Article

Chemical Enhancement of Soil-Based Marks on Nonporous Surfaces Followed by Gelatin Lifting

Louise Hammell [1]
Paul Deacon [2]
Kevin J. Farrugia [1]

Abstract: This study assessed the use of processing techniques (potassium thiocyanate, 2-2-dipyridil, potassium ferrocyanide, ammonium pyrrolidinedithiocarbamate, safranin, magnetic powder) for the enhancement of soil-based marks on nonporous surfaces, followed by gelatin lifting for the recovery of these marks. Other variables in the study included the use of nonporous substrates with varying colors (ceramic tiles, glass, linoleum, plastic bags, leaflets) and different aging periods (1, 7, 14, and 28 days) prior to enhancement and gelatin lifting. A numerical grading system from -1 (deterioration) to 4 (recovery of all fine detail) was adopted to assess the quality of the enhancement achieved.

In this study, the two most effective chemical enhancement techniques for soil-based marks on nonporous surfaces were safranin and potassium thiocyanate, specifically on grey linoleum and white ceramic tiles. One-day aging of soil-based marks provided poor results, whereas 28-day aging periods provided superior enhancement. In general, lifting with gelatin lifts provided further improvement on the initial enhancement, by means of contrast and sharpness. However, the use of gelatin lifting sometimes resulted in the deterioration of the original mark. Marks treated with safranin and lifted with white gelatin lifts provided even further improvement through fluorescence examination.

[1] School of Science, Engineering & Technology, Division of Computing and Forensic Sciences, Abertay University, Dundee, U.K.

[2] Dundee, Scotland, U.K.

Received June 11, 2014; accepted August 30, 2014

Introduction

Soil material can be encountered at crime scenes by the transfer of soil residue (dry or wet origin) between the footwear and the substrate. The composition of soil can vary with different locations, geology, and climate [1, 2]. In general, if soil has a wet origin, it is referred to colloquially as mud, which can be defined as "any sediment which contains a significant proportion of fine particles and which has a 'sticky' character when wet" [3]. Such sediments may contain elements such as iron, calcium, magnesium, copper, and zinc, among others. Chemical enhancement techniques typically target one or more of these elements to produce a color reaction, resulting in an improvement of the contrast. Other physical tests (e.g., pH analysis, organic matter content, and soil color) may assist in characterizing the soil and possibly its origin. Soil color can be determined by using the Munsell soil color charts and may also provide an indication of the organic matter that is present [4]. Croft and Pye [5] report that the color of the soil correlates to the organic content in the soil: the darker the soil color, the more organic content there is.

Chemical Enhancement

It can be argued that the force with which the mark is made, the quantity of soil transferred onto a surface, and the level of each constituent that is present in the soil will have an effect on the chemical enhancement of the footwear mark. Several studies [6–9] have investigated the use of different chemicals and procedures for the enhancement of soil-based marks. Potassium thiocyanate is a well-known enhancement technique that is recognized within the forensic community [10]. Potassium thiocyanate provides a reddish-brown color when in contact with ferric iron (Fe^{3+}); however, this can be dependent on the concentration of iron in the soil [11]. The use of ammonium thiocyanate may be considered as a substitute to potassium thiocyanate, and studies have demonstrated that both chemicals provide similar results and sensitivities [12]. Other chemicals that react with iron include potassium ferrocyanide, ammonium pyrrolidinedithiocarbamate (APD), phenanthroline hydrosulphite, pyridyldiphenyl-triazine, and 2,2-dipyridil [6–9, 13]. A modified solution in ethanol of 2,2-dipyridil provided superior enhancement of soil-based marks on fabric when compared to potassium thiocyanate. An additional advantage of this formulation was the substitution of the toxic and flammable methanol to the less flammable ethanol solvent [9].

Other chemicals react with constituents in soil other than iron. For example, bromophenol blue reacts with calcium. A number of studies [14–16] reported bromophenol blue as an excellent chemical enhancement technique for soil-based footwear marks; however, other studies [9, 17] have shown the opposite to be true. The success of this technique varies across different geological regions because it depends on a sufficient concentration of carbonates (e.g., calcium carbonate). Velders [18] successfully used 1,8-diazafluoren-9-one (DFO) for the enhancement of soil-based footwear marks after lifting and activation with a black gelatin lifter, possibly explained by the migration of amino acids in the soil [7]. This technique was recorded as the second-best enhancement process for the enhancement of soil-based marks on porous substrates, but it performed poorly on nonporous surfaces [7].

The use of safranin, a biological stain, was proposed by Velders [18] as an alternative method for the enhancement of soil-based marks. The soil marks were lifted with a black gelatin lifter and photographed. The substrates were then submerged into a working solution of safranin, rinsed with running tap water, and allowed to air dry. A white gelatin lifter was then used to transfer the safranin-dyed marks, which were visualized under green light. This study illustrated that this technique worked well on nonporous items (e.g., glass) but did not work on porous substrates (e.g., newspapers) [18].

Gelatin Lifters

The Dutch company BVDA [19] describes gelatin lifters as having three layers: the first layer, known as the carrier, holds the second layer of gelatin in a pliable and flexible format, and these layers are in turn covered by a protective acetate cover sheet. The cover sheet is a clear polyester film that is removed prior to lifting and may be replaced once the lift is completed. The main advantage of gelatin lifters over adhesive lifters is that the low tack prevents any air bubbles from being trapped between the lifter and the surface. Additionally, black gelatin lifters also have high light absorption properties that enable photography of faint impressions, and safranin-treated marks lifted with white gelatin lifters can fluoresce.

