with the Banknote Processing System (BPS 3000).[1] One dollar Federal Reserve notes (FRNs) are the most commonly used, and the population of fit notes has been reported to drop substantially 18 to 22 months after release.[2] In December 2003, eight million one dollar FRNs were released from four FRBs. Every 3 months, the four banks each retrieve 1,000 notes from the original population, sending them to BEP for testing during this new field study. For each quarterly batch, a soiling level is determined by the BPS 3000. A second, visual rating is assigned to each note based on crumple, fold, and ink wear in the portrait area. Based on the distribution in this two-parameter rating, a small subset is separated from the typical notes into a bad group of more worn notes. Typical and bad notes are then tested for properties including tensile strength, tear, roughness, and thickness. Preliminary results for the first four quarters are described, with emphasis on microscopic analysis.

Photographs illustrate features such as print wear, tears, creases, soiling, and graffiti. Transmitted light stereoscope imaging was used to monitor the condition of paper and ink at the top of the high stress center fold region. In uncirculated notes, cut edges are straight and printed features in black intaglio ink are uniformly dark and continuous. Typical notes through the fourth quarter show only a slightly irregular paper edge. There is some disruption of surface fibers and occasionally missing flecks of ink. In addition, bad notes from the second through fourth quarters show patches of thinning and fiber fuzz related to creases and partial pullout. Printed lines are degraded by fiber movement and detachment of ink under stress.

Scanning electron microscopy (SEM) and energy dispersive x-ray spectrometry (EDS) were used to analyze unprinted and printed areas on the portrait side of the notes. After backscattered electron (BSE) imaging and x-ray collection in the variable pressure (VPSEM) mode, the unprinted mounts were given a conductive coating and were examined in the secondary electron (SE) mode. The SE surface images show that typical notes through the fourth quarter maintain a moderately smooth texture in the unprinted areas sampled. Fourth quarter bad notes illustrate fiber debonding and piling, with many of the long cotton fibers hanging like loose ropes from individual points of attachment.

Backscattered electron photomicrographs reveal the changing nature of printed features with age and wear. The surfaces of intaglio ink lines on unused currency show patchy roughness that is smoothed somewhat in circulated notes. Larger scale roughness measurements by air leak also suggest surface roughness reduction. Notes classified as bad frequently have cracks across the ink lines in the portrait collar. These cracks sometimes form the boundaries of blocks of ink that are lost from printed lines during wear (Fig. 1). In plain view, the interface between ink lines and paper appears to change with currency usage. To quantify this with image analysis, substrate paper windows surrounded by printed lines were treated as individual objects whose perimeters define the interfaces of interest. The fractal dimension of each object was determined as a measure of print edge irregularity, or raggedness. The mean fractal dimensions were plotted for analyzed images in typical and bad notes. There was an overall increase in the raggedness of ink line edges, as measured by mean fractal dimension, over the four quarters of currency circulation.[3]

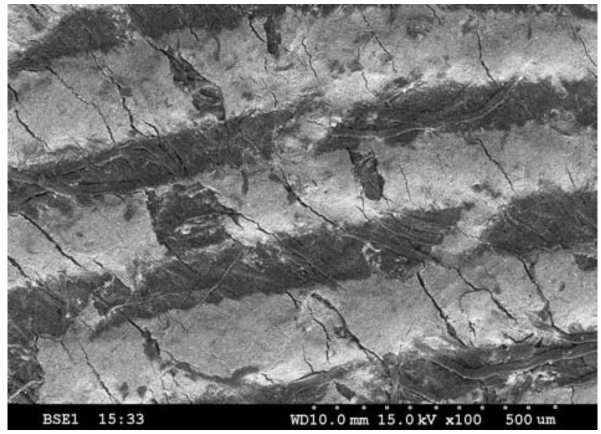

FIG. 1 Scanning electron microscope/backscattered electron micrograph of portrait shoulder pattern with cracked and missing sections of ink lines, on currency paper substrate.

References

1. BPS 3000 Banknote Processing System, manufactured by Giesecke and Devrient America, Dulles, Virginia, USA
2. Federal Reserve System: A comprehensive assessment of U.S. currency quality, age, and cost relationships. *Federal Reserve System*, Washington, D.C., USA (1991)
3. Opinions expressed by the author, although cleared for release, do not necessarily represent those of the Department of the Treasury or the United States Government.

An environmental STEM detector for ESEM: New applications for humidity control at high resolution

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An Environmental STEM detector was used in the Environmental Scanning Electron Microscope to study the morphology of two types of wet lime putty and to evaluate the fiber size of the ancient pigment known as Maya blue. Environmental Scanning Electron Microscopy (ESEM) is a technique capable of imaging non-conductive materials in their natural state.[1,2] The technique provides for neutralization of electron-induced charge build-up by the ionization of water vapour in the chamber. A novel combination of a STEM (scanning transmission electron microscopy) detector and a Peltier temperature controller extends the ESEM concept into a higher magnification range than was previously possible for dynamic experiments, opening up new parameter space in the VP/ESEM for new applications. The technique is limited by the 30 keV accelerating voltage of the primary ESEM beam energy; however, in practice this limitation was overcome by using relatively thin samples.

