

gaude & glōsa v̄e marie uir-  
ginis in cēssione ap̄esenti  
liberari tristitia & futura p̄  
firmitate p̄. do.



Oni  
te no  
deus  
salu  
tans  
nost.

**E**t

auerte iram tuā a nobis.

**D**eus in adiutoriū meū



---

RICHARD NEWMAN

## Technical Examination of an Ancient Egyptian Royal Pectoral

THE pectoral from the collection of the Museum of Fine Arts, Boston, is an elaborate example of Egyptian jewelry, combining silver and gold with natural stone and two colors of glass. In spite of the weathering of the glass inlays, the losses of material, and other damages, the interplay of golden metal with inlays of various colors and opacities can still be appreciated. Although it is unlikely that any of the techniques or materials used by the craftsmen who created this piece was unusual in Egyptian art, this matter is still one of some speculation, as extant descriptions of similar objects often are not very detailed. Small samples of most of the materials used in the creation of this pectoral were analyzed for this report in order to characterize the piece in as much detail as possible.<sup>1</sup>

The metal framework is made of silver, which probably was cast in the form of ingots and then hammered to its present thickness of less than 1 mm. It appears that three separate pieces were cut in order to form the body and wings of the vulture. Strips of silver about 3 mm wide and 0.5 mm thick were cut and soldered to the substrate to form compartments for the inlays. An x-ray fluorescence analysis of a joint between the backing sheet and one of the strips detected about 11% copper, showing that the piece was joined with a hard (silver-copper) solder of a type commonly used by silversmiths.<sup>2</sup>

Electron beam microprobe analysis of a polished section of the backing showed that the silver is relatively pure, containing about 2.5% copper, 0.3% gold, and 0.1% lead.<sup>3</sup> There is still considerable uncertainty regarding the sources of the silver used in ancient Egypt.<sup>4</sup> Deposits of native silver were one important source. Silver derived from foreign ores of lead was also widely used, particularly in later periods. Low gold content (usually less than 0.5%) and some lead, which remained from the smelting process, are typical of silver metal derived from ores such as galena (lead sulfide). The silver used in the Boston pectoral was probably of this type. Although the geographic origins of foreign silver utilized in Egypt have yet to be identified, the metal could have been imported in the form of ingots, or perhaps even as objects that were melted down for reuse.

The copper content of the backing is rather high to have been a natural component of the silver; thus copper was probably added intentionally in order to harden the silver and make it more resistant to wear, a practice that apparently was used sporadically, beginning in the earliest periods in ancient Egypt.<sup>5</sup>

Gold foil was used to sheathe the upper surfaces of the silver bands that demarcate the compartments, so that when the pectoral is viewed from the top, only gold metal is visible and the piece appears to have

---

RICHARD NEWMAN is *Research Scientist, Research Laboratory, Museum of Fine Arts, Boston.*



been made from solid gold. This procedure may have been followed because gold was less readily available (and consequently more expensive) than silver at the time the pectoral was made. However, there could be other explanations for the use of the two metals, as Peter Lacovara discusses in his article, pp. 18–29.

Strips of gold foil were folded over the silver bands, the foil usually extending only about 0.5 mm down the sides of the bands. The foil was then hammered into place in order to contact the underlying silver as closely as possible, and then heated, creating a strong bond by diffusion. Electron beam microprobe analysis of a minute polished section of foil (whose thickness ranged up to 0.13 mm) showed a region about 30 to 40  $\mu\text{m}$  wide (0.03 to 0.04 mm) on both sides of the boundary between the gold foil and the silver substrate, in which silver had diffused into gold and gold into silver.<sup>6</sup> Although some edges of the foil overlays have lifted, in most areas the bond between foil and silver remains sound.

The composition of the gold foil itself, as determined by microprobe analysis of areas well away from the diffusion zone, is 87% gold, 12% silver, and 1% copper, a composition not unusual for Egyptian gold.<sup>7</sup> In fact, the gold covering of this pectoral could simply be native material that was hammered to the thickness of foil, without any refining or alloying. The surfaces of the foil show striations, indicating that they were burnished following application.

More than four hundred individual pieces of inlay were used to create the image of the vulture. In most cases, a single piece filled a given compartment, but in some instances several pieces were fitted together. The inlays are of three different types. The red ones (of which there were originally about 112) are made of the natural stone carnelian, one of the microcrystalline varieties of silica used in ancient Egypt for amulets, beads, and other small objects; this stone was found in many areas of the Eastern Desert, where it was collected in the form of pebbles.<sup>8</sup> Individual pieces of stone would have been shaped by chipping, and then polished smooth with abrasives.