Results from a Home Office Centre for Applied Science and Technology (CAST) trial revealed that the best storage method for a gelatin lift was to keep the lift uncovered in a breathable and nonshedding box [20]. After recovery, photography is recommended as soon as possible, and the acetate cover sheet may be placed on the gelatin lift for storage purposes. Caution is required with acetate covers because repeated removal of the acetate may degrade the lifted mark. Carlsson [21] reported that electrostatic lifting may be better or equivalent to gelatin lifting, except for impressions of wet origin. Contrary to Carlsson, Wiesner et al. [22] reported that gelatin lifting appeared superior to electrostatic lifting on most substrates tested, especially on nonsmooth, porous, and fibrous substrates. For sequential analysis, the authors recommended the use of electrostatic lifting followed by gelatin lifting [22]. Additional trials by CAST [23] on the use of electrostatic lifting and gelatin lifters also showed that "in general, although both processes are very effective, visible dusty marks should give better results if lifted with a gel lift in preference to an electrostatic lift". The use of a gel scanner, such as GLScan by BVDA, may provide high-quality digital images, with a resolution of 1000 pixels per inch (ppi) or greater.

Although the use of gelatin lifts has been investigated for the lifting of marks in blood after chemical treatment [24–25] and for latent fingermarks [26], there is limited research that explores the use of such lifts for the lifting of soil-based marks after chemical treatment.

The aim of this study was to evaluate a number of chemical techniques on nonporous surfaces, followed by gelatin lifting for the enhancement and recovery of soil-based marks.

Materials and Methods

A stamp from Hobby Craft (Figure 1) was used to create a depletion series of marks. The stamp had a dove with swirl patterns within the body and contained the word "peace" under the dove. This stamp was used because it provided fine detail by means of patterns and letters that could be compared to fine detail on footwear soles.

Substrates

Various nonporous and semiporous substrates (white ceramic tiles; glass; grey linoleum; plastic bags; and semiporous, glossy-finish advertisement leaflets) were selected; each was obtained from the same batch. The age of the substrates was unknown. The substrates were washed with warm, soapy water prior to mark deposition to wash off any dirt and contaminants that may have been present, and then they were allowed to dry. Because of their semiporous nature, the leaflets were wiped clean with a damp cloth and were allowed to dry.

Figure 1

Stamp used to created soil-based marks.

Soil

One soil type, which was collected locally (Dundee, Scotland), was used for this experiment. The soil had an average pH of 7.29 and had a brown-black color and lumpy texture [9]. Two sizes of sieves [large (5.6 mm) and small (3.35 mm)] were used to remove large particles and stones from the soil. Distilled water was added to the soil and left for an hour before the excess water was removed in an attempt to create mud in a controlled manner [9].

Depletion Series

Depletion series of 10 soil-based marks were prepared to measure the sensitivity of the chemical enhancement techniques. The stamp was submerged into the mud and the excess was then removed by stamping three times on absorbent, chemical-free blue paper toweling before being stamped onto each of the substrates. This allowed the creation of a depletion series where the first five marks were slightly visible to the naked eye and the last five marks were latent. The pressure of stamping was kept constant as much as possible throughout the experiment. After each series, excess mud was washed from the stamp to ensure the quality of the stamped mark was maintained.

Aging Period and Gelatin Lifts

Various aging periods (1, 7, 14, 28 days) for each substrate and technique combination were included in the study. Marks in mud were prepared as previously described and allowed to age for the appropriate time period. After enhancement and drying, white gelatin lifters (BVDA) were employed for lifting the mark. The gelatin lifts were firmly placed down on top of each of the substrates and left in contact with the enhanced soil-based mark for approximately 30 minutes before the lift was removed and photographed with a polarized filter.

Controls

Controls were tested throughout the duration of the experiment to ensure a positive reaction with the soil-based mark on the substrates versus any other potentially contributing factor such as plasticizers in the stamp or impurities in the water. A dry negative control was performed by stamping on the substrate without any soil on the stamp followed by a wet negative control performed by stamping on a distilled water-soaked tissue before stamping on the substrate.

Photography and Fluorescence

Each depletion series in mud was photographed before and after enhancement (immediately and after 1 hour drying) using a Nikon D5100 digital SLR camera with an 18–55 mm lens or a 60 mm micro Nikon lens. Fluorescence observations were performed using a Mason Vactron Quaser 2000/30 (a 300 W Xenon arc lamp producing 4 W of visible light) [27].

Chemical Formulations

Each of the chemical formulations in this study (Appendix) was made fresh prior to use and was applied either by immersion or by spraying with an Ecosprayer (nozzle diameter: 0.70 mm, flow rate: 0.45 mL/s) at a distance of approximately 15 to 20 cm away. The use of an Ecosprayer provided a fine mist delivery that prevented the diffusion of the mark.

Potassium Thiocyanate [6]

The working solution was lightly sprayed over the stamp marks.

2-2-Dipyridil [9]

The working solution was lightly sprayed over the stamp marks.

Potassium Ferrocyanide [6]

The marks were lightly sprayed with solution A and left for 10 to 20 seconds before being lightly sprayed with solution B.

Ammonium Pyrrolidinedithiocarbamate (APD) [6]

The marks were lightly sprayed with solution A and allowed to stand until dry (approximately 30 seconds) before being lightly sprayed with solution B.

Bromophenol Blue [15]

The marks were lightly sprayed followed by exposure to water vapor from a steam iron to assist the enhancement reaction.

Black-Gelatin → Safranin [18]

A black gelatin lifter (BVDA) was applied to the mark, lifted, and photographed. The substrates were submerged into the working safranin solution for at least 2 minutes before being thoroughly rinsed under running tap water. After drying overnight, a white gelatin lifter was applied to the mark and left for several minutes before fluorescence examination on the gelatin lift using a green excitation filter (band pass filter 473–548 nm at 1% cut-on and cut-off points) and viewed with a long pass 549 nm filter (1% cut-on point).

Safranin [7]

The substrates were submerged into the working safranin solution for at least 2 minutes before being thoroughly rinsed under running tap water. After drying overnight, a white gelatin lifter was applied to the mark and left for several minutes before fluorescence examination on the gelatin lift using a green excitation filter (band pass filter 473–548 nm at 1% cut-on and cut-off points) and viewed with a long pass 549 nm filter (1% cut-on point).

