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ART, BIOLOGY, AND CONSERVATION:
BIODETERIORATION OF WORKS OF ART
THE METROPOLITAN MUSEUM OF ART

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ARTWORKS, DRAWINGS, PRINTS, AND DOCUMENTS— FUNGI EAT THEM ALL!

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ABSTRACT Our studies have focused on the examination of fungi infesting artworks and artifacts on paper. We have been concerned primarily with the mechanisms of deterioration by fungi and the role played by the composition of the substrates upon which the fungi grow. Several examples illustrate these relationships: (1) infestations that occurred after exposure to periodic floods (18th century Tilghman documents); (2) exposure to water spills (19th century watercolor and ink drawings); and (3) growth occurring in the microclimate of framed artworks exposed to fluctuating relative humidity (18th and 20th century pastel portraits).

Part of our investigation was aimed at the identification and numeration of the vast mycoflora that has been encountered on paper-based collections. Several groups of fungi appear to be common on the materials we examined. While Deuteromycetes (Fungi Imperfecti) dominate, we often find members of the Zygomycetes (bread molds), Ascomycetes (sac fungi) and Saccharomycetales (yeasts). Their growth is often linked to the materials upon which artwork and archival documents are rendered and the environment to which these works are exposed throughout their life. Moreover, fungus growth is often enhanced by the addition of artists' pigments and the great variety of materials, such as varnishes, glazes, and additives, applied later in the life of the artwork. The impact of the environment, specifically the time

of the collections' exposure to moisture, greatly enhances both the number of species and the abundance of fungal growth. This report reviews the current status of our understanding of these fungus-substrate parameters, discusses their impact upon the preservation of collections, and concludes by offering a number of suggestions to consider for future practices when choosing methods of conservation.

INTRODUCTION Fungi are the primary organisms on earth responsible for the necessary process of biodegrading organic material and recycling of nutrients to the environment. However, deterioration of museum and archival collections by fungi is extremely detrimental because it lowers the quality and value of each artwork and artifact. Recognizing elements that contribute to the biodeterioration of any collection is the first step toward avoiding conditions that promote its occurrence. Understanding the causes and mechanisms of deterioration will provide a basis for developing strategies to prevent this damaging process.

Our studies have focused on the examination of fungi infesting artworks and artifacts on paper. The mechanism of deterioration by fungi may depend on the nature of the materials upon which they grow. While the chemical composition of the substrate and media at times determines the type of fungi that will invade, the structure of the media has impact on the aerial growth of the colonies. Moreover, the environment and the length of time of the collections' exposure to moisture greatly enhance the number of species and the abundance of their growth.

Samples of fungi encountered on paper-based collections were cultured and studied in order to identify and enumerate them. Moreover, we reviewed current conservation measures that aim to prevent fungal infestation and suggest methods to remedy the damage that they inflict upon artworks.

MATERIALS AND METHODS This investigation was conducted on artworks and documents delivered by owners of private collections to the Art Conservation Studio (studio of HMS) for the purpose of conservation. Pigments and supports were examined to the extent allowed by the owners. Examinations and analyses of artwork components were conducted in the Microbiological Laboratory and the Electron Microscopy Laboratory (ARC) of the Biology Department at Gettysburg College, Gettysburg, PA.

The following objects were investigated: pastel portraits dated 1860, 1886, and 1973; an ink wash by Lady Diana Beauclerk (1734–1808); a watercolor attributed to Thomas Birch, early 20th century; and an Audubon print, *Pelican* (1838), hand colored and glazed with gamboge. A collection of documents subjected to a series of

floods, reported elsewhere (Szczepanowska and Cavaliere, 2000), supplied enormously rich material and is referenced here for comparative purposes.

Samples of fungi were collected either by lightly scraping the mold (hyphae) with a sterile lancet and transporting it to the laboratory in its sterile packet or by pressing a sterile cotton swab over the mold growth. When possible, samples of secondary supports were transferred to the laboratory wrapped in sterile paper. In some cases, clear cellophane tape was pressed over the sample and the hyphae adhering to the adhesive surface were examined directly (Butler and Mann, 1959).

Once in the laboratory, samples were examined directly and then cultured. In some cases, species producing distinctive conidiospores and conidia could be identified immediately *(Alternaria, Nigrospora, Cladosporium)*; however, in most cases, the fungi were allowed to grow in culture. All samples were plated on a series of traditionally employed fungal media—cornmeal dextrose agar (CMA), Czapek yeast extract agar (CYA), potato dextrose agar (PDA), and Sabouraud dextrose agar (SDA) (Difco, 1984). Cultures were allowed to incubate at room temperature (22–24°C). As soon as hyphal growth became apparent on the agar, the samples were subcultured to obtain unifungal isolates. In an attempt to keep our samples free from contamination, all transfers were performed in a Labconco sterile hood.

In our work we used a Nikon Optiphot with attached camera, FX-35 WA, for light microscopy; a Cambridge Stereoscan 100 and PTG Avalon EDS (for determination of pigment elemental composition as a possible source of nutrients for fungi); and a JEOL 5200 scanning electron microscope. The visual examination under light microscopy was recorded with traditional photography and digitally with a Fujifilm FinePix 4900 Zoom digital camera and Pixera digital microscope.