Lime mortars are making a comeback in conserving historic buildings because of their compatibility with masonry, compared to overly strong cement-based mortars. To evaluate the role of particle size and shape in the performance of two common types of lime mortar, samples of lime putty was diluted, placed on a TEM grid and cooled to 1.5 C to allow the slow evaporation of water from the sample. The results of the lime putty study reveal significant particle size and shape differences between traditionally slaked lime (calcium oxide reacted with excess water to form a putty; Figure 1) and lime hydrate (modern, dry powdered calcium hydroxide with added water). While both contain apparently amorphous spherical particles in the size range of 0.1 to 1 µm, the traditional lime putty contains fine needle-shaped crystals of calcium hydroxide (~0.2 µm diameter), while the modern lime contains larger, more irregular shaped grains (~0.5–2 µm). These particle differences may account for observed differences in the bulk behavior of the two types of lime.[3] The greater resolution of the STEM mode and the fine control of water condensation and evaporation through the Peltier device enabled a clearer understanding and record of the evolution of lime particle size and shape.

STEM-ESEM analysis of particles of Maya blue pigment–a complex of indigo dye and palygorskite clay–unexpectedly revealed that the clay fibers seen in gold-coated SEM samples are actually bundles of smaller fibers on the order of 10–100 nm in diameter easily seen in STEM images (Figure 2). The Environmental STEM detector will likely be applied to a wide range of problems, from bio-medical to materials science applications.[4]

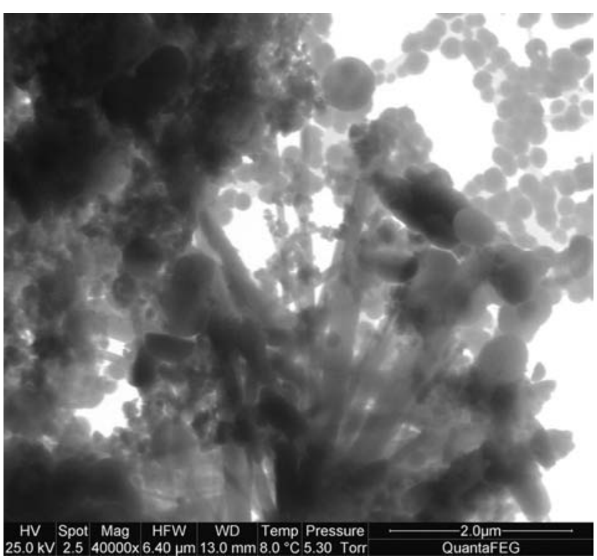

FIG. 1 Environmental STEM image of slaked lime putty. Note needles of calcium hydroxide.

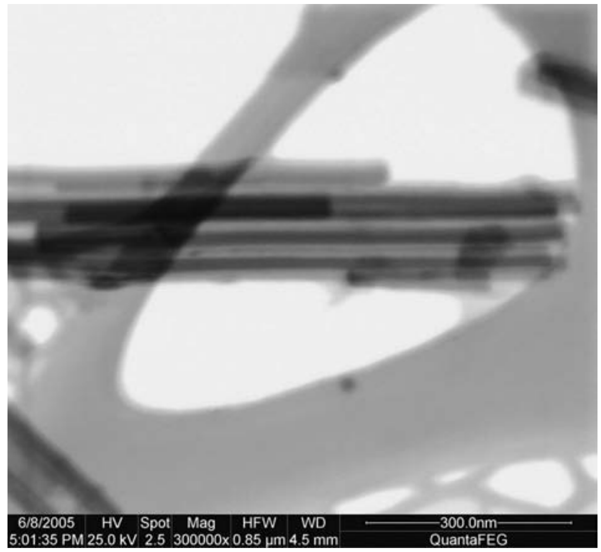

FIG. 2 STEM image of Maya blue clay fibers. Note 300,000X magnification.

References

1. Do Amaral M, Bogner A, Gauthier C, Thollet G, Jouneau P-H, Cavaille J-Y, Asua JM: Novel experimental technique for the determination of monomer droplet size distribution in miniemulsion. *Macromolec Rapid Comm* 26, 5, 365–368 (2005)
2. Doehne E: ESEM development and application in cultural heritage conservation. In *In-Situ Microscopy in Materials Research* (Eds. Gai P). Kluwer Academic Publishers, Dordrecht, (1997) 45–62
3. Doehne E, Stulik DC: Applications of the environmental scanning electron microscope to conservation science. *Scan Microsc* 4, 2, 275–286 (1990)
4. Rodriguez-Navarro C, Hansen E, Ginell W.S: Calcium hydroxide crystal evolution upon aging of lime putty. *J Amer Cer Soc* 81, 11, 3032–3034 (1998)

Novel preservation of a plant leaf from the Rock River Formation (Late Cretaceous) of Wyoming

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Taphonomy is the study of what occurs to a fossil between death and final burial. Preservation of terrestrial plants within sedimentary marine rocks is rare. Therefore the taphonomy of the leaf is interesting in the lack of major damage to the specimen. Although little of the surface is recognizable, the overall shape of the leaf allows for a general description. It is believed to be a single pinnuale of an extinct Mesozoic plant order, Cycadeoidales, (also called Bennettiales) most likely of the genus *Nilssonia*. It is identified by its long strap-like shape with linear cell structures that run the length of the leaf and a broad base that narrows to a point then expands out to the sides where it attached to the cycad frond.