1,8-Diazafluoren-9-One (DFO) [28]

Samples to be treated with DFO were immersed in the solution for a few seconds, air dried, and heated in a dry oven at 100 °C for 20 minutes before fluorescence examination using a green excitation filter (band pass filter 473–548 nm at 1% cut-on and cut-off points) and viewed with a long pass 549 nm filter (1% cut-on point).

An alternative method [7] for DFO was applied by placing a black gelatin lifter (BVDA) on the soil-based mark and removing it after a few seconds before treating the substrate with DFO, as described above. Fluorescent prints may be achieved by this method because of the migration of amino acids from the gelatin layer to the surface.

Black Magnetic Powder

Black magnetic powder (CSI Equipment Ltd.) was applied by means of a magnetic fingerprint brush.

Grading

All of the stamped, enhanced, and gelatin-lifted marks were graded using a system adopted from previous work related to footwear mark and fingermark enhancement [7, 29], as presented in Table 1. Each soil-based mark was graded before enhancement, after enhancement, and also after white gelatin lifting. The difference was calculated between the “before enhancement” and “after enhancement” grades to calculate the number of positive enhancements (the grade after enhancement was greater than that before enhancement), no enhancements (there was no difference in the grading scores between before and after enhancement), and the number of marks that deteriorated (the grade number after enhancement was less than that of before enhancement). The same researcher performed the grading and attributed the grade to each mark. This is a subjective method and other scoring methods may provide different results.

Score	Level of Detail
-1	Deterioration of mark
0	No evidence of mark
1	Weak enhancement: no evidence of fine detail present
2	Somewhat enhanced: about 1/3 of fine detail present
3	Much enhanced: about 2/3 of fine detail present
4	Very much enhanced: all fine detail present

Table 1

Grading system for enhanced and lifted marks in this study.

Roadside Dust Samples

The best performing techniques in this study were used for the enhancement of marks made with roadside dust obtained locally (Dundee, Scotland, U.K.) from the side of the pavement in the streets. This was set up as a proof of concept to assess the enhancement techniques on a local roadside dust sample that may be more realistic in towns where the presence of soil is limited. The roadside dust was prepared as described for soil above. An aging period of 7 days for the soil-based marks and a depletion series was used for this part of the study, followed by grading as described above.

Results and Discussion

Preliminary Testing

A preliminary trial period was set up to establish the most effective chemical enhancement technique on soil-based marks. The preliminary work was performed by creating a number of soil-based marks on different nonporous surfaces and leaving the marks to age for 7 days. The results from this preliminary work indicated that potassium thiocyanate, 2,2-dipyridil, potassium ferrocyanide, APD, safranin, and magnetic powder should be investigated further. The remaining techniques (bromophenol blue and DFO) did not provide any suitable enhancement, visual or fluorescent, and were not included further in the study.

Contrary to some studies [10, 15] but consistent with others [9], bromophenol blue enhancement just appeared as a yellow background coloration for all of the nonporous substrates used in this study. Because bromophenol blue reacts with calcium carbonate ($CaCO_3$) in the soil, the results suggest that $CaCO_3$ was not present in the soil used in this study or that the bromophenol blue technique was not sensitive enough to detect any $CaCO_3$ that might have been present. The subsequent application of a white gelatin lift turned the white gelatin lift blue. Furthermore, both methods proposed for the application of DFO but did not provide any positive enhancement results. This is in line with other studies [7], which reported that DFO provided suitable enhancement on porous substrates but not on nonporous substrates.

Chemical Enhancement Techniques Followed by Gelatin Lifting of Soil-Based Marks

<u>Overview</u>

In general, all seven techniques (potassium thiocyanate, 2-2-dipyridil, potassium ferrocyanide, APD, black-gelatin safranin, safranin, magnetic powder) that were used in this study provided enhancement of soil-based marks. The application of chemicals by spraying was applied carefully using an Ecosprayer to diminish the effects of diffusion on nonporous substrates. Figure 2 illustrates that, overall, safranin had the highest number of positive enhancements of soil-based marks followed by potassium thiocyanate, 2,2-dipyridil, and APD. Figure 3 demonstrates that black-gelatin safranin, safranin, and 2,2-dipyridil (all in sequence with white gelatin lifting) provided the most improvement. Figure 2 and Figure 3 show an anomaly in terms of black gelatin lifting followed by safranin and white gelatin lifting. This is because prior to white gelatin lifting, the sequence of black gelatin lifting followed by safranin showed a very small number of positive enhancements compared to the other enhancement techniques, but also little deterioration (Figure 2). In contrast, safranin without the use of black gelatin lifting exhibited a higher number of positive enhancements and further improvement with white gelatin lifting; however, there was more deterioration in comparison to when black gelatin lifting was used before (Figure 3). In Figures 2 and 3, the number of overall marks is less than 200 for the safranin techniques because of the destruction of the leaflets in the water.

Potassium Thiocyanate

The rapid color reaction provided a good color contrast between the reddish-brown mark and the substrate. Potassium thiocyanate provided the best results on linoleum; this produced the highest grade increase from a "grade one" to a "grade three" mark, followed by that of plastic bags, tiles, and glass, with minimal enhancement occurring on glossy leaflets. This minimal enhancement was, however, greatly improved because of superior contrast after white gelatin lifting (Figure 4). The enhancement by this technique appeared to improve with the increasing age of the mark, possibly because of the mark becoming drier, allowing for the soil to better adhere to the surface. Furthermore, Figure 3 demonstrates that potassium thiocyanate resulted in the highest number of marks recorded as a deterioration.