For light microscopy, specimens were mounted in either distilled water or in a 0.1% Acid Fuchsin solution. For electron microscopy all samples were processed utilizing standard methods of preparation (Dykstra, 1992; Bozzola and Russell, 1999). Small, 2-mm^2 samples of agar supporting fungal hyphae were removed from culture plates and submerged in Karnovsky's fixative for several hours. The samples were then subjected to several 15-minute washes in cacodylate buffer and dehydrated in a graded series of ethyl alcohol. The samples were then further dehydrated in a Tousimis Samdry critical point dryer, mounted on aluminum stubs, and layered with 10 nm of gold in a Denton Desk II gold coater. Under the scanning electron microscope specimens were examined, digitized, and photographed. Digital images were taken with a JEOL Digital Generator and photographed with a Polaroid 545 camera using Polaroid 55 P/N film.

CASE STUDIES

The types of objects that were selected for our study represent a large number of artworks and artifacts created on paper supports, such as pastels, drawings, prints, watercolors, and documents. Although an elevated humidity was the element that undoubtedly initiated fungal infestation in each case, we believe, based on our observations, that all, or certain elements within the artworks' structure either promoted or in some cases prohibited the growth of fungi. In an earlier observation, Strzelczyk (1981) reported that the pigments on polychrome wooden sculptures may actually have some inhibitory effects on fungal growth.

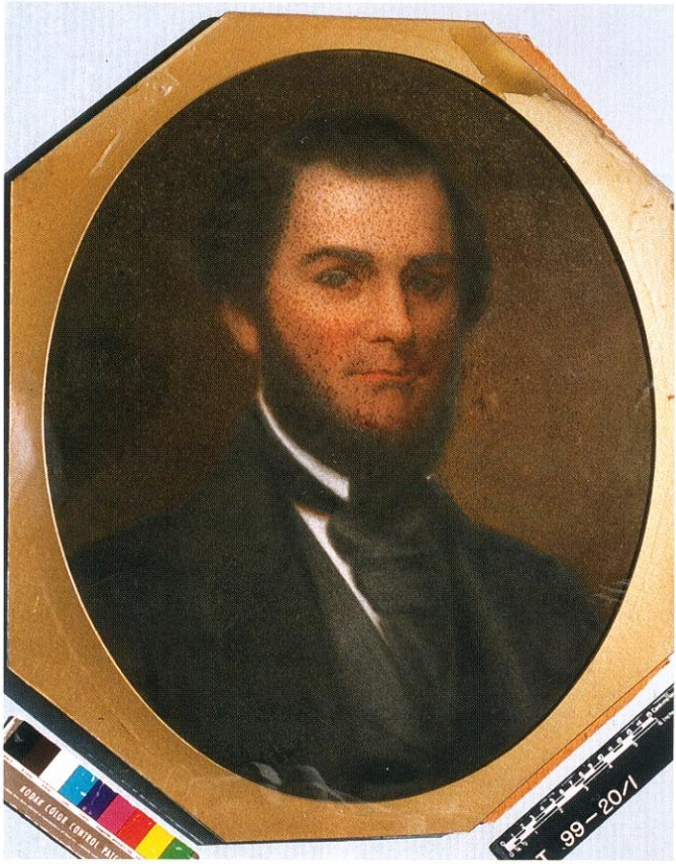
PASTELS

Media Pastel as a medium is a dry colored chalk combined with binder and filler. The pastel drawing is created by strokes of pastel stick on a support that is textured to ensure that the powder attaches to the surface. Natural chalks of various colors are derived from earth. Those occurring naturally are: gray, red, red-ochre, and white. Among pigments that were traditionally used for manufacture of dry-stick pastels are umber raw, natural and burnt sienna, and green earth (Flieder, 1982). Some of the natural pigments, such as those containing iron oxides and hematites, were found on brown and black of the pastel dated 1860.

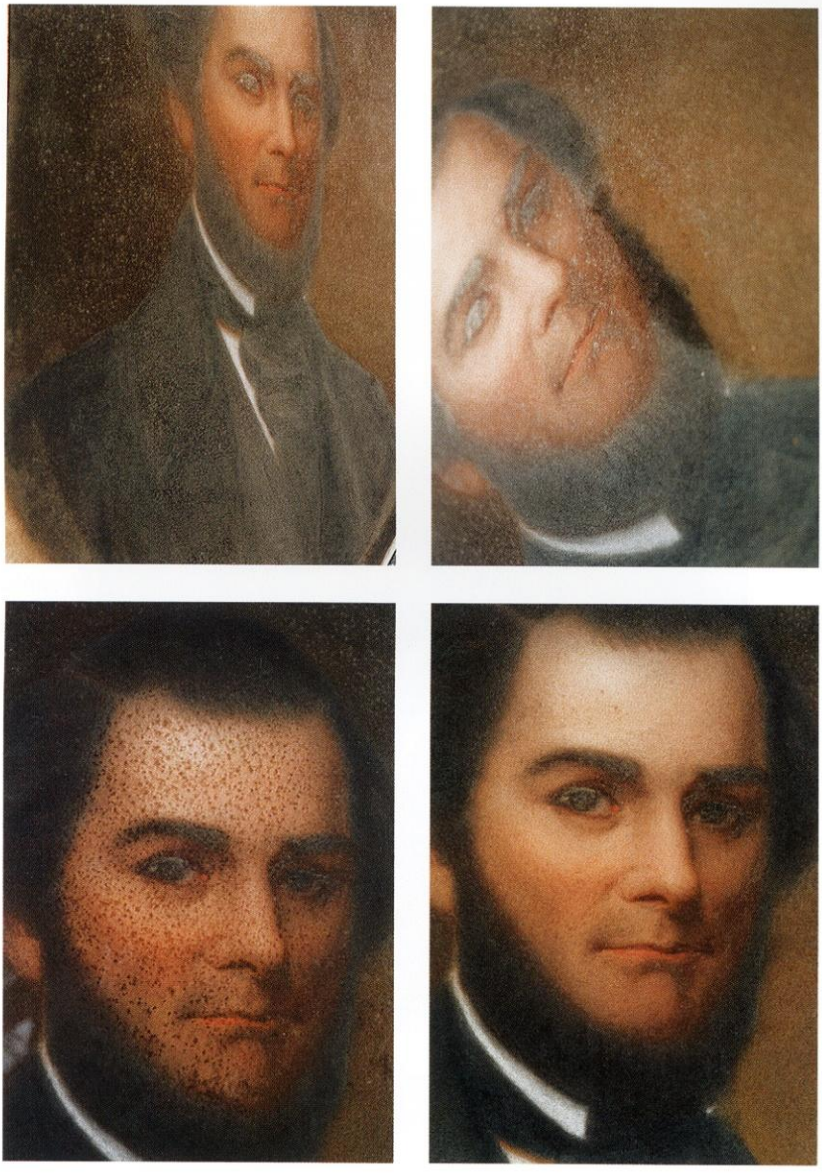
The pigment powder is held together by a small amount of binding medium, 2–3% at most of gelatin solution, gum Arabic, or gum tragacanth. Historically, skim milk was also used as a weak binding material. Plasticizers such as honey or crystallized sugar were added to eliminate brittleness (Doerner, 1984). The composition of pastel itself and the method of its application, as powder lightly arranged on the surface, promotes aerial fungal growth, allowing enough air necessary for their development. Often the aerial growth on pastels is abundant and bushy. The observation that pastels are particularly prone to fungal infestation has been made elsewhere (James et al., 1997).

