

# Stone Paper: An Overview of its Characteristics and the Impact They May Have on Forensic Document Examinations

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Stone paper is comprised mainly of calcium carbonate and plasticizers. Unlike pulp paper, it is manufactured without large amounts of water and chemicals. Due to its unique composition and manufacturing process, stone paper manufacturers claim it is: more environmentally friendly than traditional pulp paper, 100% recyclable, water, grease and tear resistant, and bio-degradable. Stone paper has been commercially available for ten years, and in the past three years has become increasingly available in household consumer-use products including notebooks and inkjet photo paper. As it becomes more available, the forensic community will likely encounter stone paper in casework. This article seeks to educate the forensic document community about stone paper characteristics, evaluate some of the manufacturers' claims outlined above, and describe special considerations that must be taken during forensic document examinations involving stone paper. Actions and associated examinations undertaken include: indented impressions, typewriting, non-destructive ink (writing instruments, toner and inkjet printing) examination, tearing, folding and stapling, water and grease interaction, and environmental exposure. Results of the current study showed that examination of stone paper can be conducted in a manner similar to traditional pulp paper, with a few exceptions regarding indented impression examinations and fracture matching.

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## Introduction

There is a potential impact on the forensic community regarding examinations conducted when a product is first introduced, or when it has been updated. Stone paper is one such product which, in recent years, has expanded into new consumer products. This expansion is due in part to the public's increasing interest in "green" products. Stone paper manufacturers assert their manufacturing process is more environmentally friendly than that of traditional pulp paper, and the paper itself is 100% recyclable (TerraSkin® Specs/Swatchbook 2009). According to the manufacturers of TerraSkin®, stone paper "is a combination of Calcium Carbonate (>75%) with a small quantity (<25%) of non-toxic resin (PE-Polyethylene) added to create a strong sustainable substrate" (TerraSkin® Specs/Swatchbook 2009). In the stone paper manufacturing process, waste material

from the building and construction industries, namely calcium carbonate (chalk) which comes primarily from marble and limestone scraps, is ground into a fine powder, and mixed with partly post-industrial recycled polyethylene, a thermosetting polymer which acts as a binder. This process produces a paper substrate that is both water and tear resistant (TerraSkin® Specs/Swatchbook 2009; [www.viastone.com/FAQs.html](http://www.viastone.com/FAQs.html) 2009). Because this manufacturing process uses minimal amounts of water and other chemicals, the manufacturers assert that stone paper offers a "greener" alternative for consumers who are concerned with the use and release of chemicals and waste resulting from the manufacturing of traditional pulp paper.

Along with claims of being "greener" and resistant to water and tearing, the makers of TerraSkin®, FiberStone® and ViaStone™ also state



that their products will degrade when left outside. The TerraSkin® package insert states their paper is “degradable, when left out in nature for approximately three to nine months” (TerraSkin® Specs/Swatchbook 2009). FiberStone® claims their product will “photodegrade after a period of about 14-18 months” (www.getfiberstone.com/what-is-fiberstone%C2%AE/ 2009), while ViaStone’s™ manufacturer’s information states that when their product is “exposed to long duration of heat...it will hardened [sic] and degraded [sic] into very small fragments” (www.viastone.com/FAQs.html 2009), and in a highly acidic environment the calcium carbonate will dissolve (www.viastone.com/FAQs.html 2009). ViaStone™ also states their paper has a “water and grease barrier protection” (www.viastone.com/FAQs.html 2009). These manufacturer claims aim to further differentiate stone paper from traditional pulp paper, and promote the stone product’s versatility, including writing and photo paper, packaging supplies, labels and maps, among other uses. For the current study, FiberStone®, Gartner®, Oxford®, TerraSkin®, and ViaStone™ stone paper samples were purchased or obtained directly from the manufacturers.

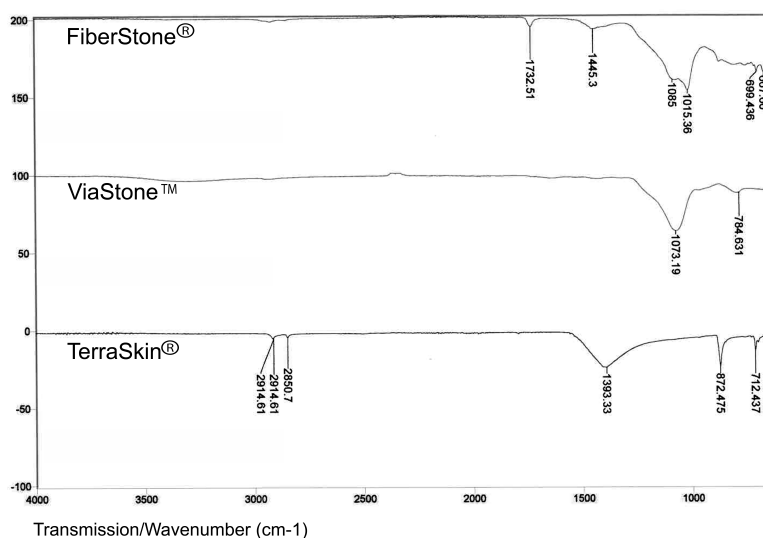
As part of their normal casework, Forensic Document Examiners (FDEs) are expected to perform myriad examinations when presented with a questioned document. This casework includes, but is not limited to, discernment of indented impressions, document authentication, ink examination, machine printing examinations (including typewriting), and stroke sequence examinations. When presented with a new type of product, FDEs need information on how the new product will respond during the examination process. Therefore, in this study, the authors obtained stone paper samples, as well as samples of traditional pulp paper, and treated them as questioned documents. Experiments were devised to reveal whether special considerations needed to be taken when presented with a case involving stone paper, or whether the conventional methods of examination would suffice. For indented impression examinations, stone and traditional pulp papers known to have indented impressions were examined using side lighting and processed on an ESDA2®. To study the effect of machine printing, stone and pulp paper samples were imprinted using inkjet and toner technology, as well as a typewriter equipped with both a carbon and a correction ribbon. The machine printed paper samples were subsequently examined

both macro- and microscopically. For document authentication examinations including stroke sequence, stone and pulp papers were written on and then folded, and vice versa, to see if the ink line was affected by the fold. To study the possibility of insertions within multi-page documents, multiple sheets of each respective type of paper were stapled together, and then the staple was removed using different methods to determine whether or not the paper would be disturbed by the staple removal. For non-destructive ink examinations, various pens were used to create ink lines on each of the papers, and these lines were observed under various lighting conditions using the VSC®6000 to determine if the lines would display disparate optical activity based upon the substrate. Finally, because uncoated traditional pulp paper is rarely said to be water, grease, and tear resistant, these claims of stone paper manufacturers’, as well as their claim that the stone paper degrades when subjected to natural outdoor conditions, were tested in order to determine whether they were valid.

Collaborative research was done with a forensic chemist and an intern to determine whether or not stone paper from different manufacturers could be differentiated using traditional tools commonly exploited by an analytical chemist. The research was conducted using a stereomicroscope, Fourier Transform Infrared Spectrophotometer (FTIR) with Attenuated Total Reflectance (ATR), Polarized Light Microscope (PLM), and Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (Hines 2010, Ziolkowski 2011). Through this research it was determined that, while there were slight differences observed in the infrared spectra of the stone papers tested which might allow some differentiation (see Figure 1 on next page), the sample size was too small to definitively state whether or not stone papers from different manufacturers can be identified (Hines 2010, Ziolkowski 2011). Nevertheless, microscopic examination of the paper surfaces allows FDEs to easily differentiate between stone and pulp papers due to the absence of fibers in the former (see Figure 2 on next page).

### Method and Materials

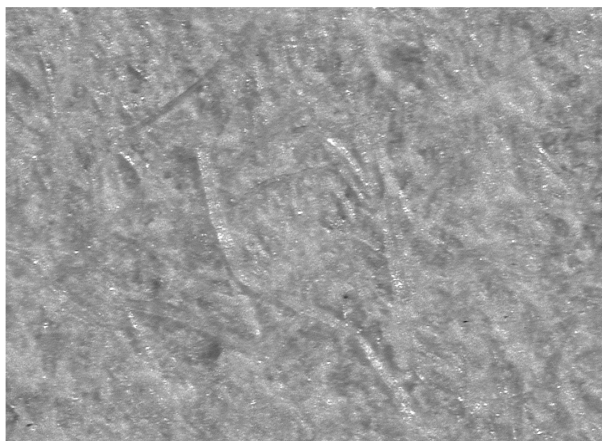
In this study, stone paper was obtained from five manufacturers: FiberStone®, Gartner®, Oxford®, TerraSkin®, and ViaStone™. Paper samples from FiberStone® and TerraSkin® were received directly from the manufacturer. FiberStone® samples were



**Figure 1** (Left) FTIR-ATR Spectra of FiberStone®, ViaStone™, and TerraSkin® showing a slight compositional difference between the three.

**Figure 2** (Below) Microscopic comparison of surfaces of pulp paper (left) and stone paper (right).

Copy Paper



FiberStone®



126x Magnification

loose sheets of paper and TerraSkin® samples were a “swatchbook” containing loose sheets of “sample size” paper. Gartner®, Oxford® and ViaStone™ samples were purchased from national chain stores. Gartner® and Oxford® were in notebook/journal form. ViaStone™ was a package of loose sheets marketed as inkjet photo paper with a coated back. (See References section for manufacturer contact information.)