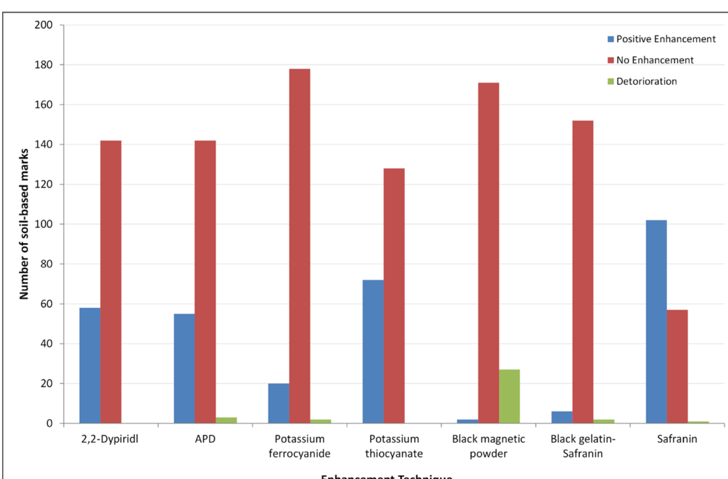


Figure 2

An overall comparison of positive enhancements, no enhancement, and deterioration of marks across all enhancement techniques, substrates, and aging periods.

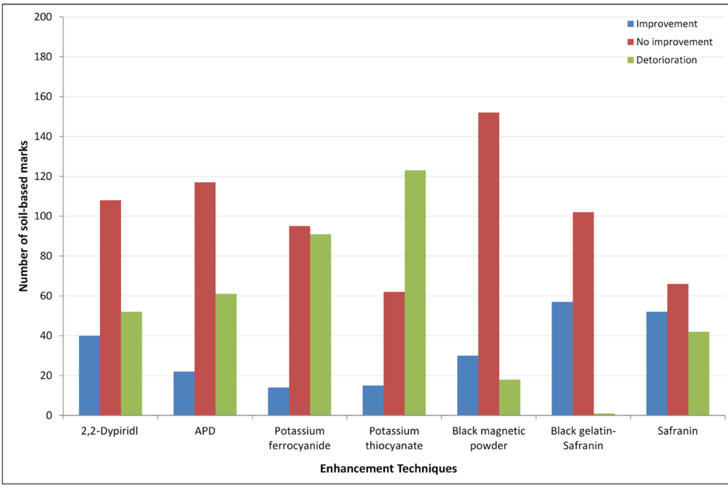
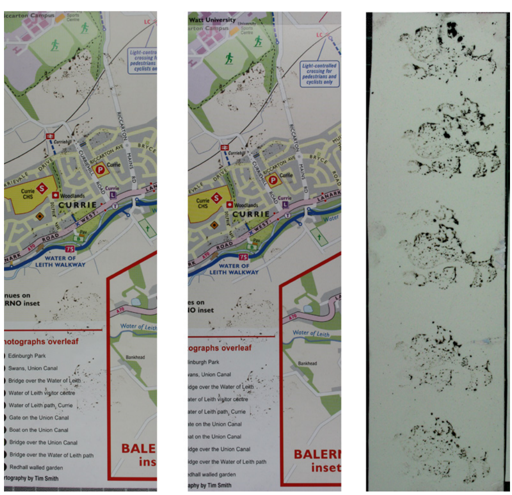


Figure 3

An overall view of the improvement or deterioration after enhancement followed by white gelatin lifting.



(a) *(b)* *(c)*

Figure 4

Soil-based marks 6 through 10 in the depletion series on glossy leaflets and aged for 7 days. (a) Before enhancement; (b) after enhancement with potassium thiocyanate; (c) followed by white gelatin lifting.

Potassium Ferrocyanide

In general, potassium ferrocyanide produced the highest number of “no enhancement” marks across all substates; however, better results were obtained on tiles and plastic bags, as evidenced in Figure 5. As reported in other studies [9], one disadvantage of this technique was the use of distilled water in solution, which resulted in diffusion of some of the marks. Similar to potassium thiocyanate, aging of the marks provided superior enhancement. The blue coloration appeared to fade over time, which is contrary to observations from another study [6]. Furthermore, the application of a white gelatin lift resulted in a high number of marks recorded as a deterioration (Figure 3).

APD

Figure 6 demonstrates APD enhancement, with subsequent white gelatin lifting improving the contrast. Tile appeared to be the most responsive substrate to this technique, followed by linoleum, plastic bags, and glass, with minimal enhancement on glossy leaflets. The results appear to contradict other studies where it was reported that APD might provide superior results than potassium thiocyanate [8]. Potassium thiocyanate, potassium ferrocyanide, and APD provided the highest number of deteriorations following white gelatin lifting. There was no obvious trend in the results observed and improvements were recorded for all techniques independent of substrate or aging. This reinforces the importance of using photography at all stages because an improvement following white gelatin lifting is not guaranteed.

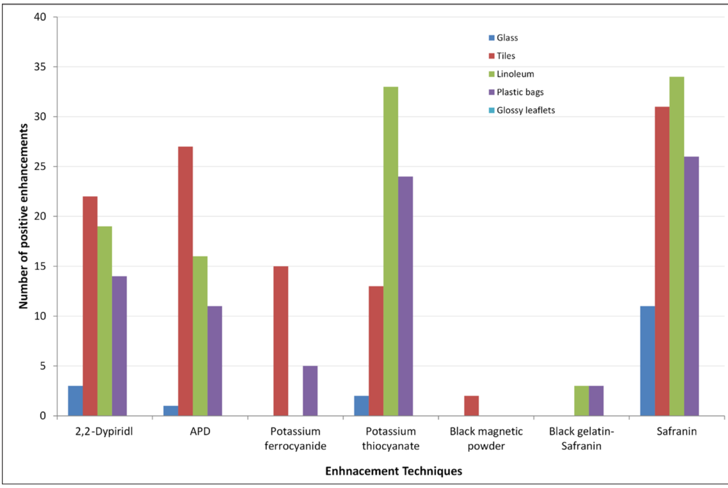
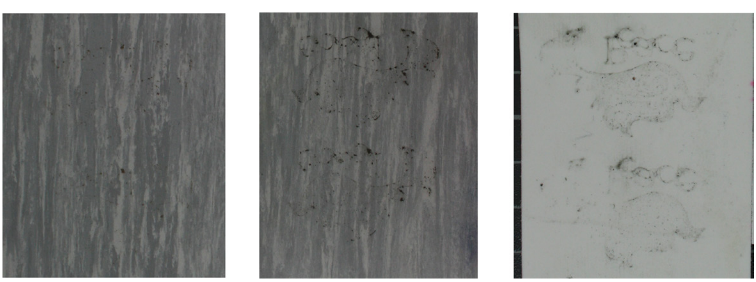


Figure 5

Comparison of chemical enhancement techniques across all substrates and aging periods.