Support for Pastel Paintings Textured paper, pasteboards, canvas, and parchment, characterized by a distinct texture, provided the means to anchor the pastel powder and to prevent its dislodging. The pastel portraits that we investigated were rendered on pumice paper (1973), textured paper (1860), and paper stretched on canvas (1886).

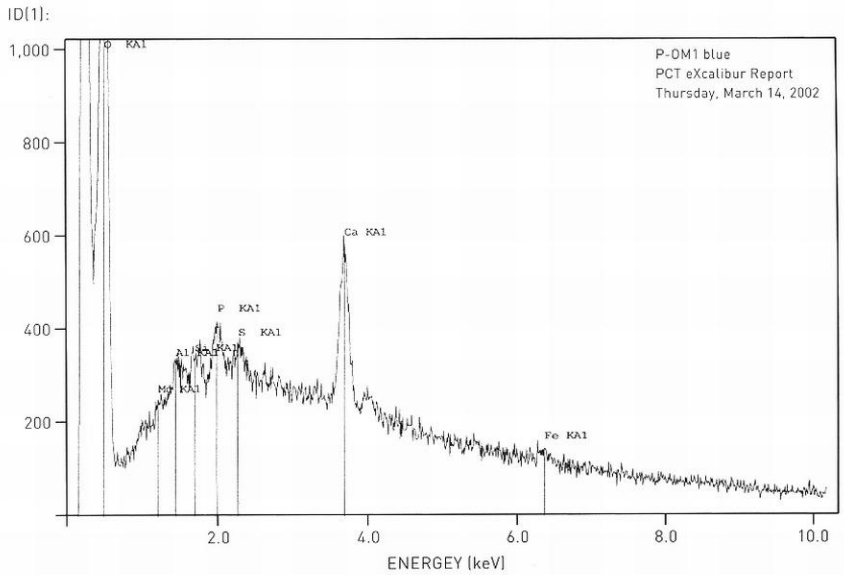
The pastel portrait of a Gentleman (#99.20–1) created in the mid 19th century was drawn on paper and mounted to a board with brown, protein base glue. [FIG. 1]



[1] *Gentleman*, pastel portrait, 1860 (#99.20-1). Overall view. Protein animal glue used for mounting the pastel to an acidic board supported heavy fungal infestation.

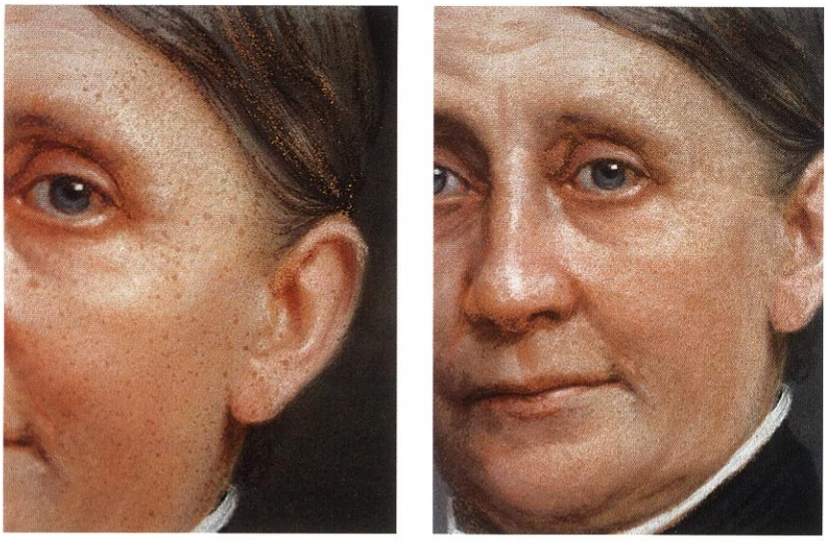


[2] *Gentleman*, pastel portrait, 1860 (#99.20-1). (a) Detail, angular view. Pattern of fungal infestation followed application of earth pigments. (b) Detail before and (c) after conservation treatment.

