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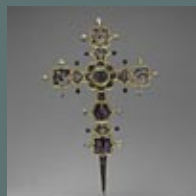
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Figure 1

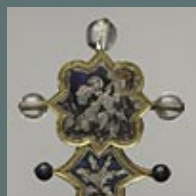


Figure 2



Figure 3

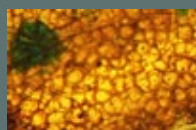


Figure 4

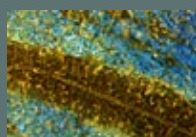


Figure 5

***Basse Taille* Enamel**

[Ursula Kugler](#)

An Italian, late-medieval processional cross in the collection of the Department of Medieval Art ([Figure 1](#)) is one of several related works that have not been exhibited for as long as five decades, largely because their *basse taille* enamel decoration has been severely affected by glass disease and other forms of deterioration. In order to identify the specific causes of decay and to establish safe methods for the treatment and preservation of these fragile works, a research project was designed, also with the hope that they can be safely displayed in the future.

Basse taille describes enamel work produced by firing colored glass frits onto a precious metal surface with chased or engraved decoration. Since light is reflected by the gold or silver substrate, the degree of color saturation within the translucent enameled fields varies with the thickness of the glass layer, a quality used to create a sense of depth and shadow. The Museum's processional cross is decorated, front and back, with scenes from the life of Christ and saints of the Franciscan order in *basse taille* enamel on silver plaques set into cast, gilded copper frames ([Figure 2](#)). Both faces also include a reliquary compartment with transparent rock-crystal cover, while the sides are covered with gilded latticework and embellished with rock-crystal and blue glass bosses.

An important consideration in enamel manufacture is that the molten glass must wet the metal surface effectively during firing, and for this reason, its viscosity often is lowered by raising the concentration of flux. The resulting "high alkali-low lime" glass is inherently unstable, and with time becomes sensitive to moisture (see [Glass disease](#)). Enamels deteriorate not only as a result of glass disease, but also due to the combined effects of several additional factors: the environment, stresses at the glass-metal interface, manufacturing flaws, and previous treatments.

Surface pitting can result from exposure to high levels of humidity, but may also appear during polishing, when gas bubbles trapped in the glass are exposed. Stresses occur in enamels for various reasons, including differences in the rates of contraction and expansion of the glass and metal, the

characteristic softening temperature and viscosity of the glass, and curvature of the substrate. Depending on their source, the resulting damages to the glass can display distinctive patterns. For example, cracks caused by tension form in parallel lines ([Figure 3](#)), or may radiate outwards from centers of stress.

Errors occurring during manufacture that adversely affect the physical stability of enamels include uneven cooling after firing, which can result in cracks, chips, dimpled and pitted surfaces, and bare patches. In humid environments, outdoor pollutants such as sulfur dioxide accelerate deterioration of the enamels, while corrosion of exposed metal substrates weakens adhesion at the glass-metal interface. Similarly, noxious fumes from display and storage materials can generate formaldehyde or acetic acid that effect the stability of both the glass and underlying metal.

Among these possible deterioration processes, it is glass disease that has most severely affected the appearance of the enamels on the processional cross. As a result of surface depletion they have lost reflectance, and the viscous alkaline film formed in the process has trapped dust, dislodged glass fragments, and copper corrosion products. On the surfaces of the blue and green enamels, opaque, angular flakes are delaminating, leaving recesses where they have become dislodged. Although the thicker applications of yellow glass are relatively well-preserved, the thinner layers are highly deteriorated and have developed networks of microscopic cracks ([Figure 4](#)). In more advanced cases larger cracks have appeared, deeply fracturing these crizzled fields.

Small brown discolorations observed within the yellow and purple enamels can be associated with microcracks that have exposed glass below the surface to the environment. More progressed discolorations are present in severely hydrated yellow and purple enamels, where opaque, dark brown sections exhibit extremely porous surfaces. Since the compositions of both discolored and unaffected enamels do not differ significantly except in their coloring agents, it may be that the multivalent colorants present—iron oxide for yellow and manganese oxide for purple—become reactive in hydrated zones. Cobalt seems to play a similar role in the characteristic discoloration of the blue enamels, although in these cases the process appears linked also to the presence of sulfide corrosion on the silver substrate ([Figure 5](#)).