Two types of glass were also used as inlays: an opaque light blue variety (about 107 individual pieces) and a darker, mottled purple one (about 190 pieces). Many small chips are missing along the edges of the blue inlays, as would be expected with pieces that were individually shaped to fit into their compartments. The purple glass was inlaid in a semimolten state; see discussion below.

All inlays whose edges can be seen vary from 0.5 to 1.0 mm in thickness. The compartments, each about 2.5 to 3.0 mm deep, were filled initially with a light blue paste consisting of ground gypsum and Egyptian blue pigment in order to make up the difference between the depth of the compartments and the thickness of the inlays. The lathlike appearance of gypsum crystals in this paste, a form not encountered in the natural mineral, indicates that the paste was actually gypsum plaster.<sup>9</sup>

Gypsum plasters, simple to make, were common in ancient Egypt and were employed for various purposes, including architectural uses. When partially dehydrated by heating and then mixed with water, natural gypsum sets chemically during rehydration, but it does so with a change in the microscopic appearance of its crystals. The blue-tinted plaster filling the compartments seems to conform quite closely to the shapes of the inlays, evidence that the inlays were most likely simply pressed into the partially set plaster. After setting, excess plaster, which may have squeezed up around the edges of the inlays, would simply have been wiped or scraped away. No additional adhesive would have been required to hold the inlays in place.<sup>10</sup>

As the fitting of the inlays was not very precise, the paste is visible between most of the inlays and the metal strips. The light blue color has little if any influence on the appearance of the glass inlays, both types of which are relatively opaque; perhaps the plaster filling was tinted merely to make it less obtrusive where it showed. However, the use of this type of paste in the vulture pectoral may simply represent traditional practice rather than any deliberate aesthetic function.

The blue paste appears under all three types of inlays, but where carnelian inlays were used, it was covered with a thin, dark layer consisting mainly of the yellow pigment orpiment (arsenic trisulfide), mixed with a lesser amount of the orange pigment realgar (arsenic disulfide), with which orpiment appears in nature. Microprobe examination of two small cross sections suggests that these pigments were simply bound with the gypsum plaster; perhaps fragments of the yellow and orange minerals were dusted into the partially set plaster before the carnelian pieces were pushed into place. The black appearance of the matrix that surrounds the grains of orpiment and realgar appears to have resulted from interaction between those sulfide pigments and the silver substrate. The original color of the paste beneath the carnelian inlays was probably bright yellow or yellowish orange, which would have complemented the semitransparent inlays by reflecting a warm color from behind them.

The mottled glass inlays appear to fit more closely into their compartments than do either the blue glass or the carnelian ones, and the edges of the former group have no small chips. This fact, and the manner in which a number of these purple inlays have cracked, suggests that they were pressed into their compartments in a semimolten state (fig. 1). Probably because these inlays were very hot when put into place, they interacted with the plaster substrate to form a stronger bond than did the other two types of inlaid materials (fig. 2).

The two types of glass differ not only in color, but quite substantially in the degree of degradation they have suffered. The blue glass, although frequently covered by thick, iridescent layers of weathering, seems nevertheless relatively unaltered, and freshly broken edges reveal

its original light blue, opaque color. The purple glass has weathered very badly, and many losses have occurred in the areas inlaid with it. When examined under a microscope, this material seems in great measure to consist of clear or translucent parts as well as opaque cream or beige ones. In some cases the clearer areas grade into the opaque regions; in others there are sharp interfaces. This suggests that these inlays were originally mottled, with alternating dark, translucent areas and lighter, more opaque areas.