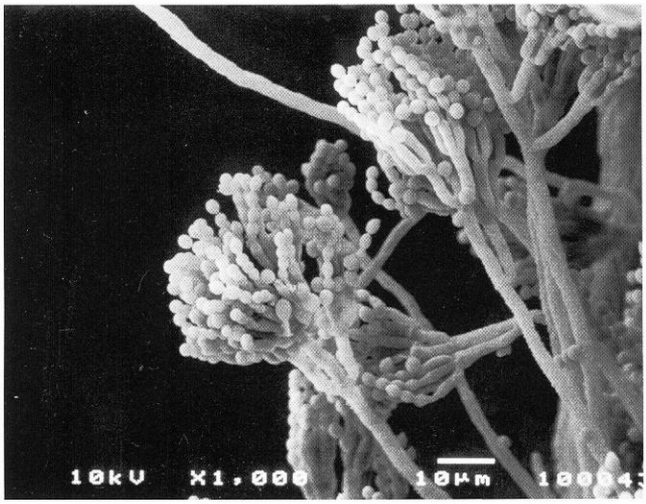


[3] *Gentleman*, pastel portrait, 1860 (#99.20-1). Spectrum produced by SEM Cambridge Stereoscan 100, EDS. Iron oxides in brown and black indicate earth pigments; dominating peak of Ca-base filler, calcium carbonate.

[4] *Hanna*, pastel portrait, 1886 (#02.20). (a) Recto and (b) verso. Pastel executed on paper mounted to canvas with protein, animal glue. Tideline on verso, indicating area exposed to water, corresponds to location of fungal colonies on recto.



[5] *Hanna*, pastel portrait, 1886 (#02.20). (a) Detail of fungus colonies before treatment and (b) after conservation treatment.



[6] *Hanna*, pastel portrait, 1886 (#02.20). *Penicillium sp.* (biverticillium group).

The pattern of extensive fungal growth is one of the best illustrations of the nutritional preferences of fungi in their choice of pigments. The aerial growth concentrated on the areas drawn with dark colors that were primarily earth pigments. [FIG. 2] Pigment analysis indicated the presence of iron oxides and hematites in brown areas of the gentleman's hair and black in the background. [FIG. 3]

The pastel of *Hanna* (1886; #02.20) was executed on textured paper lined with canvas. [FIGS. 4A–B] The brown adhesive used for lining was lightly applied and appeared to be a protein-based animal glue. Variations of gray palette dominated the portrait. Even the light pinkish tones of the face were combined with some amount of the gray pigment. Uniformity in pigment composition was reflected by uniformity of fungal colonies. [FIGS. 5A–B] Although there is no confirmation as to the type of dark pigment used in combination with gray, its presence in all colors is assumed to be the main nutrient source for the molds. [FIG. 6]

With the pastel portrait *Cecil Girl* (1973; #01.12–1), the sand-like paper was prepared traditionally by sprinkling pulverized pumice over the still wet surface of paper coated by starch paste. In addition, this portrait on the pumice-paper was attached to a board with a heavy layer of brown glue. [FIGS. 7C–D] The board was manufactured in Germany, under the name "Grumbacher, fine sanded buff pastel board." Removal of the board revealed yet another manufacturer—"Ersta made in

[7] *Cecil Girl*, pastel portrait, 1973 (#01.12-1). Before (a) and after (b) treatment. (c) Recto, portrait executed on pumice paper mounted to acidic board with heavily applied adhesive. Fungal infestation is shown as brown stains scattered on the girl's chin and neck. (d) Verso, board with insert showing adhesive layer. (e) After treatment close-up of face.

Germany, Snuffingpapier." A combination of all the elements, particularly the adhesive layers, promoted the fungal growth. [FIGS. 8A–G]

Conservation Treatment Pastels executed on textured paper form a loosely arranged layer of pigment that, when infested by fungi, promotes a light aerial (mycelial) growth. The colonies are often abundant and obscure the image, prompting the artwork's owner to seek an immediate treatment. Although the infestation often appears overwhelming, if treatment is applied in a timely fashion the removal of mold is usually successful. [FIGS. 2A-C, 5A–B] Fungal colonies growing on the surface of pastel powder are usually successfully picked up with a fine brush, 000, one colony after another. However, if the pastel layer is more compact and executed on a sand-paper (e.g., *Cecil Girl* portrait), the fungal growth is often more compact and often penetrates the layers underneath, discoloring the paper. The removal of these colonies as well as the discoloration is much more complex. One treatment that was successfully applied on the *Cecil Girl* portrait involved removal of stains from the background (non-image area) with a 0.2% aqueous solution of sodium borohydrite, a traditional bleaching technique, and local re-washing on a suction table. However, the discoloration formed on the image left a limited choice of treatment. In this case, the owner of the portrait was interested in the aesthetic improvement

of the image and approved an inpainting of stains. Results of the treatment of *Cecil Girl* portrait can be seen in FIGS. 7B AND E.

