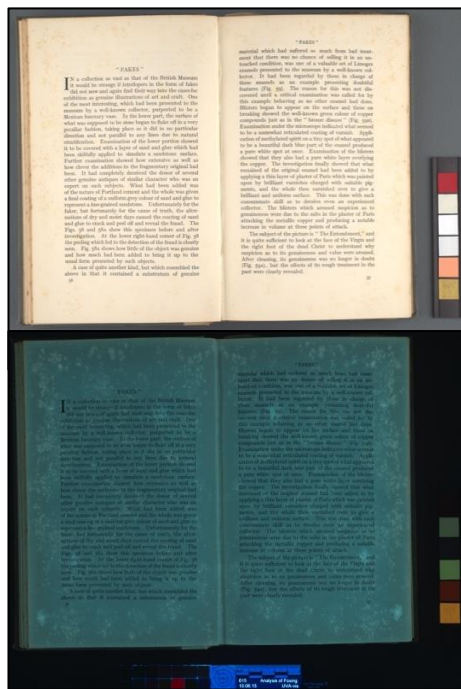


Preservation Newsletter—February, 2019

**FOXING: The Sly Slayer of All Paper!**

The term “foxing” generally refers to small, round or “snowflake” shaped, reddish, brown, or other colored stains in paper or other fiber-based material. Foxing appears to spread dimensionally through the sheet, not just over it; groupings of bound pages will show similar staining as if it spread through the pages. No specific criteria for the use of the term exist, leading to some confusion over what exactly constitutes foxing. Even the word itself has nebulous roots with some saying it is suggestive of the frequently reddish-brown color of the stains, others that it derives from the oxidation of iron (Fe) that has been frequently associated with the stains. In some ways, it is easier to define foxing by what it is NOT: mold staining, overall discoloration due to aging, mat staining, light staining, and tidelines caused by uneven wetting are not foxing. We may not know exactly what it is, but we know it when we see it.



*Fig 1. Evidence of foxing on different papers. Middle image, an UVA-vis induced fluorescence reveals the presence of foxing that is not visible to the naked eye.*

Currently, there are two major explanations for foxing: fungal activity and/or metal-induced deterioration. Both hand- and industrial paper making processes introduce organic and inorganic materials to paper that can lead to fungal growth and oxidation, so it's not possible to predict whether a specific paper or type of paper is more prone to developing foxing stains in its lifetime. Analysis of foxing stains and the fiber surface characteristic of foxed paper has not been definitive as to whether metallic inclusions in the paper catalyze mold growth under humid conditions, or whether fungal growth catalyzes the oxidation of copper and iron in paper. Now let's take a closer look on what elements are found in the intricate network of fibers of paper-based materials stored on your library shelves!