Small fragments of both types of glass were prepared as polished cross sections and quantitatively analyzed in an electron-beam microprobe (Table 1).<sup>11</sup> The blue glass (fig. 3) takes its color from a small

TABLE 1

Results of Microprobe Analyses of Glass Samples from an Ancient Egyptian Pectoral

| Oxide                          | Percentages found<br>in light blue glass<br>(clear areas)* | Percentages found in mottled glass |                        |
|--------------------------------|------------------------------------------------------------|------------------------------------|------------------------|
|                                |                                                            | Transparent<br>areas†              | Opaque white<br>areas‡ |
| Na <sub>2</sub> O              | 15.33 (±0.47)                                              | 0.16 (±0.17)                       | 0.22 (±0.03)           |
| MgO                            | 3.49 (±0.05)                                               | 2.20 (±0.52)                       | 5.01 (±1.10)           |
| Al <sub>2</sub> O <sub>3</sub> | 0.82 (±0.15)                                               | 0.27 (±0.07)                       | 0.49 (±0.08)           |
| SiO <sub>2</sub>               | 65.35 (±1.47)                                              | 79.18 (±2.50)                      | 77.84 (±1.23)          |
| K <sub>2</sub> O               | 2.71 (±0.04)                                               | 0.04 (±0.02)                       | 0.11 (±0.02)           |
| CaO                            | 9.55 (±0.18)                                               | 1.35 (±0.29)                       | 1.93 (±0.21)           |
| MnO                            | ND                                                         | 1.73 (±0.15)                       | 1.97 (±0.09)           |
| FeO                            | 0.53 (±0.09)                                               | 0.13 (±0.03)                       | 0.19 (±0.02)           |
| CoO                            | ND                                                         | ND                                 | ND                     |
| CuO                            | 0.84 (±0.05)                                               | 1.43 (±0.26)                       | 1.86 (±0.31)           |
| As <sub>2</sub> O <sub>5</sub> | 0.06 (±0.01)                                               | 0.04 (±0.02)                       | 0.13 (±0.06)           |
| SnO <sub>2</sub>               | ND                                                         | ND                                 | ND                     |
| Sb <sub>2</sub> O <sub>5</sub> | 1.26 (±0.21)                                               | ND                                 | ND                     |
| PbO                            | ND                                                         | ND                                 | 0.14 (±0.08)           |
| Total                          | 99.94 (±1.76)                                              | 86.53 (±2.38)                      | 89.89 (±0.65)          |

NOTES:

ND = not detected (minimum detectable levels were 0.08% for PbO, 0.07% for CuO, 0.06% for CoO, and 0.02–0.04% for all other elements).

\* Average of five spots from three separate samples (± one standard deviation). Visible inclusions of calcium-antimony oxide were avoided during the analyses; consequently the overall Sb<sub>2</sub>O<sub>5</sub> content of the glass is higher than the reported value.

† Average of five spots from three separate samples (± one standard deviation).

‡ Average of three spots from two separate samples (± one standard deviation).

Fig. 3. Back-scattered electron micrograph of polished cross section of a light blue glass inlay. The outer surface of the inlay is at the top. Magnification 400x, width of field 0.26 mm. The dark gray concentric arcs near the outer surface are layers of weathered glass; in places nearly three dozen of these, extending about 0.1 mm into the unaltered interior, are visible. The bright white specks and strings within the glass are inclusions of calcium antimonate, which give the glass its opacity.