#### Paper Thickness Measured Using a Manual Micrometer:

FiberStone®: 0.007 inches

Gartner®: 0.0035 inches

Oxford®: 0.0035 inches

TerraSkin®:

0.0065 inches (environment, ink, and indented impression exams)

0.0055 inches (typewriting exam)

0.004 (tear and grease resistance exams)

ViaStone™: 0.009 inches

Boise Cascade™ Inkjet Matte photo paper (matte photo paper): 0.0075 inches

Marcella™ by K Scrapbook paper (scrapbook paper): 0.008 inches

Copy paper: 0.004 inches

Construction paper: 0.006 inches

#### Environment Test

Papers tested: FiberStone®, TerraSkin®, ViaStone™, construction paper, copy paper, matte photo paper, and scrapbook paper

Procedure:

- Three approximately 2”x2” squares were cut from each paper type

- A pin hole was punched into the approximate center of each square
- Fishing line was threaded through the hole to suspend the squares from the top of a wire cage
- Paper types were separated from each other using cardboard and twine dividers
- The cage was placed outside from May 19 through October 9, 2010 (163 days total)
- Daily weather data search for "IAD" airport included: high and low temperature (°F), average percent humidity (%), precipitation (inches), wind speed (mph), barometric pressure (inches), and dew point (°F) was recorded (www.wunderground.com 2010)
- Photos of the cage and paper samples were taken approximately weekly until completion
- Papers which came loose from their hanging position were reattached whenever possible, if not possible paper samples remained in the bottom of the cage
- Observations on the condition and/or appearance of paper samples were recorded

### Folding

Papers tested: FiberStone®, Gartner®, Oxford® and ViaStone™

Procedure:

*Writing before the paper is folded*

- The words "folding test" and a squiggle were written with a ball point pen, Sharpie® fine tip marker, and a Skilcraft® Liquidmagnus™ 0.5mm microfine roller ball pen (referred to as "Skilcraft® roller ball" for the remainder of the article) on the front and back\* of each paper sample. (\*Except for ViaStone™ paper which was performed on two separate sheets of paper due to the backing of the paper).
- An image was taken using the VSC®6000 at magnification of 7.90x using default "VIS" flood light setting
- One fold was made through the writing lines resulting in a concave fold on one side and convex fold on the other side (Except for ViaStone™ paper which was performed on two separate sheets of paper due to the backing of the paper)
- An image was taken using the VSC®6000 at magnification of 7.90x using default "VIS" flood light setting
- Along the same fold line, the paper was folded

an additional 4 times simulating the paper being folded and opened and refolded a total of 5 times; an image was then taken

- The preceding step was repeated for total folding increments of 10 and 20

*Writing after a fold is made in the paper*

- Four separate folds were made in increments of 1, 5, 10, and 20 on each piece of paper, and then the phrase "folding test" and a squiggle were written over the fold using: ball point, Sharpie® fine tip, and Skilcraft® roller ball pens on either side of the paper\* to simulate writing over a convex and concave fold (\*Except for ViaStone™ paper which was performed on two separate sheets of paper due to the backing of the paper).
- Images using the VSC®6000 were then taken at magnification of 7.90x

### Grease

Papers tested: FiberStone®, Gartner®, Oxford®, TerraSkin®, ViaStone™, and copy paper

Procedure:

- Thirteen greases/oils were obtained: Bath and Body Works® Green Clover and Aloe Body Lotion, Burt's Bees® Beeswax Lip Balm, Burt's Bees® Shea Butter Hand Repair Cream, Exxon Superflo® 10W-30 Motor Oil, Groom and Clean® Greaseless Hair Control, Humco™ Castor Oil, Johnson's® Baby Oil, Peoples Glycerin Suppositories, Paraffin Oil, Prestone®™ Synthetic Brake Fluid dot 3, Valvoline® Automotive and Industrial multi-purpose grease, Vaseline®, and 3 in 1® Household Oil. One stain remover, Tide® To Go Stick Instant Stain Remover, was also obtained.
- A squiggle was written on each paper type with the following writing instruments: ball point pen, Bic® brite liner, Sharpie® fine tip, Sharpie® pen, and Skilcraft® roller ball. Inkjet printing was also tested on FiberStone®, ViaStone™, and copy paper.
- Each ink sample was dotted, using a cotton swab as an applicator, with a few small drops of each grease/oil/stain remover
- Macroscopic observations were recorded
- Samples were allowed to dry a number of days, then excess grease/oil/stain remover was removed by blotting
- All samples were examined using the VSC®6000, and images were taken

### Indented Impressions

Papers tested: FiberStone®, TerraSkin®, ViaStone™, construction paper, copy paper, matte photo paper and scrapbook paper were initially tested simultaneously. Gartner® and Oxford® papers were tested simultaneously, at a later date, using the same method.

#### Procedure:

- One 1.5"x1.5" piece of each paper type was cut
- A clean piece of copy paper was placed over each square
- Using a ball point pen indented impressions were created on each sample with medium pressure
- Side light examination was conducted using the VSC®5000 (FiberStone®, TerraSkin®, ViaStone™, construction paper, copy paper, matte photo paper and scrapbook paper) and VSC®6000 (Gartner® and Oxford®), and images were captured
- All paper samples were processed twice using the cascade development method on the ESDA2®
  - First set was done without humidification prior to processing
  - Second set was done after 5 minutes of humidification
- Lifts were taken of the FiberStone®, TerraSkin®, ViaStone™, copy paper, manila construction paper, matte photo paper and scrapbook paper; no lifts were made of Gartner® and Oxford®

### Ink

Papers tested: FiberStone®, Gartner®, Oxford®, TerraSkin®, ViaStone™, construction paper, copy paper, matte photo paper, and scrapbook paper

#### Procedure:

- Writing instruments examined: ball point pen, Bic® brite liner, Sharpie® extra fine point, Sharpie® pen, and Skilcraft® roller ball
- One 1.5"x1.5" piece of each paper type was cut
- Squiggles were made using each writing instrument on each paper sample so each square had all five writing instruments represented
- The nine paper samples were placed together (3x3 formation) in the VSC®5000. The paper samples were examined simultaneously using the following wavelengths: 254nm,

312nm, 365nm, visible light, IR (645nm, 715nm, and 830nm), and spot fluorescence filter (bandpass 445-675nm, longpass 725nm)

- The reactions for visible light and UV 312nm were imaged

### Staples

Papers tested: FiberStone®, Gartner®, Oxford®, ViaStone™, and copy paper

#### Procedure:

- Three approximately 4"x5" sheets of each type of paper were stacked in a pile and labeled as A, B, and C from top down
- Three corners of each stack were stapled using a standard manual desk stapler
- Photos were taken
- Staple 1 was removed by first loosening the tines on the back with the staple remover and then pulling the staple from the front with the staple remover
- Staple 2 was removed by pulling the staple from the front with a staple remover
- Staple 3 was removed by holding pages B and C in one hand and pulling page A off with the other, pages B and C were then pulled apart

### Tear Test

Papers tested: FiberStone®, Gartner®, Oxford®, TerraSkin®, ViaStone™, and copy paper

#### Procedure:

- Four squares measuring approximately 4"x4" were cut from each paper type
- One sheet of paper was torn with fingers touching each other
- One sheet of paper was torn with fingers placed approximately 1" apart
- Two sheets of paper were placed one on top of the other and torn with fingers touching each other
- The tearing of each sample was video recorded
- Paper samples were photographed post-tear and imaged with the VSC®6000

### Toner and Inkjet

Papers tested: FiberStone®, ViaStone™, copy paper, matte photo paper, and scrapbook paper

#### Procedure:

- "TEST 9/9/2010" and "Toner" or "Inkjet", depending on the printing process used, were printed on each sheet of paper in cyan,



magenta, yellow, and black (the colors were chosen from the color wheel to be as "pure" as possible in order to test the different colors separately)

- The printed sheets were collected immediately from the printer tray and laid flat to air dry
- Using the VSC®5000 external camera, images were taken of the "o" in "Toner" and the "e" in Inkjet" at magnification 20X and in the "TE" in "TEST" at magnification 50X
- Using medium pressure a finger was run back and forth across the letter "o" in "Toner" 5 times
- Images were taken using the VSC®5000 external camera magnification 20X
- Rubbing was again conducted on the same samples on April 22, 2011 in the "0" of the date; no images were taken

### Typewriting

Papers tested: FiberStone®, Gartner®, Oxford®, TerraSkin®, ViaStone™, and copy paper

#### Procedure:

- Used IBM® Wheelwriter 15 by Lexmark™ (electric, daisywheel, equipped with a carbon ribbon and correction ribbon)
- Typed the following entries in a two line format:
  - Line 1 - RESPECTIVE PAPER TYPE "TYPE SAMPLE"
  - Line 2 - "THIS IS ERASER SAMPLE"
- The backspace key was then used to delete the characters "SER SAMPLE" from Line 2 on each of the papers tested
- Multiple images were taken using the VSC®6000 internal magnification function (ranging from 5.68 to 18.69 magnification)

### Water

Papers tested: FiberStone®, ViaStone™, and copy paper

#### Procedure:

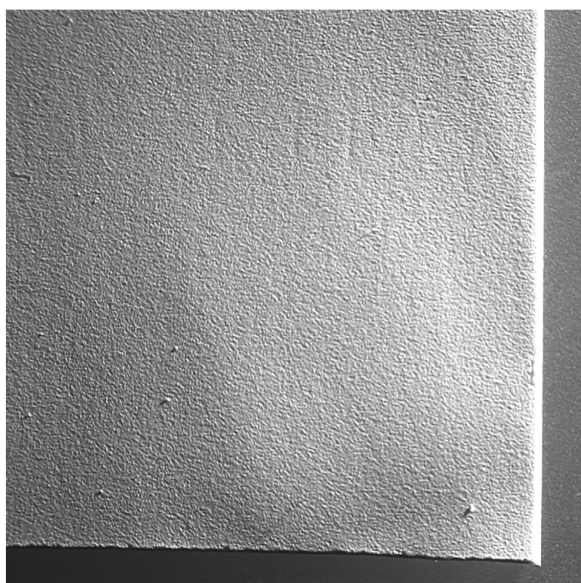
- Five strips, approximately 1"x7" in size, of each paper type were cut; a strip was also cut from an inkjet printed sample
- Each strip was squiggled on using one of the following writing instruments: ball point pen, Skilcraft® roller ball, Sharpie® pen, Sharpie® fine tip, and Bic® brite liner
- 3-1L beakers were obtained (one for each paper type) and filled with 700 mL of water.