(a) *(b)* *(c)*

Figure 6

Soil-based marks 7 and 8 in the depletion series on linoleum and aged for 28 days. (a) Before enhancement; (b) after enhancement with APD; (c) followed by white gelatin lifting.

2,2-Dipyridil

Overall, 2,2-dipyridil was shown to be the third most effective technique for the application of chemical enhancement on soil-based marks in terms of the number of positive enhancements, with a deep red coloration appearing. In general, 2,2-dipyridil was shown to enhance a greater number of marks on tiles followed by linoleum, plastic bags, and glass, with minimal enhancement occurring on glossy leaflets (Figure 5). The addition of hydrochloric acid in the formulation allows the ferric iron in the soil to become reduced into its ferrous state, resulting in a red color change. The color reached a maximum intensity approximately 30 minutes after chemical treatment, as reported elsewhere [6, 9]. In general, after gelatin lifting, there was further improvement in terms of enhancement and contrast; however, there were also a number of marks with deterioration (Figure 7).

Black-Gelatin → Safranin

In general, the application of a black gelatin lifter before safranin treatment produced good enhancement on plastic bags and linoleum; however, the use of a gelatin lift prior to chemical treatment may hinder the success of subsequent chemical enhancement (Figure 8). Theeuwen et al. [7] reported that black gelatin lifting and photography provided the best enhancement on nonporous substrates; however, in this study, the use of black gelatin lifting was not always successful. Subsequent safranin enhancement on the substrate after black gelatin lifting yielded inferior results than when black gelatin lifting or safranin were used as separate enhancement techniques.

(a) (b) (c)

Figure 7

Soil-based marks 1 through 5 in the depletion series on linoleum and aged for 14 days. (a) Before enhancement; (b) after enhancement with 2,2-dipyridil; (c) followed by white gelatin lifting.

(a) (b) (c)

Figure 8

Soil-based mark 6 in the depletion series on plastic bag and aged for 14 days. (a) Before enhancement; (b) after lifting with black gelatin lifter, observed with oblique lighting; (c) after enhancement of (a) with safranin.

Safranin

Safranin enhancement yielded the highest number of positive enhancements compared to any other chemical technique (Figure 2). Similar to other techniques, superior results were observed on linoleum (Figure 9), followed by tiles, plastic bags (Figure 10), and glass, with minimal or no enhancement on glossy leaflets (Figure 5). In contradiction to other studies [7], the treatment of glass with safranin was not as successful as expected. Figures 9 and 10 demonstrate that white gelatin lifting provided further contrast to the safranin enhancement; however, bleeding of the chemicals into the gelatin will occur over time, and photography should be completed as soon as possible. Lifted marks treated with safranin will fluoresce under green light when viewed with an orange filter, which may improve the visualization of certain details (Figure 11).

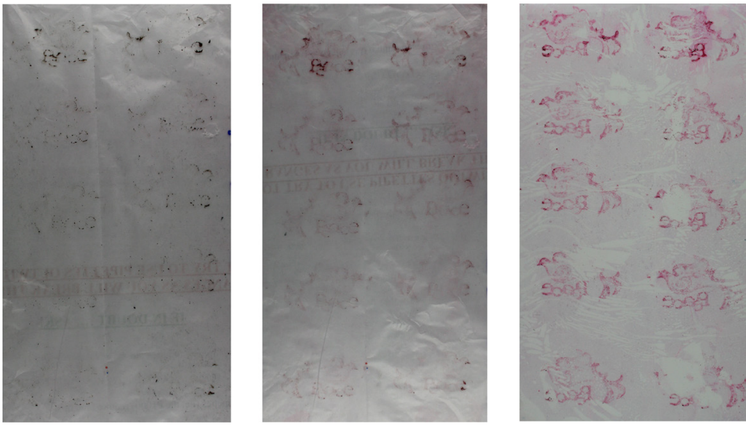
Black Magnetic Powder

Enhancements of soil-based marks with black magnetic powder was only observed on tiles (Figure 5). The magnetic powder appeared to build up the marks that were already present on the substrates which in turn made the mark appear darker in color, but no positive enhancement grades were recorded. Lifting with a white gelatin lifter provided no further enhancement.

(a) *(b)* *(c)*

Figure 9

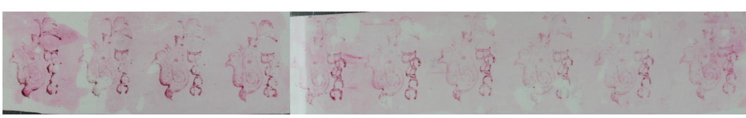
Soil-based mark 10 in the depletion series on linoleum and aged for 1 day. (a) Before enhancement; (b) after enhancement with safranin; (c) followed by white gelatin lifting.



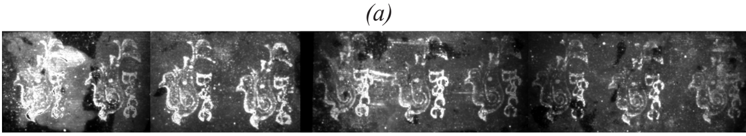
(a) (b) (c)

Figure 10

Soil-based marks 1 through 10 in the depletion series on plastic bags and aged for 14 days. (a) Before enhancement; (b) after enhancement with safranin; (c) followed by white gelatin lifting.