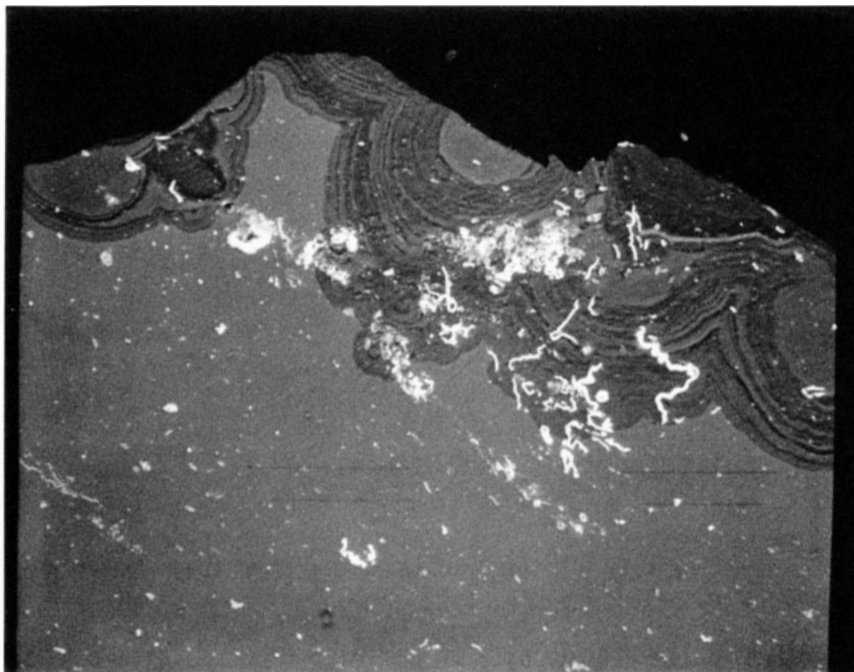
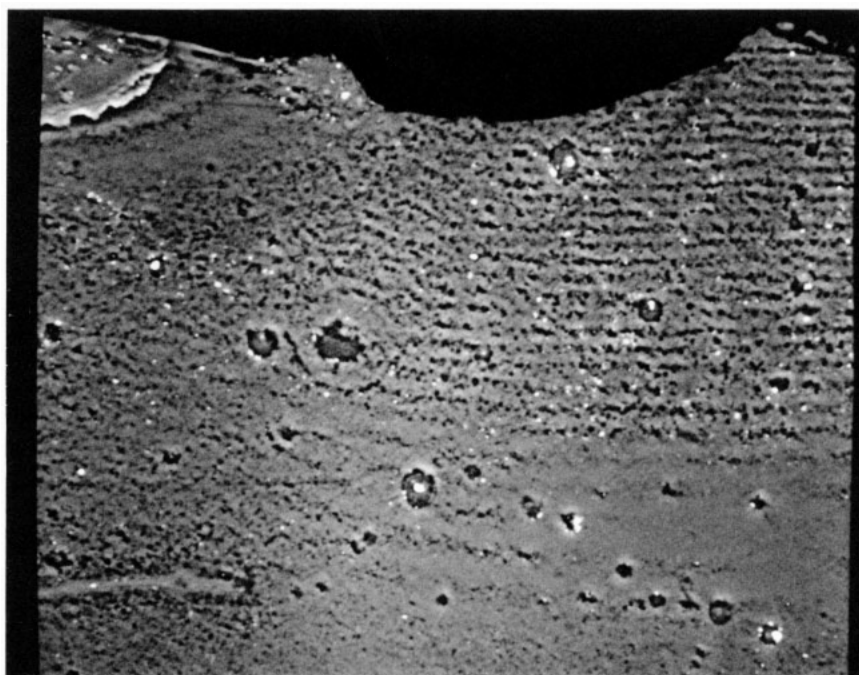


Fig. 4. Back-scattered electron micrograph of polished cross section of a mottled glass inlay. The outer surface of the inlay is at the top. Magnification 800x, width of field 0.13 mm. The outer surface of the chip shows no layers of weathering. The inlay is peppered with small pores that run in lines roughly parallel to the surface.



amount of copper. Cobalt, which has also been identified as a colorant in ancient Egyptian glasses, was not detected.<sup>12</sup> The blue glass contained no more than traces of either tin or lead, suggesting that the color derived from a fairly pure copper ore or metal rather than from bronze filings. The glass was rendered opaque by the incorporation of calcium antimony oxide, the only opacifier that has been found in glasses of this early period. The general composition of this blue glass closely matches the profile of certain glasses of the second millennium B.C.<sup>13</sup> Typical of these early glasses are levels of magnesium oxide which range from 2 to 5%, and levels of potassium oxide of 1 to 3%.

The basic raw materials required to manufacture glass are sand (the source of silica), some source of alkali elements, and small amounts of colorants or opacifiers. The levels of alkali elements (sodium, magnesium, calcium, and potassium) in glasses of the second millennium B.C. indicate that natron, a mixture of salts which crystallizes on the edges of ponds and lakes, was not used in their manufacture.<sup>14</sup> In ancient Egypt, natron from places such as Wadi al-Natrun and El Kab appears to have been used in glasses of the Roman period and later eras, but not earlier. Although the alkali sources used in the manufacture of earlier glasses – such as those inlaid in the pectoral – are not known, residues from evaporation of water from the Nile River could have provided the proper combination of elements. It is also possible, however, that the glass used in the pectoral was imported.

The analyses of the mottled glass (Table 1) need to be interpreted with caution because of its poor condition. Interestingly, the level of magnesium oxide in this glass falls within the expected range for the high-magnesia category of ancient glasses, into which fit virtually all glasses from the second millennium B.C. By contrast, calcium oxide is present at a considerably lower level than is expected for this category. Calcium is known to stabilize alkali glasses, and perhaps this element was present at an unusually low level in the purple glass, resulting in an unstable composition that was more subject to degradation than that of the blue glass. It seems unlikely that the present ratio of calcium oxide to magnesium oxide in the mottled glass (about 0.5) would be so different from that of the blue glass (about 2.7) if they had not originally been quite different. To the best of this writer's knowledge, no other analyses of such an unstable glass in Egyptian artifacts have been published.