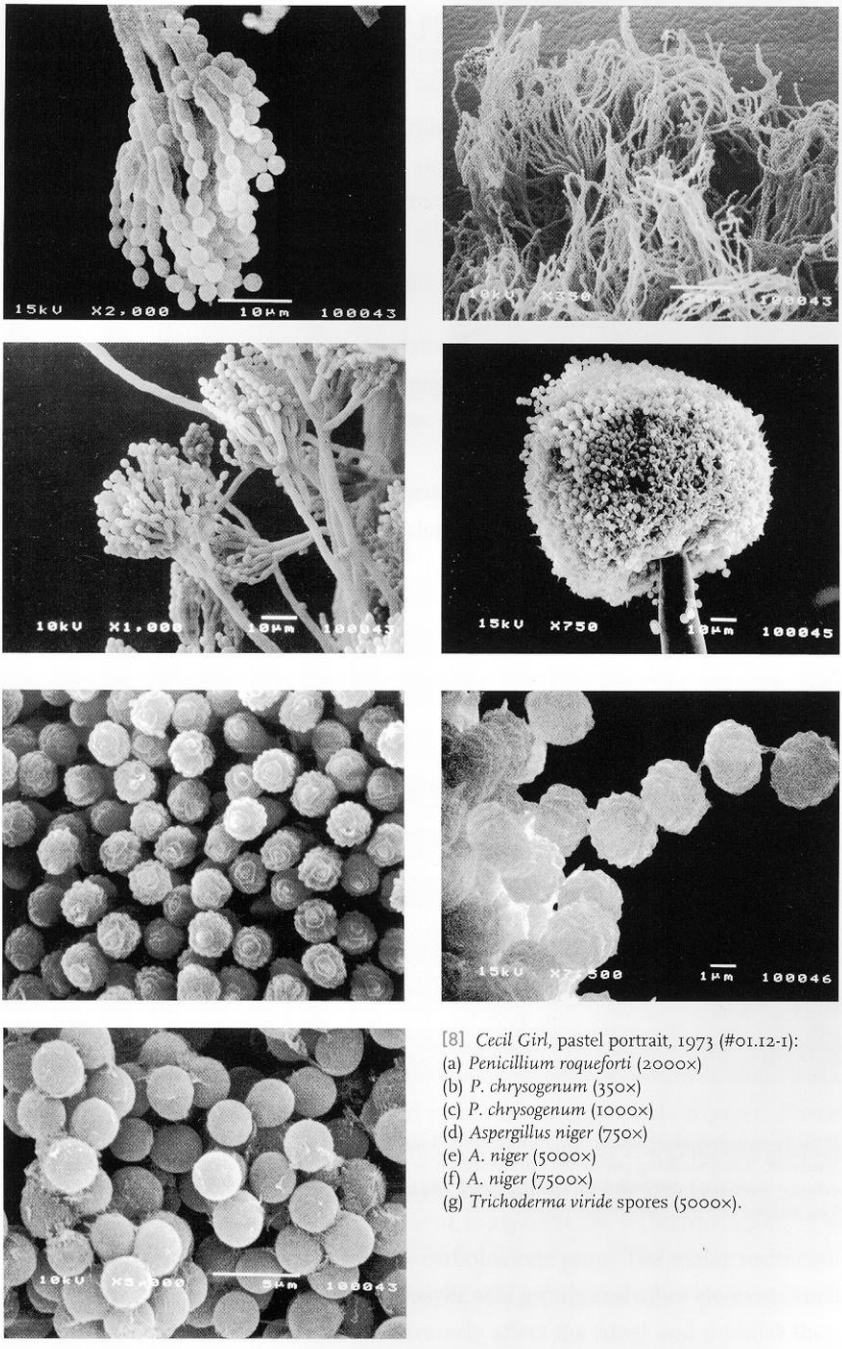
WATERCOLOR

Media A watercolor painting is created with paint applied in very thin layers, allowing lightness of the ground to become an integral element of the art piece. To achieve transparency of colors, the paint requires a relatively small amount of pigment suspended in binding media—gum arabic, tragacanth or fish glue. In order to achieve an even flow of paint, plasticizers have often been used, such as glycerin, crystallized sugar or honey. The consistency of paint is a colloidal suspension of solid particles in a light watery solution of binding and plasticizer. The presence of gum in watercolor is essential to ensure the paints' capacity to stick to paper. Gum arabic also plays a crucial role in the maintenance of a stable dispersion of pigment particles in water until the film of wash has dried, and the colors are gummed in place.

Support To achieve the desired effects of the watercolor technique, and even distribution of pigment particles on the surface, the texture of that surface must be relatively even and uniform. Dry, rough paper, on the other hand, more appreciated in the 19th century, was used for quick handling of the drawing, capturing the paint only across the highest points of the sheet's surface. Historically, until the end of the 18th century, gelatin was used as surface sizing for western papers. According to 19th and early 20th century manuals and product sources (Cohn, 1977), the sizing that was used for preparation of watercolor followed Whatman's innovation that produced papers with hard-sized surface. However, any organic sizing was prone to fungal infestation by providing a source of nutrient.

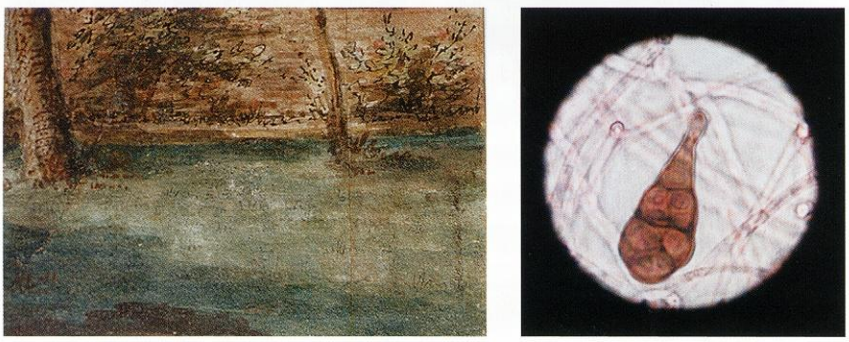
The artist of the early-20th-century watercolor that we examined (work attributed to Thomas Birch) chose a medium textured paper. [FIG. 9A] The moderately applied sizing allowed detailing of the garden scene. Based on microscopic examination of the work, it became clear that the paint is thinly applied and partially absorbed by the support. The light sheen of the surface suggests use of gum arabic. However, this can be assumed only based on the history of watercolor media and information about this artist's technique and style of painting.