Gases exuded by materials used in vitrines or storage facilities have reacted with the gilded framing elements on the cross, forming hygroscopic corrosion products such as copper formate and copper acetate that migrated into fissures in the enamels, leading to further delamination, while the accumulation of hydrophilic cleaning agents in these recesses also accelerated the deterioration process. Several plaques

were re-enamelled in the nineteenth century and their positions changed, while in subsequent years various waxes and resins were used to fill other losses, stabilize cracks, and revive formerly reflective surfaces. Consolidation with synthetic polymers facilitated the formation of a concentrated corrosive alkali layer on the glass surfaces, while fracturing has resulted from the use of materials with a high glass-transition temperature.

Relatively new on the long list of natural and synthetic adhesives and consolidants applied to cultural materials is Ormocere[®], an organic-inorganic polymer based on acrylic resins and modified silanes originally developed for the

treatment of outdoor bronzes and exterior surfaces of painted glass windows. Recently reformulated specifically for the treatment of enamels, Ormocere® has now been used in several important collections in Germany. This blend of three low-molecular-weight polymers provided excellent results in laboratory tests with respect to adhesion, penetration, and long-term stability, and it has a refractive index very close to that of glass. However, the polymer does not form an impermeable barrier to water vapor, nor is it reversible, and it was ultimately rejected as a consolidant for the Museum's medieval *basse taille* enamels. The problem has now been addressed with a less-than-permanent solution, using a fully reversible consolidant and providing the works with self-contained, passivating environments that inhibit the free exchange of ions and will not cause the enamels to hydrate.

For this purpose a sealed Plexiglas® case was built in which the processional cross can be stored upright. Using silica gel, the relative humidity inside is stabilized at forty percent, just below the point at which potassium ions react with water vapor, while the inclusion of activated charcoal prevents the formation of silver tarnish. Treatment of the enamels included removal of the alkaline layer, silver and copper corrosion products, and old restoration materials, as well as the consolidation of unstable sections. Since a safe storage environment is ensured, Paraloid® B-72 could be used as the consolidant, offering the benefits of reversibility, excellent long-term stability, compatibility with alkaline materials, and a suitable glass-transition temperature. The acrylic resin was applied in a solution of equal parts xylene and ethanol, a mixture that penetrates well, with slow evaporation.

It is the wish of the Department of Medieval Art that in the future its entire collection of Italian medieval *basse taille* enamels will be displayed, and currently, two of the other works examined and treated in the past two years—a second processional cross and a crozier—can be viewed in the Medieval Treasury.

With many thanks to Barbara Boehm, Curator, Department of Medieval of Art and the Cloisters, for her kind support.

Glass disease

Glass is an amorphous matrix of negatively charged silicate ions and metal cations. The main refractory ingredient is silica (SiO_2), to which alkaline substances such as potash (K_2CO_3) or soda ash (Na_2CO_3) are added as fluxes, together with lime (CaO) or magnesium oxide (MgO) as stabilizers.

The incidence of glass disease is directly related to the composition of the affected glass, and the deterioration that occurs can be thought of as a two-phase process. When high flux-low lime glass is exposed to a humid environment, the first step, known as alkali depletion, occurs as alkali ions contributed by the fluxing materials migrate to the surface of the glass matrix, where they are replaced with hydrogen ions present in water vapor. The resulting alkali-deficient, hydrogen-rich layer—the "gel layer" or so-called hydrogen glass—has a lower reflectance. The potassium and sodium hydroxides formed in this process react with carbon dioxide and sulfur dioxide from the air, and the resultant hygroscopic

salts form a greasy, highly corrosive alkali-rich film on top of the depleted glass. In extreme cases, droplets form on the surface of the glass, a phenomenon known as "weeping". When glass affected by glass disease is placed in an environment with a lower relative humidity, the sodium and potassium carbonates form a white precipitate on the surface.

The second part of this process occurs due to the difference in size between the hydrogen and alkali ions. Replacement of the latter with smaller hydrogen ions causes surfaces to contract, leading to fracturing of the glass and exfoliation of the upper layers. Ion exchange will continue at the newly exposed surfaces of these breaks and losses, causing the damage to progressively worsen, eventually resulting in the disintegration of the glass.

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Ursula Kugler first came to the Fairchild Center as an intern in the summer of 1997, returning in 1999 as a Kress Fellow. Since that time she has worked on several projects, in the last two years in her capacity as Sherman Fairchild Fellow. After receiving her certification as a goldsmith, Ursula trained in the Metal Conservation Department at the Bayerisches Nationalmuseum, Munich, and subsequently worked there as a conservator of metal objects. In keeping with her expertise in the field of medieval enamelwork, she now specializes in the conservation of objects of mixed media.

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