(a)



(b)

Figure 11

Soil-based marks 1 through 10 in the depletion series on tiles with an aging period of 28 days and after enhancement with safranin followed by white gelatin lifting observed under (a) white light; (b) green light (orange 549 nm filter) [greyscale].

Substrates

Figure 5 demonstrates that linoleum and tile were the most responsive substrates to the enhancement techniques used in this study. The enhancement of soil-based marks on glossy leaflets was minimal, if at all, and on a number of occasions resulted in the deterioration of the mark. The highest number of positive enhancements was recorded on tiles, where the main improvement before and after enhancement was by 1 grade. A positive enhancement by 2 grades was limited, and positive enhancements by a grade 3 or 4 only occurred once (Figure 12).

Gelatin Lifting

Gelatin lifting is a useful way of transferring marks although subsequent chemical enhancement may be limited. Additionally, users must be aware that the lifted mark is a mirror image of the original. The results from this study suggest that the quality of the marks on the gelatin lift depend more on the substrate than on the chemical enhancement technique. Figure 13 reveals the percentage of soil-based marks that were either unchanged or improved after white gelatin lifting. Glass and glossy leaflets exhibited the lowest percentage of marks that were adversely affected by gelatin lifting, which can be attributed to the minimal chemical enhancement achieved by the techniques used in this study. Because there was a considerable percentage of marks that deteriorated, it is recommended that photography be carried out prior to white gelatin lifting and after every enhancement attempt.

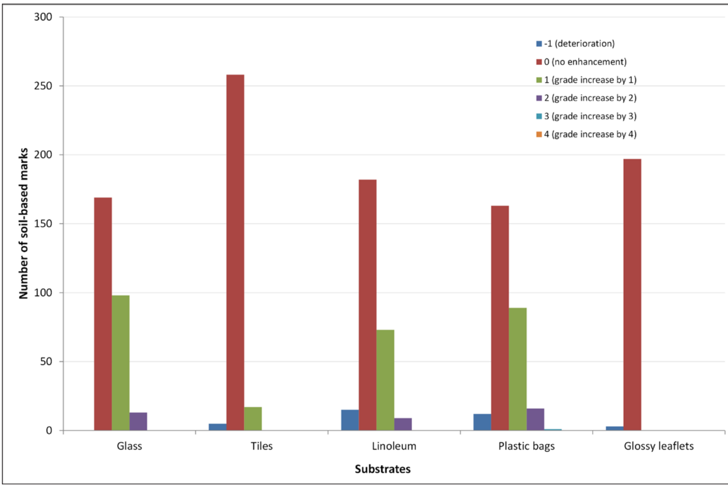


Figure 12

Comparison of grading across all substrates, aging periods, and enhancement techniques.

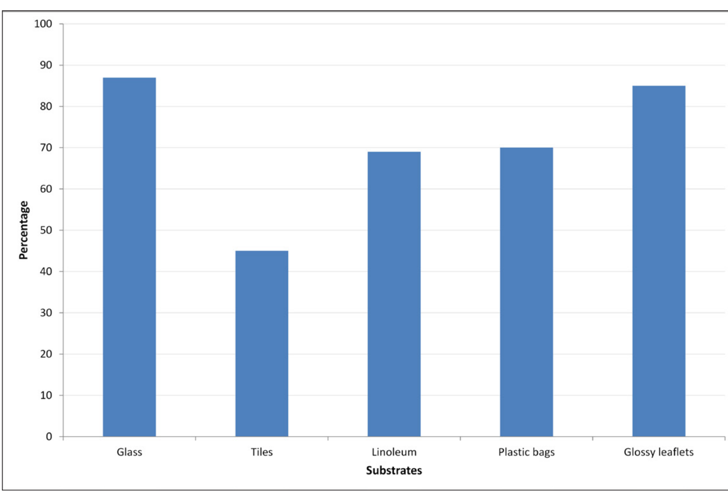


Figure 13

Percentage of soil-based enhanced marks that were either unchanged or improved after white gelatin lifting across all aging periods and chemical enhancement techniques.

Aging Period and Depletion Series

Overall, soil-based marks aged for a period of 28 days prior to chemical enhancement and white gelatin lifting produced a higher number of positive enhancement across all substrates when compared to the other aging periods of 1, 7, and 14 days (Figure 14). Short aging periods may result in the soil-based mark not being completely dry and resulting in diffusion during chemical treatment, especially if distilled water is part of the formulation. Nonetheless, longer aging periods may result in the mark being thoroughly dry, causing loose soil material to easily be lost during the techniques involving the spraying of chemicals.

Figure 15 demonstrates that the grading for each mark was consistent across the depletion series. A positive enhancement of 1 was the most common assigned grading for each mark. The other grading of 2 was also similar across the series; however, the deterioration grading of -1 was slightly more pronounced for marks 1 through 4 than marks 5 through 10.

Roadside Dust Samples

A small trial was also carried out using roadside dust collected locally, with an aging period of 7 days. Safranin and potassium thiocyanate were selected as the best performing techniques, and results demonstrated that these two techniques, followed by white gelatin lifting, worked as well as the marks prepared from soil obtained locally. Further research using roadside dust samples is required with additional aging periods and substrates in future pseudo-operational trials.

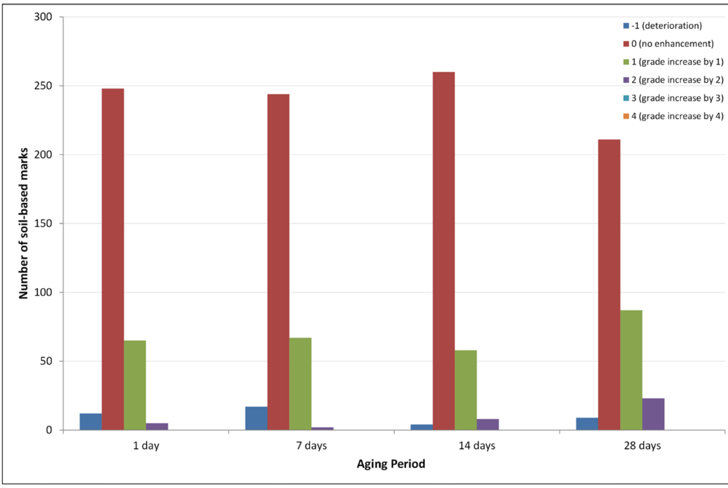


Figure 14

Comparison of grading across the aging periods for all substrates and enhancement techniques.