Areas of the watercolor that were exposed to water (as illustrated by the photograph of verso [FIG. 9B]) were infested by fungi that at one time had produced sexual reproductive perithecia. [FIG. 10] The fruiting structures were old, as evidenced by the fact that no spores were apparent and most of the bodies were broken. Those



[8] *Cecil Girl*, pastel portrait, 1973 (#01.12-1):
(a) *Penicillium roqueforti* (2000×)
(b) *P. chrysogenum* (350×)
(c) *P. chrysogenum* (1000×)
(d) *Aspergillus niger* (750×)
(e) *A. niger* (5000×)
(f) *A. niger* (7500×)
(g) *Trichoderma viride* spores (5000×).

[9] Twentieth-century watercolor attributed to Thomas Birch (#4.29.2): (a) recto and (b) verso. Tideline on verso indicates a brief exposure to water.



[10] Twentieth-century watercolor attributed to Thomas Birch (#4.29.2). Detail of Fig. 9, bottom right quadrant; insert showing perithecia embedded on recto in the area exposed to water. [11] Twentieth-century watercolor attributed to Thomas Birch (#4.29.2). *Alternaria alternata*; didymospore, showing longitudinal and transverse septa (1000×).

that were still intact were cultured but proved to be nonviable. However, other, active molds were found and cultured from the same watercolor. [FIG. 11]

Conservation Treatment Embedded perithecia could not be removed safely without adversely affecting the image. Laboratory testing proved that the perithecia did not contain active spores; therefore no treatment aiming to remove fungal residue was performed.

INK WASH

The technique of ink wash resembles watercolor, but is monochromatic. The composition of the medium is a mixture of a pigment (carbon black, brown bister, sepia, or other colors) with a vegetable gum. The distinction between colored ink and watercolor is not easy to make.

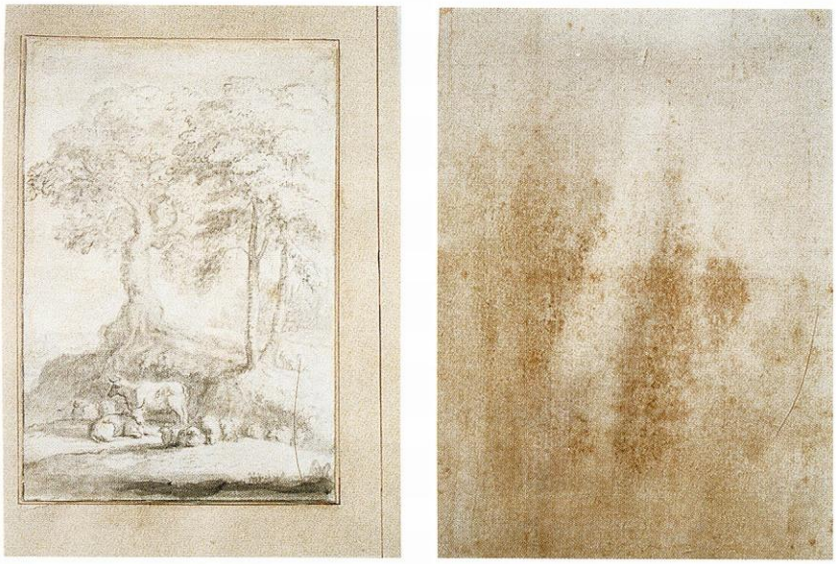
The ink wash medium in the investigated *Trees and Animals* (#01.53–4), created in the 18th century by Lady Diana Beauclerk (1734–1808), was very thinly and uniformly applied on paper. [FIGS. 12A–B] The fungal infestation that became visible on the surface was attributed to the composition of the artwork itself. The original drawing was mounted to a secondary support, tertiary paper and canvas. Each layer was interleaved with heavily applied paste. Once separated they revealed the full extent of the fungal infestation. [FIGS. 13A–C]

Conservation Treatment The drawing was separated from inferior secondary supports and washed to remove the primary source of nutrient-paste. Minor bleaching was carried out locally with a 0.2% aqueous solution of sodium borohydride. The artwork was re-washed after completion of the conservation treatment. [FIGS. 14A–B]