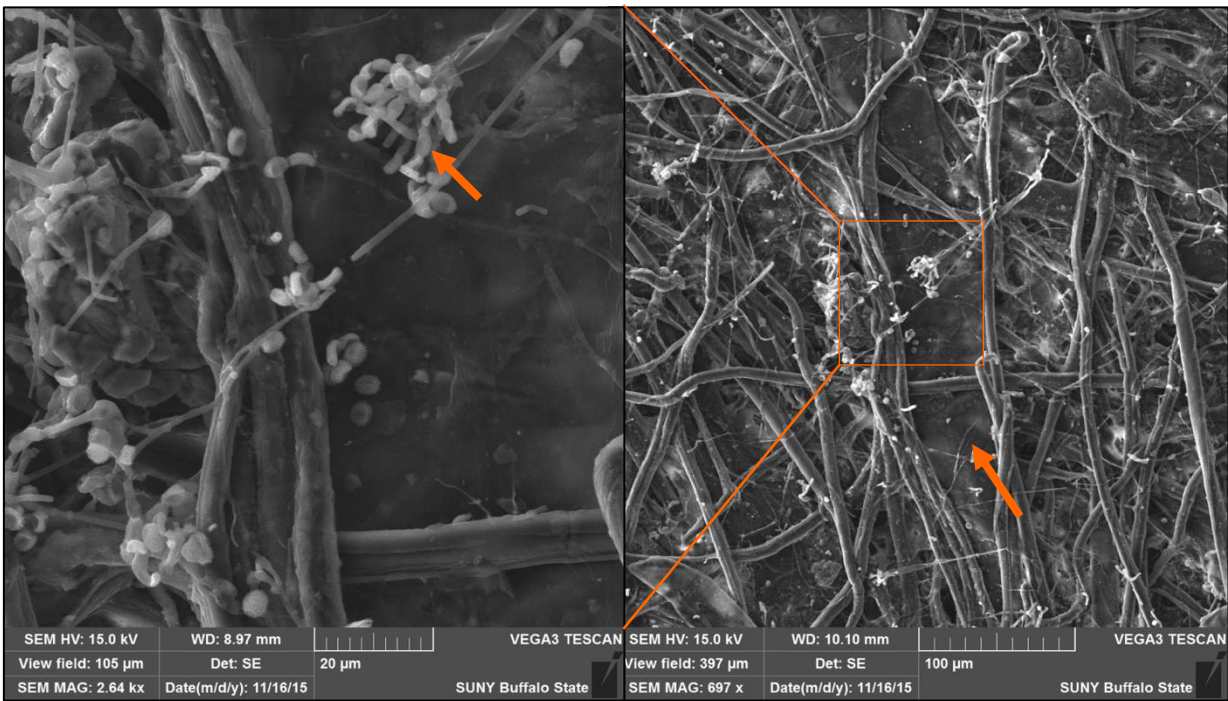


Fig2. SEM image of **foxed** area on paper. Left image is a magnification of a **foxed** area affected by fungi growth, on the right.

The SEM images of foxed areas in figures 2 illustrate the presence of fungi growth. At higher magnification using SEM microscope, the spores are clearly visible with spikes, as shown in the left image in figure 2. The foxed area also exhibits a large network of thin hyphae spread out between the fibers, seen in the right image of figure 2. These images also illustrate that foxing is a three-dimensional phenomenon that develops between the pages of the book.