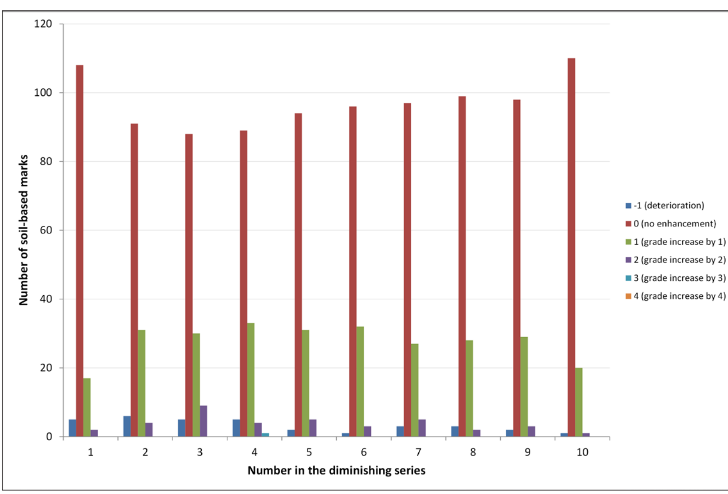


Figure 15

Comparison of grading for each of the 10 marks in the depletion series across all substrates, aging periods, and enhancement techniques.

Conclusion

The results of this study show that, overall, the most effective chemical enhancement technique for soil-based marks on nonporous substrates was safranin. This technique produced the highest percentage of positive enhancements across all substrates, and the use of white gelatin lifting and associated fluorescence may improve visualization of characteristics. Tiles and linoleum were the most responsive substrates to the enhancement techniques used in this study, whereas glossy leaflets provided minimal or no enhancement. Nonetheless, occasionally, the use of a white gelatin lifter on glossy leaflets provided improved contrast on the lift. An aging period of 28 days provided superior enhancement with less diffusion than the other aging periods, suggesting that marks should be allowed to dry before chemical treatment.

The use of gelatin lifting can be successful in the recovery and transfer of soil-based marks; however, subsequent chemical enhancement may be limited. Photography should be taken at every stage of the enhancement process. Future work will assess and compare soil samples from different geological areas as well as varying roadside dust samples and aging periods. The use of a GLScan to scan the gelatin lifts may also provide higher resolution, magnification, and illumination.

Acknowledgment

The authors would like to thank WA Products (Essex, U.K.) for donating the BVDA gelatin lifts that were used in this study.

For further information, please contact:

Kevin J. Farrugia
School of Science, Engineering and Technology
Abertay University
Dundee
DD1 1HG
U.K.
Kevin.farrugia@abertay.ac.uk

References

1. Ruffell, A.; McKinley, J. *Geoforensics*; Wiley: Chichester, England, 2008.
2. Morgan, R. M.; Freudiger-Bonzon, J.; Nichols, K. H.; Jellis, T.; Dunkerley, S.; Zelazowski, P.; Bull, P. A. The Forensic Analysis of Sediments Recovered from Footwear. In *Criminal and Environmental Soil Forensics*; Ritz, K., Dawson, L., Miller, D., Eds.; Springer: Netherlands, 2009.

3. Pye, K. *Geological and Soil Evidence: Forensic Applications*; CRC Press: Boca Raton, FL, 2007.
4. Tibbett, M.; Carter, D. O. *Soil Analysis in Forensic Taphonomy: Chemical and Biological Effect of Buried Human Remains*; CRC Press: Boca Raton, FL, 2008.
5. Croft, D. J.; Pye, K. Color Theory and Evaluation of an Instrumental Method of Measurement Using Geological Samples for Forensic Applications. In *Forensic Geoscience: Principles, Techniques and Applications–Geological Society Special Publication 232*; Pye, K., Croft, D. J., Eds.; Geological Society: London, 2004; pp 49–62.
6. Someha, S. Chemical Techniques for the Enhancement of Footwear and Tire Impressions in Japan. Presented at the International Symposium on the Forensic Aspects of Footwear and Tire Impressions Evidence, FBI Academy, Quantico, VA, 1994.
7. Theeuwen, A. B. E.; van Barneveld, S.; Drok, J. W.; Keereweer, I.; Lesger, B.; Limborgh, J. C. M.; Naber, W. M.; Schrok, R.; Velders, T. Enhancement of Muddy Footwear Impressions. *For. Sci. Int.* **2001**, *119* (1), 57–67.
8. Croft, S.; Nic Daéid, N.; Savage, K.; Vallance, R.; Ramage, R. The Enhancement and Recovery of Footwear Marks Contaminated in Soil: A Feasibility Study. *J. For. Ident.* **2010**, *60* (6), 718–737.
9. Farrugia, K. J.; Bandey, H.; Dawson, L.; Nic Daéid, N. Chemical Enhancement of Soil Based Footwear Impressions on Fabric. *For. Sci. Int.* **2012**, *219* (1–3), 12–28.
10. McNeil, K.; Knapp, W. Bromophenol Blue as a Chemical Enhancement Technique for Latent Shoeprints. *J. For. Ident.* **2012**, *62* (2), 143–153.
11. Bodziak, W. J. *Footwear Impression Evidence: Detection, Recovery, and Examination*, 2nd ed.; CRC Press: Boca Raton, FL, 2000.
12. Froude, J. H. Using Ammonium Thiocyanate and Potassium Thiocyanate. *J. For. Ident.* **1998**, *48* (6), 718–724.
13. Ross, E.; Gorn, M. A Study of Pyridyldiphenyl-Triazine as a Chemical Enhancement Technique for Soil and Dust Impressions. *J. For. Ident.* **2010**, *60* (5), 532–546.
14. Glattstein, B.; Shor, Y.; Levin, N.; Zeichner, A. Improved Chemical Reagents for the Enhancement of Footwear Marks. Presented at the International Symposium on the Forensic Aspects of Footwear and Tire Impression Evidence, FBI Academy, Quantico, VA, 1994.
15. Glattstein, B.; Shor, Y.; Levin, N.; Zeichner, A. pH Indicators as Chemical Reagents for the Enhancement of Footwear Marks. *J. For. Sci.* **1996**, *41* (1), 23–26.