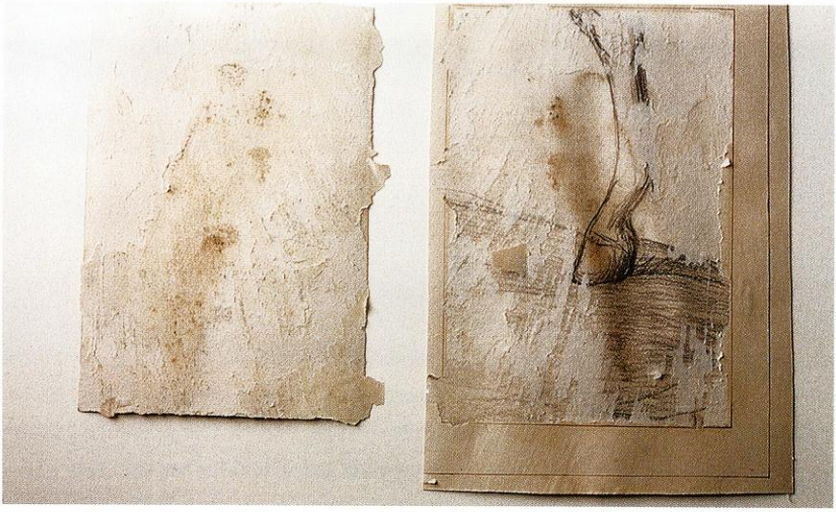
PRINT

We all live surrounded by prints created in a great variety of media, and volumes have been published about the artist-printing techniques. Therefore, our investigation focused not on the printing technique itself, but on a particular case of a print with gamboge glazing. The investigated print was an engraving on paper, *Brown Pelican* (#01.8), by John James Audubon, 1838. [FIGS. 15A–B] The gamboge glazing was frequently used by Audubon to enhance his green and brown colors.

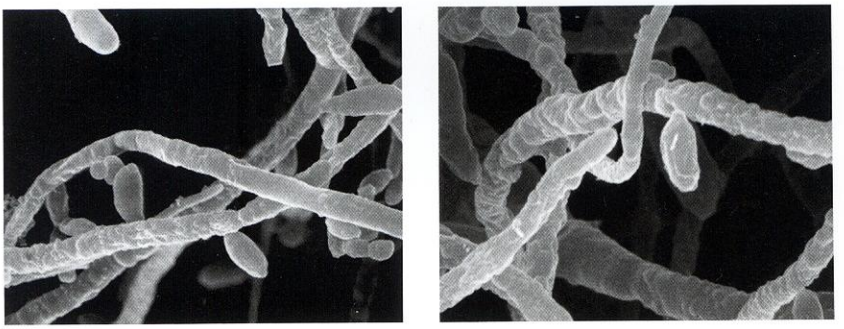
Gamboge, a transparent yellow pigment, is a gum resin. It contains about 70% yellow resin, and 15–25% water-soluble carbohydrate gum. The major resin constituent, gambogic acid, contains a carboxylic acid group, and other elements such as phenolic compounds that should adversely affect the fungi and prohibit their



[12] *Trees and Animals*, ink wash by Lady Diana Beauclerk (1734–1808) (#01.53-4). (a) Recto and (b) verso before conservation treatment.



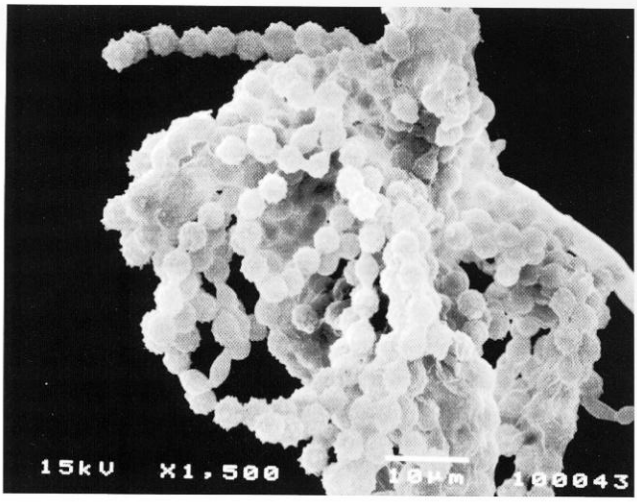
[13A] *Trees and Animals*, ink wash by Lady Diana Beauclerk (1734–1808) (#01.53-4). Paste used for mounting of several layers of secondary supports contributed to biodeterioration of the artwork.



[13B,C] *Trees and Animals*, ink wash by Lady Diana Beauclerk (1734–1808) (#01.53-4): b) *Aureobasidium pullulans* (2000×); c) *Aureobasidium pullulans* (3500×).

[14] *Trees and Animals*, ink wash by Lady Diana Beauclerk (1734–1808) (#01.53-4). (a) Recto and (b) verso after completion of conservation treatment. Fungal residue was removed mechanically and by washing and local bleaching with 0.03% sodium borohydrate.

[15] *Brown Pelican*, 1838, John James Audubon (#01.8). Hand-colored engraving with gamboge glazing. (a) Recto before conservation (plus insert) and (b) verso after conservation (plus insert). Inserts illustrate details before and after conservation treatment.



[16] *Brown Pelican*, 1838, John James Audubon (#01.8). *Aspergillus versicolor*, characterized by spherical conidial head (1500×).

development (Winter, 1977). In the case of the investigated Audubon print no such effect was noted. Fungi flourished on the areas glazed with gamboges. The laboratory testing established an abundance of mold. [FIG. 16]

Conservation Treatment The abundant growth of fungi was first removed mechanically with scalpels and brushes. Considering the presence of water-soluble yellow pigment gamboges, all subsequent aqueous treatment procedures were carried out locally on a suction table, avoiding the areas coated with gamboges. A 70% aqueous ethyl alcohol solution was introduced from verso for the purpose of disinfecting any remaining viable fungal elements.