- 6 slits in a circle formation were cut into 3 pieces of card stock
- The strips were then attached to the card stock (the card stock allowed the strips to hang freely in a 1L beaker without touching the sides or each other)
- Photographs were taken
- The strips were placed into the water, with care taken to not allow them to touch the sides or other strips
- After 10 min, 30 min, and 60 min the strips were removed and approximately 1" was cut from the bottom of each strip. The paper cutting was allowed to dry on paper towel.
- The strips were then left in the water over the weekend for a total of 66 hours submergence
- The strips were removed, the water level marked in pencil as well as the wicking front if applicable, and were allowed to dry on paper towel
- Observations were recorded throughout the process and photographs were taken
- The samples were examined using the VSC®6000

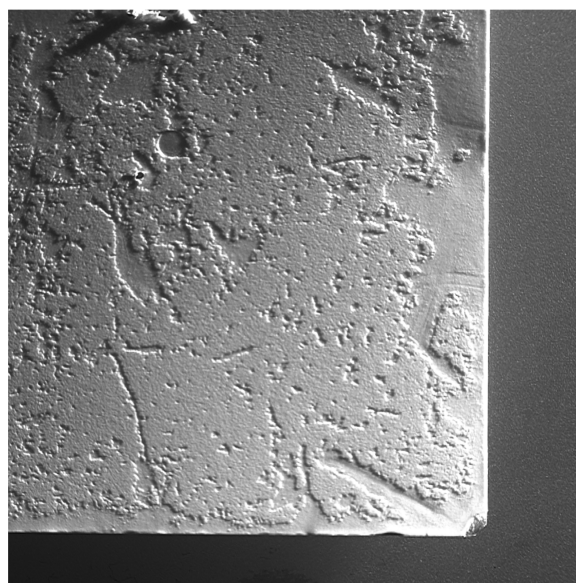
### Results: Environment Test

After subjection of the seven paper samples to environmental conditions including; heavy rain, high humidity, direct sunlight, and high temperatures, all three stone papers tested (FiberStone®, TerraSkin®, and ViaStone™) showed varying degrees of disintegration (see Table 1). After 56 days of exposure, two pieces of TerraSkin® began to show signs of disintegration when they became brittle and began to break apart. The paper was so brittle by this point that they could not be reattached to the fishing line, which was suspending the paper in the cage, so the fragments of TerraSkin® remained on the bottom of the cage for the duration of the experiment. After 82 days of exposure, one piece of the FiberStone® paper began showing signs of disintegration similar to those observed in the TerraSkin® samples. As pieces of the FiberStone® broke off, they remained on the bottom of the cage as well. After 132 days of exposure all samples of the FiberStone® and TerraSkin® paper had fallen to the bottom of the cage. However, all three ViaStone™ samples were still suspended by the fishing line. It was observed that the ViaStone™ samples were beginning to separate into layers. Therefore, one piece of ViaStone™ was removed from the cage for additional microscopic testing





**Figure 3a** ViaStone™ paper sample prior to environment test (magnification 5.52x, side lighting)



**Figure 3b** ViaStone® paper sample removed from cage on day 132 of environment test for further examination (magnification 5.52x, side lighting)

conducted within our laboratory by an expert in trace evidence (See Figures 3a and 3b for images of ViaStone™ paper before and after environment test). The aim of this additional testing was to determine whether chemical analysis showed a difference in the separating layers as compared to the intact ViaStone™ sample. Upon examination, the expert determined that chemical analysis did not show a difference between the separating and intact ViaStone™ samples. On day 163 the environmental study was ended due to the extent of disintegration of all FiberStone® and TerraSkin® paper samples. By the completion of the study, the two remaining samples of ViaStone™ paper were still attached to the fishing line.

Just as the stone paper samples changed during the environment test, all four pulp papers tested (construction paper, copy paper, matte photo paper, scrapbook paper) also displayed various changes. Samples of all four types of pulp paper had to be reattached multiple times to the fishing line. The construction and copy paper samples began to curl, and folded over on themselves after 1 day of exposure. By day 14, the scrapbook paper printed design had started to fade. By day 77, construction and copy paper samples had evidence of mold growth. By day 98, the matte photo paper also showed signs of mold growth. On day 132, two pieces of construction paper, 1/2 piece of copy paper, and all three pieces of the matte photo and scrapbook paper samples remained

suspended in the cage. At the completion of study on day 163, one piece each of the construction, matte photo and scrapbook papers remained suspended in the cage. The remaining samples had either fallen to the bottom of the cage or had blown out of the cage and could not be recovered.

#### Discussion: Environment Test

The results of the environment test were mostly as expected by the authors at the outset of the experiment. The pure stone papers, that is FiberStone® and TerraSkin®, had begun to degrade within two to three months of outdoor exposure, on days 56 and 82 (TerraSkin® and FiberStone®, respectively), whereas ViaStone™ did not. Although the layers of the ViaStone™ paper began to separate from each other by day 132, the paper as a whole remained intact throughout the duration of the experiment. Perhaps if the ViaStone™ samples did not have a coated back, they would have started degrading in a time frame more similar to that of the two other papers tested.

#### Results: Folding

FDE's casework at times involves requests for determining authenticity and/or sequencing of strokes. Understanding how various common inks interact with stone papers, before and after a fold is made, is essential for determining sequence (see Table 2, Figure 4).

**Table 1: Environmental Test Summary**

| DAY | Date      | Observations |            |           |           |              |             |           |
|-----|-----------|--------------|------------|-----------|-----------|--------------|-------------|-----------|
|     |           | FiberStone®  | TerraSkin® | ViaStone™ | Copy      | Construction | Matte Photo | Scrapbook |
| 0   | 19-May-10 | 3-S          | 3-S        | 3-S       | 3-S       | 3-S          | 3-S         | 3-S       |
| 1   | 20-May-10 | NR           | NR         | NR        | 3-C       | 3-C          | NR          | NR        |
| 14  | 2-Jun-10  | NR           | NR         | NR        | NR        | NR           | NR          | 3-F       |
| 56  | 14-Jul-10 | NR           | 2-B        | NR        | 1-M       | NR           | NR          | NR        |
| 77  | 4-Aug-10  | NR           | 3-B        | NR        | 2-MG      | 3-MG         | NR          | NR        |
| 82  | 9-Aug-10  | 1-B          | 3-B        | NR        | 2-NS      | NR           | NR          | NR        |
| 92  | 19-Aug-10 | 1-B          | 3-B        | NR        | 1-RS, 1-M | NR           | 1-RS        | 1-RS      |
| 98  | 25-Aug-10 | 1-B          | 3-B        | NR        | NR        | NR           | 1-RS, 3-MG  | NR        |
| 132 | 28-Sep-10 | 3-B, 3-NS    | 3-B, 3-NS  | 3-LS, 1-E | 1/2-S     | 2-S          | 3-S         | 3-S       |
| 163 | 29-Oct-10 | 3-B, 3-NS    | 3-B, 3-NS  | 2-S       | 1/2-NS    | 1-S          | 1-S         | 1-S       |
| 163 | 29-Oct-10 | END          | END        | END       | END       | END          | END         | END       |

**Table 1** B, brittle/breaking apart; C, curling; E, removed for further examination; F, fading; LS, layers separating and edges flaking; M, missing; MG, mold growth; NR, nothing remarkable noted/no change from previous observation; NS, no longer suspended; RS, re-suspended; S, suspended. The number preceding the abbreviation refers to the number of samples affected.

### *Writing before the paper is folded*

#### *Convex fold*

When examining the FiberStone® paper microscopically, the Skilcraft® roller ball and Sharpie® fine tip ink lines showed slight line disruption after folds 1 and 5. By 10 folds, all four ink samples showed varying degrees of disruption when examined microscopically. After 20 folds, small voids were noted macroscopically in all three ink samples on the FiberStone® paper, and the paper itself displayed a marked curling when unfolded, with defined creases through all of the ink samples. Microscopic examination of the paper and ink line after 20 folds showed major paper surface disruption and voids in the ink lines.