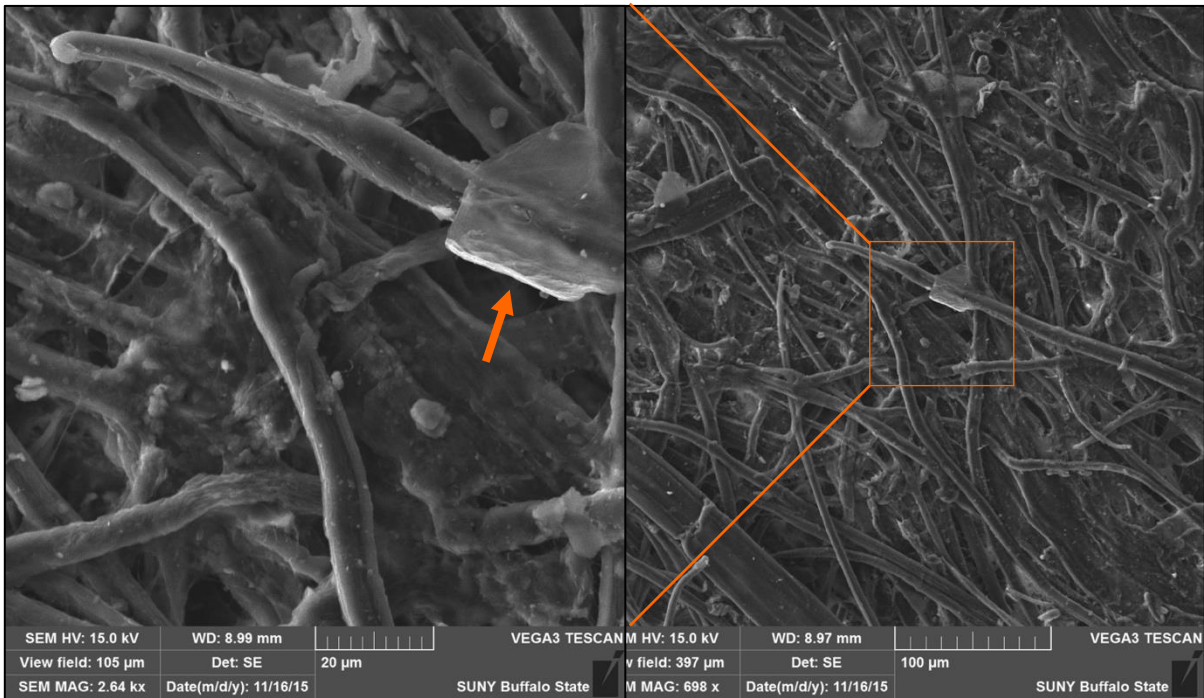
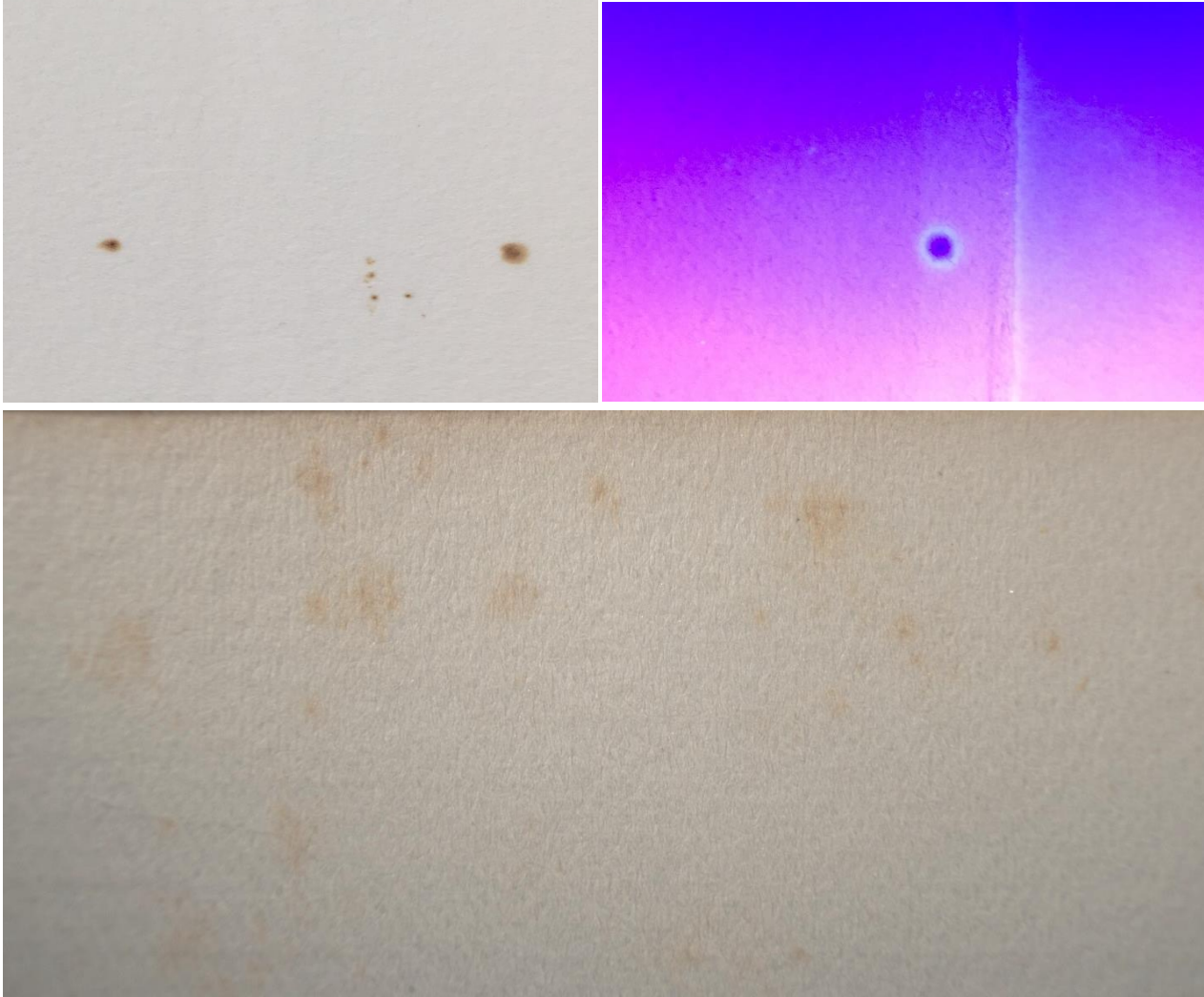


Fig 3. SEM image of **unfoxed** area on paper. Left image is a magnification of an **unfoxed** area on the right.

In figure 3, the images illustrate the unfoxed areas of the paper, with a large piece of clay identified. Although the visual examples above focus on fungi growth in paper, metal inclusions known as “bullseye” foxing are also considered as one of the major causes of foxing, as seen in figure 4. Metal contamination can be either airborne dust or come from the papermaking process. Metal inclusions will cause rusty stains through oxidation causing a distinct dark center within a lighter ring on paper. Snowflake foxing marks are of varying size but generally quite large, round, and have uneven diffuse edges, as seen in figure 4. Under UV illumination snowflake foxing will fluoresce white, as opposed to bullseye inclusions that appear dark blue/black.



*Fig 4. Top right and left: Examples of “bullseye” fox stain on paper. Top left illustrates foxing under UV illumination. Bottom: Illustrates the “snowflake” foxing.*

Foxing sometimes can be prevented if the papers are maintained in a stable environment, retaining their original, neutral, off-white tone. However, high humidity and temperature can catalyze a reaction in the unstable additives found in papers. Consequently, controlling your storage conditions and protecting collections from dust can reduce foxing formation and will greatly impact the stability and legibility of the materials. Please don't hesitate to reach out to us if you have any question about materials in your collections that have been affected by foxing!