Iron (0.1 to 0.2%), manganese (1.7 to 2.0%) and copper (1.4 to 1.9%) are all present in this glass, although the very low level of iron indicates that it was probably an unintentional contaminant. Combinations of these three elements in various amounts are typical of Egyptian glasses.<sup>15</sup> Many colors can be produced from such combinations, depending on their relative concentrations, on other components in the glass, and on the conditions of the furnace used. The translucent areas

of the mottled inlays appear pinkish violet in transmitted light, and it is probable that they were originally violet in color.

As discussed by Lacovara, the dating of this pectoral is somewhat problematic. Although analysis of materials can sometimes be valuable in helping to establish origins for artifacts, given the scope of current knowledge of Egyptian materials, none of the components of this pectoral support an origin in the New Kingdom rather than in the Middle Kingdom.

#### NOTES

1. X-ray diffraction and x-ray fluorescence analyses of the silver solder were made during an examination by Lambertus van Zelst and Pamela England (unpublished report, Research Laboratory, Museum of Fine Arts, Boston, June 1981).
2. Analyses were made using a 1 mm-diameter nickel-filtered tungsten x-ray source and an EG & G Ortec energy-dispersive x-ray detector and data processing system; the composition was calculated with reference to a standard silver alloy. Due to interference from the surrounding silver substrate, the actual copper content of the solder may be higher than is indicated by the analysis.
3. Analyses were carried out using wavelength-dispersive x-ray fluorescence in a Cameca MBX microprobe with a Tracor-Northern 5500 x-ray analyzer system (Department of Earth and Planetary Sciences, Harvard University). Pure element standards were employed and matrix corrections determined by the ZAF method. Six separate spots were analyzed and an average calculated.
4. N. H. Gale and Z. A. Stos-Gale have summarized current knowledge regarding this material in "Ancient Egyptian Silver," *Journal of Egyptian Archaeology*, vol. 67 (1981), pp. 103-115.
5. *Ibid.*
6. Analyses were done using wavelength-dispersive x-ray fluorescence with pure element standards and ZAF matrix corrections. The extent of diffusion was determined by carrying out spot analyses, moving away from the boundary at regular intervals.
7. Z. Stos-Fertner and N. H. Gale, "Chemical and Lead Isotope Analysis of Ancient Egyptian Gold, Silver and Lead," *Archaeo-Physika*, vol. 10 (1979), pp. 299-314.
8. A. Lucas and J. R. Harris, *Ancient Egyptian Materials and Industries* (London, 1962), pp. 391-392.
9. W. David Kingery, Pamela B. Vandiver, and Martha Prickett discuss the microscopic appearance of gypsum plasters and rocks in "The Beginnings of Pyrotechnology, Part II: Production and Use of Lime and Gypsum Plaster in the Pre-Pottery Neolithic Near East," *Journal of Field Archaeology*, vol. 15 (1988), pp. 219-244.
10. Microchemical tests for carbohydrate and protein binding media were carried out on small samples of the blue paste. For carbohydrates, the furfural test was used (Fritz Feigl, *Spot Tests in Organic Analysis*, translated by Ralph E. Oesper [Amsterdam, 1960], p. 426); for proteins, a test with ninhydrin was done on a hydrolyzed fragment (*ibid.*, p. 293). Neither test gave a positive result.
11. Analyses were done using wavelength-dispersive x-ray fluorescence with a variety of natural and synthetic mineral standards; matrix corrections were made with the Bence-Albee (empirical) method. A 12  $\mu\text{m}$  raster was employed in order to minimize the possibility of damage to the glass during the analyses.
12. The limit of detection in the analyses was 0.06% for this element.
13. E. Sayre and R. Smith, "Analytical Studies of Ancient Egyptian Glass" in A. Bishay, ed., *Recent Advances in Science and Technology of Materials*, vol. 3 (New York, 1974), pp. 47-70. The earliest Egyptian glasses in this study date from the New Kingdom.
14. *Ibid.*
15. Earle R. Caley, *Analyses of Ancient Glasses 1790-1957* (Corning, New York, 1962), pp. 67-82.