When the ball point pen and Sharpie® fine tip lines were examined both macro- and microscopically after the Gartner® paper sample was folded 1, 5, 10 and 20 times, it was determined that the folding had no effect on either ink lines. After 5 folds, a void developed in the Skilcraft® roller ball line, which increased in size at 10 and 20 folds. After 20 folds macroscopically, Gartner® displayed some smearing of the Skilcraft® roller

ball ink sample and a small void area was seen in the loops. Overall, the creases in the Gartner® were defined, but the paper laid flat when completely unfolded.

When looking at the ink samples on the Oxford® paper after they were folded 20 times, the Skilcraft® roller ball sample showed ink smearing, with some evidence of ink transfer across the fold. The creases created through all of the ink samples after 20 folds were defined, yet the paper laid flat when completely unfolded. Microscopically, there was no disruption to any of the three ink lines. However, the Sharpie® fine tip line seemed to show some slight lightening, perhaps due to ink being removed during the folding process or due to the disturbance of paper surface, which could give the illusion that the ink line was lightened at the ink-fold intersection.

There was a clearly visible void present through all of the ink writing lines on ViaStone™ paper after 20 folds, the fold creases were pronounced, and some curling remained when the paper was completely unfolded. When the ink lines were examined microscopically, the ball point pen and Sharpie® fine tip showed some small signs of flaking after 1 fold. By 5, 10 and 20 folds there

**Table 2: Ink Line and Paper Fold Sequencing**

| Fold Type | Writing/Fold Sequence  | Number of folds | FiberStone® |      |   | Gartner® |    |   | Oxford® |    |   | ViaStone™ |      |      |
|-----------|------------------------|-----------------|-------------|------|---|----------|----|---|---------|----|---|-----------|------|------|
|           |                        |                 | RB          | BP   | S | RB       | BP | S | RB      | BP | S | RB        | BP   | S    |
| Convex    | writing before folding | 1               | F           | -    | F | -        | -  | - | -       | -  | - | F, V      | F, V | F, V |
|           |                        | 5               | F           | -    | F | F        | -  | - | -       | -  | - | V         | V    | V    |
|           |                        | 10              | F           | F    | F | F        | -  | - | -       | -  | - | V         | V    | V    |
|           |                        | 20              | F           | F    | F | F        | -  | - | Sm      | -  | F | V         | V    | V    |
|           | writing after folding  | 1               | C           | C    | B | B        | -  | B | C       | C  | C | V         | V    | V, B |
|           |                        | 5               | V, C        | V, C | B | B        | V* | B | C       | C  | C | V         | V    | V, B |
|           |                        | 10              | V, C        | V, C | B | B        | V* | B | C       | C  | C | V         | V    | V, B |
|           |                        | 20              | V, C        | V, C | B | B        | V* | B | C       | C  | C | V         | V    | V, B |
| Concave   | writing before folding | 1               | F           | -    | - | -        | -  | - | -       | -  | - | F         | F, V | F    |
|           |                        | 5               | F           | -    | - | -        | -  | - | -       | -  | - | F, V      | F, V | F    |
|           |                        | 10              | F           | -    | - | -        | -  | - | -       | -  | - | F, V      | F, V | F    |
|           |                        | 20              | F           | -    | - | -        | F* | F | -       | -  | - | F, V      | F, V | F    |
|           | writing after folding  | 1               | -           | -    | V | -        | -  | - | B       | -  | - | V         | V    | V    |
|           |                        | 5               | -           | -    | V | -        | -  | B | B       | -  | - | V         | V    | V    |
|           |                        | 10              | -           | -    | V | -        | V  | B | B       | -  | - | V         | V    | V    |
|           |                        | 20              | -           | V*   | V | -        | V  | B | B       | -  | - | V         | V    | V    |

**Table 2** RB, Skilcraft® roller ball; BP, ball point; S, sharpie® fine tip marker; B, bleeding of ink; C, compression of fold at intersection; F, flaking of ink line; Sm, smearing of ink; V, void in ink line; \*, in some of the ink/fold intersections but not all; -, nothing remarkable/nochange in the ink line.

was a solid void area through the ink lines of each sample. The Skilcraft® roller ball showed more substantial flaking after 1 fold, which increased like the others to a solid line at 5, 10 and 20 folds.

#### *Concave fold*

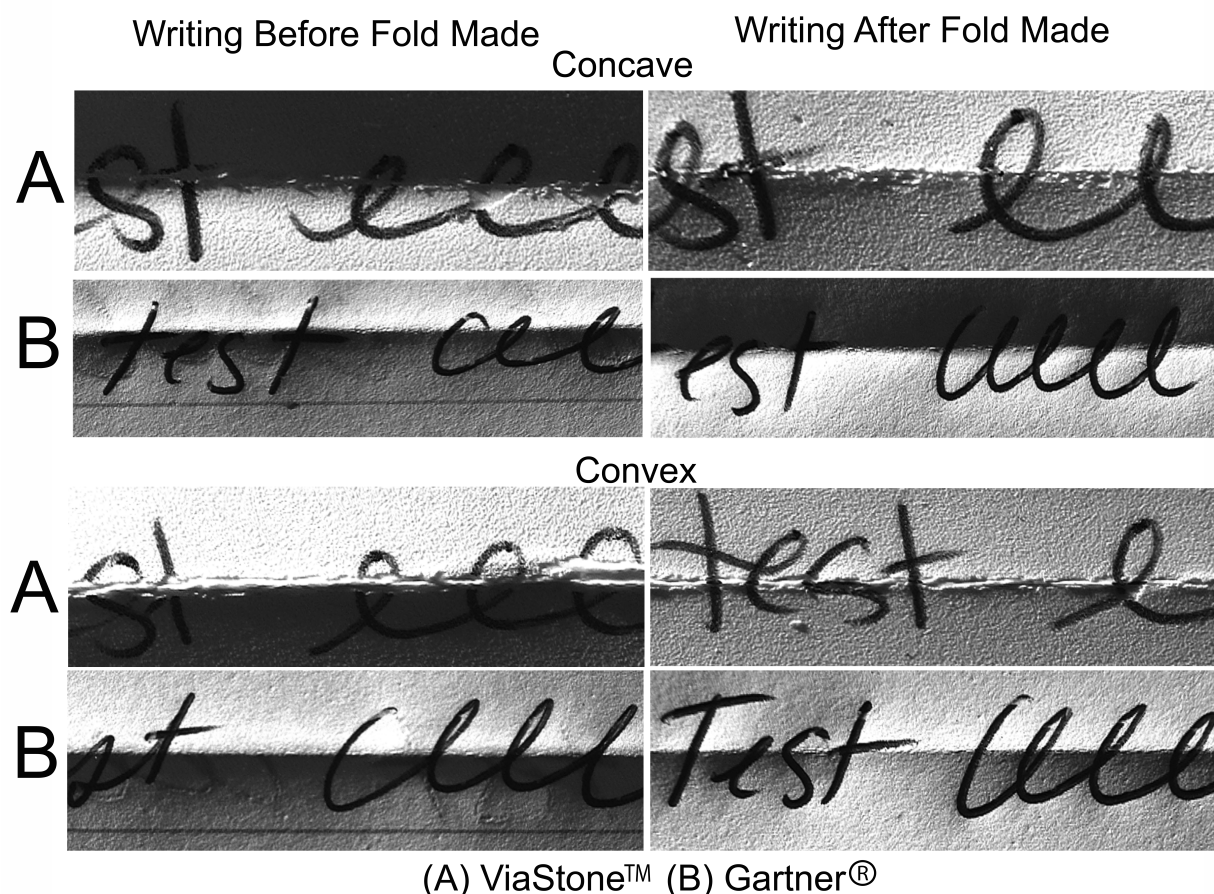
After 20 folds of the FiberStone® paper, there was no overt ink line disruption, but there was marked curling of the paper and defined creases through each of the ink lines. The Skilcraft® roller ball ink line showed a void after 1, 5, 10 and 20 folds. The ball point and Sharpie® fine tip ink lines started to show flaking at the fold intersections after 10 folds.

Like the ink lines on the FiberStone® sample, the ink lines on the Gartner® and Oxford® papers showed no macroscopically visible voids in the ink line after 20 folds. The creases in the Gartner® and Oxford® papers were defined, but both papers laid flat when they were completely unfolded. Microscopically, folding had no effect on the Skilcraft® roller ball ink line, while the ball point pen line displayed a slight flaking interruption after 20 folds, and the Sharpie® fine tip

line showed some lightening at all folds on the Gartner® paper. On the Oxford paper, folding did not cause any disruption to the three ink lines.

When examining the ViaStone™ paper macroscopically after the paper had been folded 20 times, all three ink samples had void areas, the crease in the paper was pronounced, and there was also some curling of the paper when it was unfolded. The ball point pen and Sharpie® fine tip showed minimal signs of flaking after 1 fold, and the flaking increased as the folding increment increased. Increase in flaking was noted as the number of folds increased, the Sharpie® fine tip line remained fairly intact after being folded 20 times, while the ball point pen samples showed only small voids. The Skilcraft® roller ball showed more substantial flaking at 1 fold than the other two ink lines, which increased to void areas in the ink line, as well as paper surface disruption as the folds increased.





**Figure 4** Comparison of ink line and paper fold intersections. Ink line more disrupted by convex folding (bottom set of images) and folding on thicker stone papers (paper (A) - ViaStone™).