BIODETERIORATION BY FUNGI

The results of our studies reveal the presence of a number of fungi infesting and growing on artworks, drawings, prints, and old documents. All major groups of the fungi are represented and very few are specific to a particular substrate. While the Deuteromycetes (Fungi Imperfecti) predominate, the mycoflora we encounter includes members of the Zygomycetes (so-called bread molds), Ascomycetes (sac

fungi), and Saccharomycetales (yeasts) (Alexopoulos, Mims, and Blackwell, 1996). All of the species we encounter are ubiquitous in nature and are normally found growing on a large number of organic substrates, including soil particles, dung, living and dead plants and their parts, humus, and wood products. In some cases, they infest, infect, and parasitize wild or domesticated animals, as well as humans. In recent years, several of the species have been implicated as having a major role in causing allergies, respiratory infections, and the production of toxins responsible for a number of human illnesses in cases where the quality of indoor air has been compromised by water damage to the building (Morey et al., 1990; McNeel and Kreutzer, 1966; New York City Department of Health, 2000).

The species of fungi we encounter on works of art and documents have become old, familiar friends. Many of them, such as *Aspergillus* and *Penicillium* (Deuteromycetes) are ubiquitous. It is rare, indeed, if we do not find the growth of one or more species of *Aspergillus* appear or dominate water-damaged drawings, pastels, or prints. Common species that we almost always harvest are *A. nidulans, A. niger* [FIG. 8D], *A. oryzae, A. terreus,* and *A. versicolor.* [FIG. 15] While *A. flavus* and *A. parasticus* have been noted on occasion, they do not appear often. We usually find a piece of artwork partially or substantially infested by a single species, generally covering a specific pigment on the work. However, it is not uncommon to find more than one species of *Aspergillus* claiming several territorial regions on a single piece of work. When several species are harvested from a single work, they are usually separated as distinct colonies. Although *Penicillium* is not as commonly found, it, too, is a sure bet among our cultures of damaged artworks. Two species that we encounter often are *P. chysogenum* and *P. roqueforti.* Only under rare conditions (*A. niger*), is it possible to distinguish between the two genera, *Penicillium* and *Aspergillus,* by the characteristics of their colonies. Positive identification separating the two genera as well as the species within each genus is only attainable through microscopic examination coupled with gross morphology of the colony. Several other conidial Deuteromycetes make up the familiar species line-up—*Alternaria, Aureobasidium, Cladosporium, Nigrospora,* and *Trichoderma.* All five of these produce distinctive conidiophores and/or conidia and are almost always harvested on our artworks and documents. The two genera of yeasts, *Rhodotorula* and *Saccharomyces* (Saccharomycetales), are often found at random growing with the conidial molds. *Rhizophus nigricans* (Zygomycetes) is not encountered with any frequency. The fungus grows very rapidly and sporulates quickly. It is considered opportunistic and may represent the first fungus in a successional series to establish on a substrate.

Chaetomium is a distinctive genus in the Ascomycetes and is readily identified by the characteristic hairs or setae surrounding the sexual reproductive structures (perithecia). Hundreds of species of *Chaetomium* occur in nature and several of them have been encountered in our work (Szczepanowska and Cavaliere, 2000).

CONSERVATION PRACTICES The conservation aspect of dealing with fungal infestation includes three major areas—environment, treatment of infestation that has occurred, and prevention.

The ambient environment in the storage or exhibit spaces is as important to the longevity of artworks as is the immediate microenvironment within the frame. Elevated humidity in the environment combined with stagnant air trapped within the frame will provide the most favorable conditions for mold growth. Often the colonies expand onto the glass surface. [FIG. 2B] The proper environmental condition for art collections is one of the most fundamental elements affecting them. Of equal significance is the impact of materials remaining in direct contact with the artwork itself, such as inferior backing boards, excessive animal glues, and cumbersome frames. Our studies indicate that a direct correlation exists between all elements of artworks and the fungi infesting them. Consequently, maintaining a proper environment, particularly with the RH under 65% and the use of inert materials that may come in contact with the artwork (framing, storage, exhibition, shipment) will reduce chances of fungal infestation.

Treatment Techniques The delicate nature of art surfaces poses limitations to the type of treatment that can be employed. A conservator often has to settle for minimal or no intervention in order to preserve the unity of the image. Surprisingly, although pastels are executed in one of the most vulnerable media, their airy and loose structure supports colonies loosely sitting on the surface, allowing for their gentle and successful removal. The severity of biodeterioration of prints, ink washes, or watercolors is often correlated with the length of time the artwork is exposed to water. The longer the period of exposure to moisture, the more severe the growth, staining, and formation of fungal structures, often embedded in the image. Secreted metabolic products create stains that cannot be removed by mechanical treatment; however, a local bleaching with sodium borohydride might be successful. The last resource in restoring esthetically disfiguring discoloration and stains caused by fungi could be inpainting of the affected areas.

CONCLUSIONS Our studies indicate that there are about a dozen ubiquitous fungi (or molds) that tend to infest artworks and documents on paper. Although these fungi, in most cases, do not appear to be substrate-specific, some appear to be promoted and supported by the medium used in creating the art piece, as well as by the nature of their support (acidic pH and excessive amount of starch glues and other organic adhesives). The growth of molds on any piece of artwork or document may be an indication of the fungi that were present and incorporated into the fabric of the artwork when it was rendered. Or they may represent airborne species that very recently landed on the work and found the pigments nutrient-rich and capable of sustaining their growth.

As with most substrates upon which fungi grow, each colony is distinct and represents a single species. Often colonies representing different species are in close proximity. However, even on pieces of art, fungi secrete chemicals that tend to prevent unwanted neighbors from getting too close. What is extremely interesting is that a successional pattern of fungal growth appears to occur on artworks and documents similar to that which occurs in nature. On paper-base substrates Zygomycetes (the bread molds) are followed by Deuteromycetes (mold), and only with longer exposures to moisture do the perithecial fungi of the Ascomycetes, such as *Chaetomium*, appear.

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