733, another gaming piece.

The analysis of the gaming piece no. 1733 is worth noting. This object is just the same as the white opaque gaming piece no. 1732, except that it is a very dark olive color—so dark, in fact, that we chose to describe it as black. From the graphs of the data, it can be seen that this glass, although categorized as a plant-ash glass, always lies intermediate between the two groups. If this glass had been made from a remelted mixture of broken bits of glass from these two groups, this is precisely what its composition would be. One cannot help but wonder if the little gaming pieces were made locally from bits of broken objects that had not survived a lengthy transit to Nubia.

We have analyzed a fragment of an enameled colorless beaker from Begram19 and five other col-

orless Begram glasses (as yet unpublished). The compositions of the Begram glasses (summarized in Table 3) are quite similar to the antimony-containing, natron-type Sedeinga fragments—similar enough, in fact, that one can certainly say they come from the same general glassmaking traditions and possibly from the same region. This is true even allowing for the fact that the Begram glasses are at least a century earlier and that they differ stylistically in their shapes and, where present, enameled decoration. The similarities in chemical composition are evident in Figures 11–13.

A Lead Isotope Determination

The determination of isotope ratios in ancient samples of lead, or lead extracted from ancient objects, offers valuable information on the possible geographical origins of those objects. This method, which is thoroughly discussed in the literature, was applied to a specimen of galena ore (lead sulfide) excavated in one of the Sedeinga tombs. The analysis was carried out by Dr. J. Lynus Barnes of the National Bureau of Standards. The results are shown below.

\[
\begin{array}{ccc}
\text{Pb}^{207}/\text{Pb}^{206} & 0.83196 \\
\text{Pb}^{208}/\text{Pb}^{206} & 2.0725 \\
\text{Pb}^{204}/\text{Pb}^{206} & 0.05300
\end{array}
\]

on an electron microprobe by Stephen S. C. Tong of Corning Glass Works in March 1987. At present, we have some two dozen additional samples of Begram glass which are being analyzed. These were provided by the Musée Guimet.

David Whitehouse tentatively dates the Begram glasses to about A.D. 50–125.

The sample has an isotopic composition significantly different from the vast majority of the more than 1,600 other ancient lead-containing objects we have studied so far, and two facts emerge quite clearly. The Sedeinga lead is entirely different from leads present in the early Egyptian objects we have studied. Those are all of much earlier date (Dynasties VI to XVIII), and they are believed to have originated in mines in the Eastern Desert. The sample is also markedly different from Laurion leads and from the type of lead most commonly found throughout the eastern Mediterranean at sites dating from the period of the Sedeinga tombs—our so-called Levantine type of lead.

Thus, the Sedeinga specimen came from a mining region as yet unfamiliar to us, possibly a local Nubian mine or a mine connected with trade routes we have yet to encounter. Future analyses of kohls and galenas from this part of the world should eventually lead us to an identification of that source.

Some Observations on the Animals

The author asked George Schaller of the New York Zoological Society whether it might be possible to make precise identifications of the species of the animals painted on the blue flutes (Figs. 2–4). Dr. Schaller examined photographs of the flutes and consulted with William Conway, director of the New York Zoological Society, and Richard Estes, curator of mammals at the Philadelphia Academy of Sciences. Their consensus was that one could not be certain as to just what the animals were intended to be.

Dr. Schaller noted that one creature is obviously a deer and that some of the candidates considered were the Atlas stag (a relative of the red deer), the Persian fallow deer, and the axis deer (or chital). The ideas for the other creature ranged from gazelle to oryx to goat—both wild and domestic. Some characteristics that would serve to identify the species are the general body shape; the shape of the head, the tail, and the horns (their length, shape, and spiraling); the black slash on the shoulder; and the lack of a beard. Dr. Schaller remarked that one can read all sorts of animals into those pictured, but that unfortunately one can also find arguments against any of the identifications they considered.23

It may be concluded, then, either that the artist did not have particular animals in mind or that, if he did, the animals were not rendered faithfully. The latter could indicate that the artist was an unskilled painter or a poor observer of nature, or that he was simply exercising artistic license. Alternatively, of course, the artist might have been attempting to paint, sight unseen, some exotic animals from faraway places.

Sample Descriptions

Footed Flute from Sedeinga

Rim fragment of blue transparent flute with gilded and enameled border decoration. Leclant no. W T8 c13; no. 230 in the Michela Schiff-Gior- gini Collection, University of Pisa. This sample

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23. Similar problems exist with the “painted” glasses from Begram. For example, one glass we analyzed (Kabul Museum no. 58.1.3) contains human and animal figures with widely diverse geographical associations. These figures include fish that Hackin judged to be from “the Ethiopian Sea”; an unmistakable tiger, whose native habitat could only be Asiatic; and a dark-skinned slave clad in a loincloth made of the skin of a spotted cat—presumably of African origin. There is also an antelope-like figure with long, straight horns projecting back in the plane of the forehead, like those of an oryx. This creature has what this author reads as a shoulder slash, a large dark eye patch, and a horizontal stripe on its flanks; the latter two features are also reminiscent of an oryx. See reference cited in note 19 and J. Hackin, “Nouvelles Recherches Archéologiques à Begram,” Mémoires de la Délégation Archéologique Française en Afghanistan, v. 11, Paris, 1934, no. 54 and figs. 257–260.
number refers to the blue glass body. Greatest dimension ca. 4.0 cm, wall thickness 1.1 mm.

1721
Gilded region of the above fragment. The gold-leaf decoration covers a band of yellowish green enamel and is outlined by a black organic paint. Two thin red opaque enamel bands are also in this region.

1722
Bluish white blob of enamel.

Other Glasses from Sedeinga

1725
Fragment of Leclant's large flute no. 1, colorless with lightly cut horizontal bands, few patches of light weathering scum. W T8 c26; Kh. 20418. (Leclant's figs. 2 and 3.) [A]

1726
Fragment of blown vessel, bluish aqua, no weathering. Possibly the corner of a square bottle similar to vessel from Tomb W T6. [B]

1727
Fragment of heavy-walled blown vessel, possibly an unguentarium, bluish aqua, no weathering. Believed similar to vessels from Tomb W T6. (Leclant's fig. 1.) [C]

1728
Fragment of flat glass, probably window glass, possibly a large vessel, bluish aqua, with very large blisters, some surface scum. [D]

1729
Fragment of bowl with deep-cut, rounded decoration, colorless, lightly weathered. Believed to be W T8 c27. [E]

1730
Fragment of bowl or cup, purple, some weathering scum. Resembles W T8 c20 and c28. [F]

1731
Fragment of thin-walled blown vessel, bluish aqua, no weathering. W T8 c37i. [G]

1732
Fragment of small gaming piece, white opaque, some surface scum and erosion. W T8 c16. [H]

1733
Small bits of gaming piece, “black” transparent glass (actually dark olive), some surface weathering. W T8 c16. [I]

Pb-809
Small lump of galena (lead sulfide) found in one of the tombs. Used for lead isotope determination. [J]