#### *Writing after the paper is folded*

##### *Convex fold*

Microscopically, the Sharpie® fine tip line showed bleeding at the fold intersection on the FiberStone® paper after 1, 5, 10, and 20 folds, while the Skilcraft® roller ball and ball point pen line compressed the fold as it crossed the intersection point at 1, 5, 10 and 20 folds. Slight voids in these two pen lines were also noted at the intersection at 5, 10 and 20 folds.

The folds on the Gartner® paper caused the Sharpie® fine tip and Skilcraft® roller ball pen to display slight bleeding in some crossings, but not all, after 1, 5, 10 and 20 folds. After 5 folds, the ball point pen line had small voids at some of the fold crossings.

Overall, the three pen lines on the Oxford® paper showed nothing remarkable as far as the intersection points. The fold was slightly compressed at the intersection points where the pen line crossed it, so the author was able to deter-

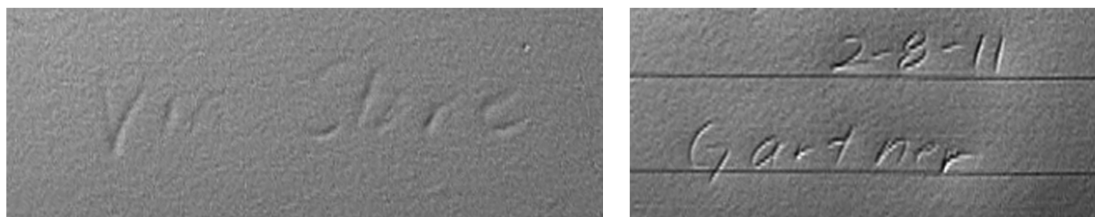
mine that the pen line had been drawn after the fold was created.

Because of the surface of the ViaStone™ paper, the three pen lines at 1, 5, 10 and 20 folds were extremely disrupted. The lines all skipped over the fold, creating voids while also leaving some ink in the crease created by the broken paper surface. The Sharpie® fine tip also displayed some bleeding of the ink at the fold intersection points.

##### *Concave fold*

Overall, the Sharpie® line on the FiberStone® paper showed voids at the crease after 1, 5, 10, and 20 folds. Microscopically, voids were also noted in the ball point pen ink line at 20 folds. Macroscopically, no visible ink line disruption was seen on the Gartner® paper, and the paper itself laid flat. Similarly, Oxford® showed no visible ink line disruption; however there was marked curling of the paper at top and bottom of half sheet. The ViaStone™ paper surface showed disturbance at the crease at 1, 5, 10 and 20 folds,





**Figure 5** Side light images of indented impressions on ViaStone™ (left) and Gartner® (right) paper samples

and there were voids in the pen line.

The line intersections of the three pens with the concave and convex folds of the Gartner® and Oxford® papers were examined microscopically. On the Gartner® paper, there was slight bleeding of the Sharpie® pen line after 5 folds, and after 10 folds there were slight voids in the ball point pen ink line noted, but those could have been due to the pen itself, and not necessarily the fold. There was slight bleeding at the folds in the roller ball ink line after 1, 5, 10 and 20 folds on the Oxford® paper, but there was no change in the Sharpie® or ball point pen ink lines.

### Discussion: Folding

For this portion of the study, the paper folding was done by hand. Although this most closely simulates folding paper in a real-world scenario, it was not standardized since it was done manually. Therefore, in order to ensure that the same pressure and the same motion were applied to all of the folds on all of the papers, the use of a machine may have been beneficial.

That being said, when examining the intersections between the ink lines and the folds, the authors concluded that it may be possible to state whether an ink line was laid down prior to or after a fold was made. It was easier to determine this line/fold sequence in the papers whose surfaces were more disrupted by the folding action (e.g., ViaStone™), and when the ink line intersected with convex folds.

### Results: Grease

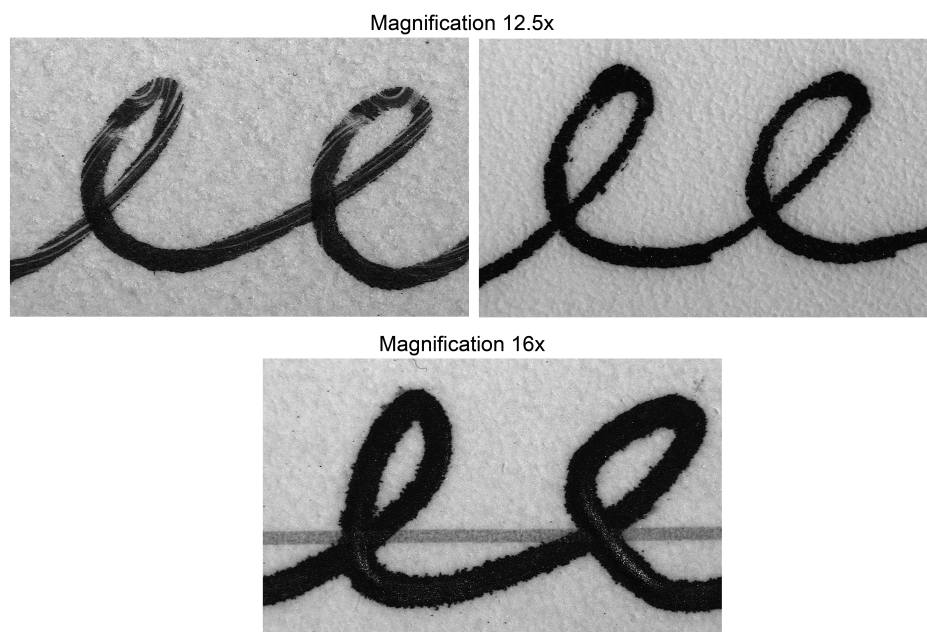
The Burt's Bees® Beeswax Lip Balm, Groom and Clean® Greaseless Hair Control, Johnson's® Baby Oil, Paraffin Oil, and 3 in 1® Household Oil, all affected the six paper samples tested by changing the opacity of the paper, though the Johnson's® Baby Oil had a lesser effect on the Oxford® paper sample than on the others. The Humco™ Castor Oil changed the opacity of all paper samples except the Gartner® sample. Bath

and Body Works® Green Clover and Aloe Body Lotion, Exxon Superflo® 10W-30 Motor Oil, and Vaseline® affected all paper samples except for FiberStone®. Burt's Bees® Shea Butter Hand Repair Cream affected the thicker stone papers, that is FiberStone®, TerraSkin®, and ViaStone™, but did not appear to affect the thinner samples, Gartner® and Oxford®. Tide® To Go Stick Instant Stain Remover affected only the FiberStone®, and ViaStone™ papers. Prestone® Synthetic Brake Fluid dot 3 affected only the Gartner® paper sample. Peoples Glycerin Suppositories and Valvoline® Automotive and Industrial multi-purpose grease had no effect on the opacity of any of the paper samples. In addition to changes in opacity, disturbance in the paper surface was observed on FiberStone® in areas treated with Exxon Superflo® 10W-30 Motor Oil, Humco™ Castor Oil, Paraffin Oil, and 3 in 1® Household Oil. Some of the grease samples used also affected the various ink samples, however for the purposes of this study the authors' focus and analysis was limited to the grease/oil/stain remover reaction with the paper samples.

### Discussion: Grease

According to the results of this portion of the study, stone papers are not grease resistant as the manufacturers claim. In fact, the opacity of all of the stone papers tested was changed by at least eight of the substances tested, with ViaStone's™ opacity being changed by 11 out of the 14 substances tested.

When the concept for this portion of the study was first developed, the authors thought that the interaction between the greases/oils/stain remover and the ink on paper would be more important to study than the actual interaction between the aforementioned substances and the paper itself. However, once it was completed, and all of the data was compiled, it became apparent that, in order to truly test the manufacturers' claims of grease resistance, determining how the greases/oils/stain remover affected the opacity of



**Figure 6a** (left) Blue ballpoint ink line on FiberStone® paper showing ball impression at the top of each loop and pronounced stria

**Figure 6b** (right) Black roller ball ink line on ViaStone™ paper showing abrupt thinning at the trough of the connection

**Figure 6c** (bottom) Black roller ball ink line on Gartner® paper showing feathering of ink throughout the line

the papers themselves yielded more significance.

If this portion of the study was undertaken again, the authors would abandon the use of writing inks, and would either spot the greases/oils/stain removers on well-defined sections of each of the papers, or place them on completely separate squares of paper so that they could not combine or run into each other, as was seen on some of the papers currently tested.

### Results: Indented Impressions

Examination of the FiberStone®, Gartner®, Oxford®, TerraSkin®, and construction papers using the cascade method on the ESDA2® (Foster + Freeman 2003) did not result in the decipherment of any indented impressions. Faint indented impressions were found on ViaStone™, and more pronounced indented impressions were found on copy paper, matte photo paper and scrapbook paper samples. It was noted that, during the cascading of the beads over the papers, the beads seemed to adhere to the FiberStone® sample. While indented impressions were not successfully developed using the ESDA2® on the FiberStone®, Gartner®, Oxford®, and TerraSkin® papers, very good and clear indentations were discernible using side lighting on the VSC®5000 and VSC®6000 (see Figure 5).