16. Shor, Y.; Vinokurov, A.; Glattstein, B. The Use of an Adhesive Lifter and pH Indicator for the Removal and Enhancement of Shoeprints in Dust. *J. For. Sci.* **1998**, *43* (1), 182–184.
17. Law, W. Investigating the Possible Processes for the Enhancement of Shoe Marks. M. Sc. Thesis, University of Strathclyde, Glasgow, U.K., 2006.
18. Velders, M. J. M. The Visualization and Securing of Shoeprints Made with Wet or Muddy Outsoles. Presented at the 82nd Educational Conference of the International Association of Identification, Danvers, MA, 1997.
19. BVDA. Gellifters: Lift Your Evidence to the Highest Level. 2012. http://www.bvda.com/EN/download/Gellifter_brochure_EN_2012.pdf (Accessed June 4, 2014).
20. Bandey, H. L. *Special Edition: Footwear Mark Recovery.* H.O.S.D.B. May 2008, Publication no. 24/08.
21. Carlsson, K. Comparison of Lifting Shoeprints with Gelatin Lifter Versus with Electrostatic Methods. Proceedings of the Second European Meeting for SP/TM: April 21–24, 1997; Hague. Information Bulleting for Shoeprint/Toolmark Examiners 1998: 4 (1), 109–120.
22. Wiesner, S.; Tsach, T.; Belser, C.; Shor, Y. A Comparative Research of Two Lifting Methods: Electrostatic Lifter and Gelatin Lifter. *J. For. Sci.* **2011**, *56* (1), S58–S62.
23. Bandey, H. L.; Bleay, S. *Fingerprint and Footwear Forensics Newsletter.* H.O.S.D.B. 2010, Report Number 6/10.
24. Velders, M. J. M. Fluorescing Traces in Blood on White Gelatin Lifters with Hungarian Red. Presented at the 81st Educational Conference of the International Association of Identification, Greensboro, NC, 1996.
25. Theeuwen, A. B. E.; van Barneveld, S.; Drok, J. W.; Keereweer, I.; Limborgh, J. C. M.; Naber, W. M.; Velders, T. Enhancement of Footwear Impressions in Blood. *For. Sci. Int.* **1998**, *95* (2), 133–151.
26. Bleay, S. M.; Bandey, H. L.; Black, M.; Sears, V. G. The Gelatin Lifting Process: An Evaluation of its Effectiveness in the Recovery of Latent Fingerprints. *J. For. Ident.* **2011**, *61* (6), 581–606.
27. Foster & Freeman Ltd. Quaser 2000/30. www.mggsacv.com/imagenes/Quaser(US).pdf (Accessed July 14, 2014).
28. Ramotowski, R. S. Amino Acid Reagents. In *Lee and Gaensslen's Advances in Fingerprint Technology*, 3rd ed.; Ramotowski, R. S., Ed.; CRC Press: Boca Raton, FL, 2012; pp 17–54.
29. Sears, V. G.; Bleay, S. M.; Bandey, H. L.; Bowman, V. J. A Methodology for Fingermark Research. *Sci. & Just.* **2012**, *52* (3), 145–160.

Appendix

Potassium Thiocyanate [6]

Potassium thiocyanate (15 g, Acros) was added to distilled water (15 mL) and acetone (120 mL, Sigma) and dissolved by stirring with a magnetic stirrer. Dilute sulphuric acid [concentrated sulphuric acid (1 mL, Sigma) added to distilled water (9 mL)] was then added slowly to the potassium thiocyanate solution to produce a milky mixture that separated into two layers. The top layer was then poured into a dark glass bottle, and the bottom layer was discarded.

2-2-Dipyridil [9]

2-2-Bipyridine (4 g, Acros) and (+) ascorbic acid (1 g, BDH) were dissolved in ethanol (100 mL, Fisher), followed by the slow addition of concentrated hydrochloric acid (3 mL, Fisher).

Potassium Ferrocyanide [6]

Solution A: Hydrochloric acid (10 mL, Fisher) and ethanol (90 mL, Fisher).

Solution B: Potassium ferrocyanide (5 g, Acros) dissolved in distilled water (100 mL).

Ammonium Pyrrolidinedithiocarbamate (APD) [6]

Solution A: Hydrochloric acid (1 mL, Fisher) and ethanol (9 mL, Fisher).

Solution B: Ammonium pyrrolidinedithiocarbamate (1 g, Acros) and sodium citrate.

(3 g, Acros) were dissolved in ethanol (50 mL, Fisher) and distilled water (50 mL).

Bromophenol Blue [15]

Bromophenol blue (1g, Acros) was dissolved in methanol (95 mL, Fisher) and distilled water (5 mL).

Safranin [18]

Safranin (1 g, Acros) was dissolved in distilled water (1 L) and stirred with a magnetic stirrer until all the solid was dissolved to give a dark red color.

1,8-Diazafluoren-9-one (DFO) [28]

DFO (0.5 g, Sirchie) was completely dissolved in methanol (100 mL, Fisher), ethyl acetate (100 mL, Fisher), and acetic acid (20 mL, Fisher) using a magnetic stirrer. Petroleum ether (780 mL, Fisher) was then added with further stirring.