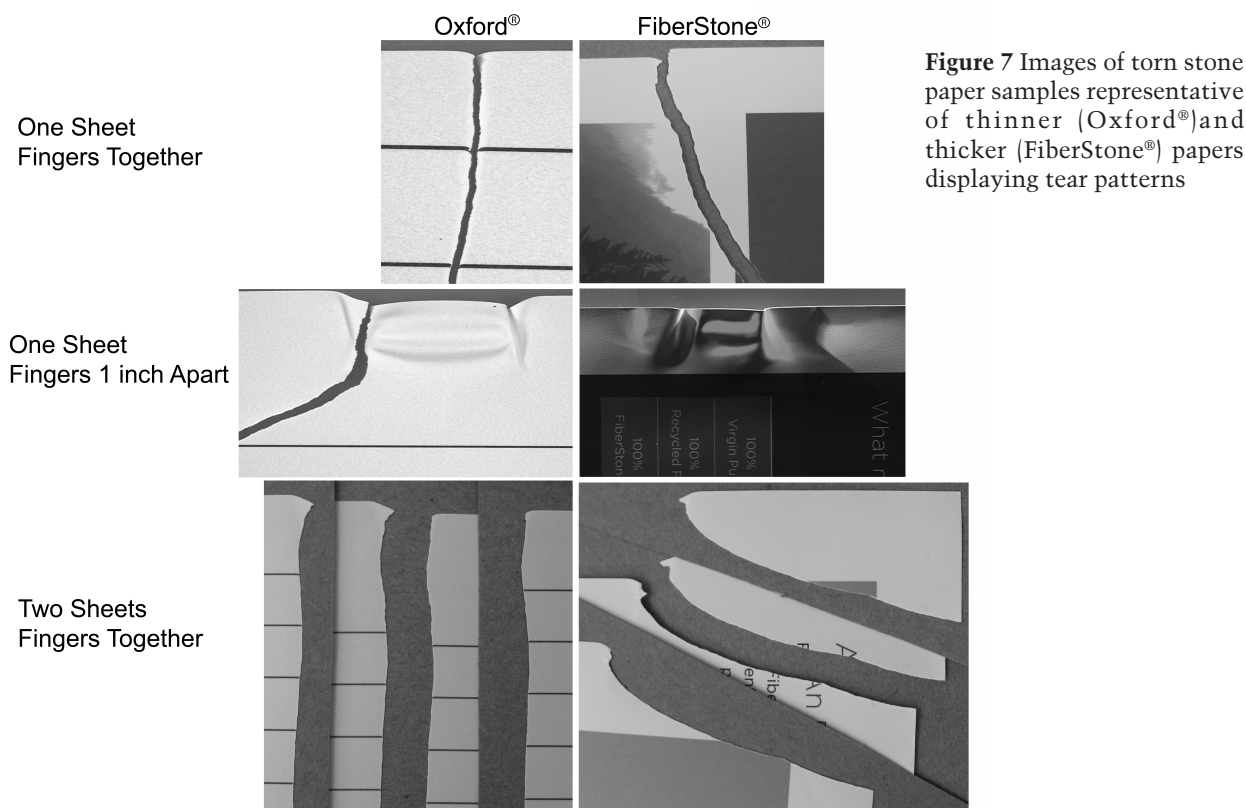
### Discussion: Indented Impressions

It is well known in the forensic document com-

munity that examiners have a hard time developing indented impressions on plastics due to electrical conductivity issues and thick pulp paper due to indented impression being too deep using an ESDA2®. In this study, the indented impressions generated on the stone paper samples were deep enough that the examiner could easily discern what was indented using side lighting. The deep impressions in combination with the presence of plasticizers in the stone paper precluded more effective indented impression development using an ESDA2®.

### Results: Ink

In general, the microscopic appearance of the ink lines on the stone paper samples, as compared to copy paper, was more fluid, with a crisper edge, and the indentations lent themselves better to line sequencing because they were deeper. When preparing the ink samples, it was noted that the surface of the ViaStone™ paper was easily removed as the ink line was laid down. This resulted in flaking of the paper surface, which at times caused the writer to modify the pen movement in order to minimize the paper disturbance. Abrupt thinning of the ink line was also noted when using specific pens on stone paper samples. The ball point pen line displayed more pronounced stria, including showing the ball impression after the turn on FiberStone®, Gartner®, Oxford®, and TerraSkin® stone papers



**Figure 7** Images of torn stone paper samples representative of thinner (Oxford®) and thicker (FiberStone®) papers displaying tear patterns

(see Figures 6a through 6c). The ball point pen line on the ViaStone™ sample also had stria present, and appeared to take on the texture of the paper surface. The Sharpie® extra fine point ink line appeared very fluid on all stone paper samples tested; however, the crispness of line edge varied depending on the stone paper substrate. The Bic® brite liner ink line appeared to take on the texture of the paper substrate whether it was on stone or copy paper. The Skilcraft® roller ball pen ink line edges were not crisp on any of the stone or copy paper samples, and slight feathering was observed on Gartner® and Oxford® stone papers. The Sharpie® pen ink line, like the Sharpie® extra fine point ink line, appeared fluid but edge crispness varied depending on the paper substrate. In one instance, on the ViaStone™ paper, the paper surface texture was visible within the Sharpie® pen ink line.

Through microscopic examinations of all of the ink lines, the authors determined that the possibility of ink line sequencing on stone paper samples is similar to that of copy paper. That is, if there is an indentation in the ink line, stroke sequence is easier to determine than if no indentation is present. Of course the presence of an indentation does not guarantee that stroke

sequence can be determined in all cases.

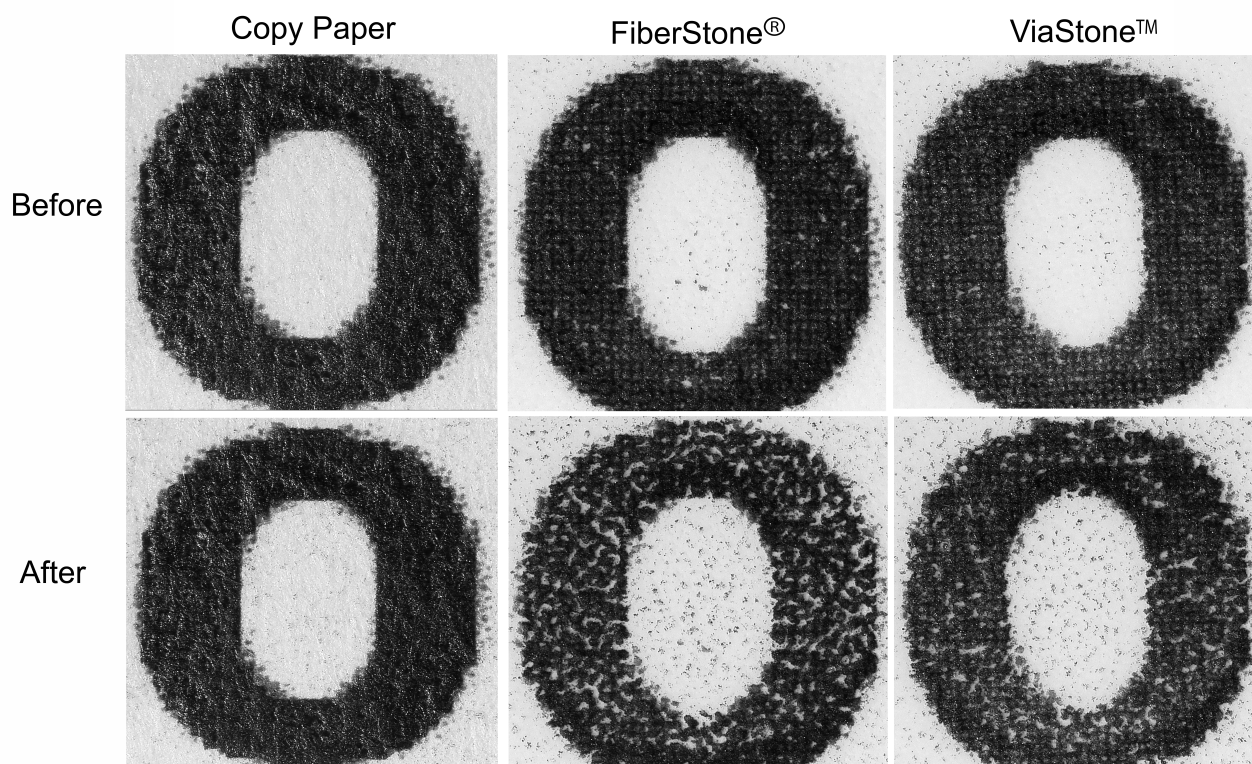
#### Discussion: Ink

When examining ink lines on stone paper and comparing them to ink lines on pulp paper, the lines on both kinds of paper displayed similar optical activity when examined using different light sources. When examined microscopically under flood light, the ink lines on the stone paper took on a similar appearance to ink lines found on coated pulp paper, like the matte photo paper used in this study.

#### Results: Staples

The purpose of this test was to determine whether the insertion of a page within a stapled multi-page stone paper document could be detected. It was noted that, like in traditional pulp papers, the removal of a staple from stone paper, whether using a staple remover or by manual removal, left distinct staple holes which could be easily seen. As expected, staple removal in the thinner stone papers (i.e., Gartner® and Oxford®) caused greater paper disturbance than in the thicker stone papers, and manual removal of the staples left larger holes than when using a staple remover.





**Figure 8** Images of toner printed character “o”, before and after light rubbing, displaying poor adhesion to stone paper samples

### Discussion: Staples

As in the folding and tearing studies, the staple removal was done manually, and therefore may not have been done as uniformly as possible across all types of paper. Although all of the staple removal was done by one person, and in a similar manner for all samples, in the future, it may be prudent to devise a method which allows the staple to be removed in the exact same manner with the exact same pressure every time, for every sample.

### Results: Tear Test

The tearing of a single sheet of paper with fingers placed together resulted in complete tears in all paper samples. The tearing of ViaStone™ paper resulted in a more diagonal/horizontal tear so that only a small corner segment was separated from the sheet. The remaining papers all tore in a more vertical or vertical/diagonal manner resulting in two pieces of roughly the same size or an approximately a 70/30 split of the original sheet.

The simultaneous tearing with fingers together of two sheets of paper resulted in complete tears of all papers. The tearing of the FiberStone® papers

resulted in a more diagonal/horizontal tear so that only a small corner segment was separated from each sheet (see Figure 7). The remaining papers all tore in a more vertical manner resulting in more or less four even paper halves. After the two sheets were torn, the edges of the two layered halves on the left shared a similar contour, as did the torn edges of the layered halves on the right; yet a guess as to which two halves previously comprised the top paper and which two halves previously comprised the bottom paper could be made due to slight differences in the torn edges' jigsaw patterns. Although a guess could be made as to which two halves previously made up one sheet, the torn edges could not be completely aligned along the entire tear due to stretching at the tear initiation site. This stretching precluded the ability to perform a definitive fracture match examination.

The tearing of a single sheet of paper by pinching the paper edge with both hands placed approximately one inch apart from each other was attempted for ten seconds, and resulted only in stretching of the FiberStone®, TerraSkin® and ViaStone™ samples (see Figure 7). The tears in the three remaining samples, that is, copy paper,

Gartner® and Oxford®, looked similar to those found in the FiberStone® papers torn together as described above, with only a corner being removed. Stretching at the points the papers were held was also observed in the Gartner® and Oxford® (see Figure 7) samples but those papers were eventually able to be torn within the prescribed 10 second time frame.

### Discussion: Tearing

In casework, the ability to prove that two pieces of paper were once one continuous sheet can be very important. Therefore, the goal of this portion of the study was to determine first, if fracture matching can be done on a piece of stone paper that has been torn into two, and second, if the resulting tears formed when two pieces of stone paper are torn together are distinct enough for the examiner to determine which two pieces were once one contiguous sheet. Through this experiment, the authors determined that, although the four halves of two sheets of stone paper torn together can be macroscopically separated into the original two full sheets, because of the plasticizers present in the stone paper and the pulling/stretching that occurs during a tear, a microscopic fracture match examination cannot be done.

As in the folding and staple removal portions of this study, the tearing was done manually, and therefore may not have been done as uniformly as possible across all types of paper. In their June 2010 paper, Welch et al. discussed a mechanism for creating uniform tears in paper which could be applied in future stone paper fracture match studies (Welch et al. 2010). Aside from the lack of uniformity in the tearing method, another limitation of this portion of the study was the amount of paper available. Because the authors had a limited supply of both FiberStone® and TerraSkin®, it was decided that all of the papers to be used in the tear test would be cut into smaller pieces so that there would be enough of the FiberStone® and TerraSkin® samples to do the experiment. Even with cutting the samples, the authors did not have enough to tear two sheets of TerraSkin® together. However, the TerraSkin® paper was so strong that a single sheet could not be torn within 10 seconds when fingers were placed one inch apart, so it most likely would be extremely difficult to tear two sheets simultaneously using this method.

It can be said then, in some of the stone paper samples, specifically the thicker samples, the

“tear resistance” was much higher and therefore it was much harder for them to be torn, especially when the tear was attempted with fingers held one inch apart. However, when fingers were held together, all of the stone paper samples were able to be torn into two pieces. In the stronger/thicker samples, this was achieved by the person making a very small tear at the edge of the paper by using the tips of their fingers and rotating their hands in opposite directions.

### Results: Toner and Inkjet

The toner adhesion to the three pulp paper samples tested (copy paper, matte photo and scrapbook) was markedly better than to the stone paper samples tested (FiberStone® and ViaStone™). The toner on the stone paper samples was easily smudged with very slight rubbing (see Figure 8). After approximately seven months, adhesion was tested for a second time, with the results being the same as the first test.

In contrast, the inkjet printed entries on four of the five pulp paper samples were extremely stable, and could not be removed via manual manipulation. The matte photo printed entries smudged after both one hour and at approximately seven months after production.

Unlike the toner machine printed entries, the stone papers retained the inkjet printed entries, which could not be rubbed off with the application of light rubbing. When the inkjet printed entries were examined microscopically, it was noted that the entries on the stone paper looked similar to those on the matte photo paper; that is, the printing remained more on the surface of the paper rather than being absorbed by it.

### Discussion: Toner and Inkjet

According to their manufacturers' information, neither FiberStone® nor ViaStone™ is recommended to be used with office machines which print using toner technology. The package insert sent with the FiberStone® samples clearly states “use this paper with inkjet printers only. Do not use in laser printers or laser copiers.” (Natural Source Partners™ 2010). Similarly, in its FAQ section of their website, ViaStone® states “laser printers and copiers use heat-fusion technology which will harden and make the products brittle” ([www.viastone.com/FAQs.html](http://www.viastone.com/FAQs.html) 2009). However, even though the manufacturers do not recommend their products to be used in office machines that utilize toner technology, because

**Table 3: Water Test Summary**

| Time (min)   | Light Source | FiberStone® |      |      |    |    |      | ViaStone™ |      |      |    |    |      | Copy |    |    |    |    |      |
|--------------|--------------|-------------|------|------|----|----|------|-----------|------|------|----|----|------|------|----|----|----|----|------|
|              |              | RB          | H    | BP   | SP | IJ | S    | RB        | H    | BP   | SP | IJ | S    | RB   | H  | BP | SP | IJ | S    |
| 0            | flood        | -           | -    | -    | -  | -  | -    | -         | C    | -    | -  | -  | -    | -    | -  | -  | -  | -  | -    |
|              | UV           | -           | F    | -    | -  | -  | -    | -         | F    | -    | -  | -  | -    | -    | L  | -  | -  | -  | -    |
|              | IR           | A           | L    | L    | T  | A  | L    | A         | L    | L    | T  | A  | L    | A    | L  | A  | A  | A  | A    |
| 10           | flood        | -           | NV   | -    | -  | -  | -    | -         | -    | R    | -  | -  | R    | -    | NV | -  | -  | R  | -    |
|              | UV           | -           | F, R | -    | -  | -  | -    | -         | F, R | -    | -  | -  | -    | -    | NV | -  | -  | -  | -    |
|              | IR           | A           | T    | L, R | T  | A  | L, R | A         | L    | L, R | T  | A  | A    | A    | NV | Q  | T  | A  | R, A |
| 30           | flood        | -           | NV   | -    | -  | -  | -    | -         | R    | R    | -  | -  | R    | -    | NV | -  | -  | R  | -    |
|              | UV           | -           | NV   | -    | -  | -  | -    | -         | F, R | -    | -  | -  | -    | -    | NV | -  | -  | -  | -    |
|              | IR           | A           | T    | L, R | T  | A  | A    | A         | L    | L, R | A  | A  | Q, R | A    | NV | Q  | T  | A  | R, A |
| 60           | flood        | -           | NV   | -    | -  | -  | -    | -         | -    | -    | -  | -  | -    | -    | NV | -  | -  | R  | -    |
|              | UV           | -           | NV   | -    | -  | -  | -    | -         | F, R | -    | -  | -  | -    | -    | NV | -  | -  | -  | -    |
|              | IR           | A           | T    | L, R | T  | A  | A    | A         | L    | L, R | A  | A  | Q, R | A    | NV | Q  | T  | A  | R, A |
| 3960 (66 hr) | flood        | -           | NV   | -    | -  | -  | -    | -         | -    | -    | -  | -  | -    | -    | NV | -  | -  | R  | -    |
|              | UV           | -           | NV   | -    | -  | -  | -    | -         | F, R | -    | -  | -  | -    | -    | NV | -  | -  | -  | -    |
|              | IR           | A           | T    | L, R | T  | A  | A    | A         | L    | L, R | A  | A  | Q, R | A    | NV | Q  | T  | A  | R, A |

**Table 3** RB, Skilcraft® roller ball; H, Bio® brite liner; BP, ball point; SP, Sharpie® pen; IJ, inkjet; S, Sharpie® fine tip marker. A, Absorb; C, Color Change; F, Fluoresce; L, Luminesce; NV, No visible trace of the ink line; Q, Ink line absorbs with a luminescent halo; R, Ink line is running/bleeding; T, transmit; -, No reaction, no change in the line

laser copiers and printers are widely used, the authors wanted to see the interaction between the stone paper samples and toner machine printing. When the toner adherence on the samples of FiberStone® and ViaStone™ was tested, the manufacturers' claims were corroborated during both testing periods, both right after printing and seven months later. The ViaStone® paper did not become hard or brittle as the manufacturer claimed it would ([www.viastone.com/FAQs.html](http://www.viastone.com/FAQs.html) 2009).

The problem with this portion of the experiment is that the authors were again limited as to which samples could be used, but this time it was due to the paper size requirement of the laser and inkjet printers. Therefore, the toner and inkjet adherence to Gartner®, Oxford® and TerraSkin® could not be tested. Another issue was that the matte photo paper contained one matte printing side and one glossy printing side, and only the glossy printing side was printed on using toner and inkjet. Perhaps if the matte side had been tested, there would not have been an issue with the inkjet retention on this particular pulp paper.

### Results: Typewriting

The typewritten entries on Gartner®, Oxford®, and TerraSkin® resulted in high embossing on the reverse of the paper, as well as some buckling of the paper on the front around the typed characters. The ViaStone™ sample exhibited limited embossing on the reverse side, and FiberStone® paper displayed even less. No embossing was observed on the copy paper.

The use of the correction ribbon did not result in complete removal of the typewritten characters on any of the paper samples; however, on the FiberStone® and copy paper samples, all the characters that were "corrected" appeared lighter than those that were not, indicating some of the carbon was removed. The use of the correction ribbon on the Via Stone™ sample resulted in the partial removal of not only the carbon character but also portions of the underlying paper surface. On the TerraSkin® and Oxford® samples, the "corrected" characters were unevenly removed, leaving portions of carbon on the paper. The Gartner® sample, when examined microscopi-



cally, showed only a very small amount of carbon removed, resulting in a duller and slightly less crisp appearance.

### Discussion: Typewriting

Although the stone paper samples proved to be a good substrate for crisp, clean typewritten entries, the thicker stone papers (FiberStone®, TerraSkin® and ViaStone™) were more conducive to the typed impressions than the thinner papers (Gartner® and Oxford®). This was because the impressions on the thinner papers were extremely deep and therefore resulted in buckling of the paper on the front around the characters, and heavy embossing on the reverse. It was also noted during this portion of the experiment, that the characters could not be easily removed from the stone paper samples using the correction ribbon supplied with the typewriter. In fact, when the correction ribbon was applied to all of the papers tested, including the copy paper, it seemed only to lighten the carbon of the characters, and did not fully remove it. It was determined that, although the interaction of the carbon with the stone paper substrate may somewhat affect the effectiveness of the correction ribbon, this incomplete carbon removal may also be partially due to the poor condition of the correction ribbon itself. When the lack of character removal was noted on the copy paper, the correction ribbon was closely inspected and was found to be old and somewhat dried out.

### Results: Water

Examination of the ink entries on the FiberStone®, ViaStone™, and copy paper yielded a variety of results depending on the paper (see Table 3). This variation was most noticeable when looking at the green Bic® brite liner ink sample. When viewed under flood light at time zero, the ink appeared to be a different shade depending on the substrate. By ten minutes of submergence in the water, the Bic® brite liner ink line, when viewed under flood light, was intact on ViaStone™; however, it had started to run on FiberStone®, and was no longer visible on the copy paper. Viewing these samples under IR spot (bandpass filter 400-640nm, longpass filter at 695nm), the ink line transmitted light on FiberStone® sample and luminesced on the ViaStone™ sample; no residual line was observed on the copy paper. Under UV (254, 312 and 365nm), the ink line fluoresced on the FiberStone® and ViaStone™ samples and

again, no residual fluorescence from the ink line was noted on the copy paper.

Skilcraft® roller ball, Sharpie® pen and inkjet printed samples behaved similarly optically on all substrates throughout the duration of the experiment. That is, the observations made at time zero under flood, IR spot (bandpass filter 400-640nm, longpass filter at 695nm), and UV (254, 312 and 365nm) light sources were consistent with those made at 10min, 30min, 60min and 66 hours. Under flood light, the ink/printed line for these samples, with the exception of the minimal running of the inkjet printing on the copy paper and flaking of Skilcraft® roller ball on the ViaStone™ sample, remained unchanged throughout this portion of the study. Under IR spot (bandpass filter 400-640nm, longpass filter at 695nm) the Skilcraft® roller ball and inkjet ink lines absorbed light, and the Sharpie® pen ink line slightly transmitted light on all substrates. Under UV (254, 312 and 365nm) none of these inks fluoresced.

The ball point ink line sample behaved similarly on all three substrates when observed under flood and UV (254, 312 and 365nm) light; there was no reaction when under UV lighting. Under IR spot (bandpass filter 400-640nm, longpass filter at 695nm) the ink line behaved similarly on the stone paper samples, the ink luminesced and displayed slight running of the ink line. However on the copy paper, the ink line itself absorbed the light and there was a luminescent halo present.

The Sharpie® fine tip ink line sample started to run by ten minutes on the ViaStone™ sample under flood light. A similar reaction was not observed on the other substrates. However, when the copy paper and FiberStone® were observed under IR spot (bandpass filter 400-640nm, longpass filter at 695nm), running of the ink line was observed. Under IR spot (bandpass filter 400-640nm, longpass filter at 695nm), the ink line itself absorbed the light on the ViaStone™ and copy paper samples by ten minutes of submergence and by 60 minutes of submergence on the FiberStone® sample. Prior to 60 minutes, the ink line on the FiberStone® sample luminesced. Under UV (254, 312 and 365nm), Sharpie® fine tip ink line had no reaction on all three substrates.

### Discussion: Water

The purpose of this portion of the study was to test the manufacturers' claims that their stone papers were water resistant. In this test, samples

were submerged in water for prescribed periods of time. However, water resistance may have been better tested by simply spilling or cascading water over the surface of the paper samples rather than by total submergence. As tested, the papers all appeared to hold up well in the water; even the copy paper only had areas of slight deterioration.

Results suggest that some of the papers proved to be better at retaining the ink samples than others when submerged in water. For example, the Bic® brite liner completely bled off of the copy paper, and only remnants of the ink could be seen on the FiberStone® samples when examined under IR spot fluorescence; the Bic® brite liner mostly remained on the ViaStone™ sample, although it did change color. When all of the paper samples were examined using UV light, slight fluorescence was noted on some of the samples that were not observed on the zero time sample. This artifact could have been caused by the bleeding of the Bic® brite liner into the water, which was absorbed by the other paper samples. This accidental contamination of the paper samples would have been prevented through the use of separate containers for each pen type.

When examining the paper samples under IR spot, it was noted that the ball point pen ink line on copy paper and the Sharpie® line on the ViaStone™ paper both originally luminesced at time zero, however, as the ink/paper was submerged, both ink lines started to bleed, which resulted in an ink line that absorbed the light, with a luminescent halo surrounding it. This change in luminescence was most likely caused by the components of the ink separating.

### Discussion Overall

Overall, there were a couple of limitations encountered during this study of stone papers. The first and largest limitation was limited samples of stone paper for use in this study. This was especially true of the TerraSkin® paper, which is currently only available on the commercial scale. The company provided a sample packet for our research purposes and additional samples could not be purchased or obtained. Thus, the authors were required to make decisions regarding which experiments would be conducted on TerraSkin®. The supply of FiberStone® paper also dwindled rather quickly once the study was underway because, like TerraSkin®, FiberStone® paper is only available for commercial printing and not for retail sale, thus the only samples that were used

in this study were provided in an initial sample pack sent by the manufacturer. Another limitation was the late acquisition of the Gartner® and Oxford® samples, which precluded these papers from being included in some aspects of testing, such as the environment test. While attempts were made to ensure all of the papers were of similar thickness, the Gartner® and Oxford® samples were thinner than the others probably because they were marketed as notebook rather than photo papers. Finally, the fact that the ViaStone™ sample had a coated back may have had an impact on how the paper performed in some of the tests, such as the environment test.

### Conclusion

Overall, in terms of forensic document analysis, stone paper examinations can be conducted in a manner similar to those of traditional pulp paper, with a few exceptions regarding indented impression examination with the ESDA2® and fracture matching. Neither of these two pulp paper examination methods could be successfully applied to the stone paper samples during this study. As suggested in the discussion section for the indented impression examination and the tear test, one possible reason why these examination methods yielded less than optimal results is because of the plasticizers which are added during the stone paper manufacturing process. In the future, additional examinations of indentations made by writing on stone paper to stone paper and/or stone paper to traditional pulp paper are warranted, as would be the study of indentations on multiple sheets of stone paper.

The presence of plasticizers in the composition of the stone paper also seemed to affect the microscopic appearance of the ink lines examined; however, if the FDE becomes familiar with the appearance of different types of ink lines on stone paper, the disparity between stone and pulp paper should not prove problematic in case examination.

The authors have begun the process of looking at stone paper; however, there are a number of additional examinations which would provide valuable supporting data. The preliminary tests undertaken through this research study showed that the manufacturers' claims that stone paper is water resistant were valid. Depending on the tearing method, the manufacturers' tear resistance claims were also substantiated, although all samples tested could be torn when a single

sheet was held with fingers together on the page edge. The claims of grease resistance were not supported. Additional tests related to water resistance beyond submersion would provide additional foundation upon which to assess such manufacturer's claims.

Additional topics for study related to stone paper by forensic document examiners include how a person's individual handwriting characteristics may change to accommodate the various writing surfaces presented by different stone papers. Studies that may also be beneficial for investigation include: 1) determining how commercial printing media interacts with the different kinds of stone paper, 2) testing the effects fire may have on stone paper (i.e., how does it burn? Can the resulting charred document be treated similarly to a pulp paper charred document), 3) studying how rubber stamps interact with stone paper, and 4) identifying how tape and other adhesives like stickers behave when applied/removed from stone paper. Collaborative research is already underway in the authors' laboratory regarding the interaction between latent prints and stone paper where a Latent Print Examiner is attempting to determine whether latent prints can be successfully developed on stone paper, and whether special considerations need to be undertaken when working with stone paper on these types of examinations.

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