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Fingerprints' Third Dimension: The Depth and Shape of Fingerprints Penetration into Paper—Cross Section Examination by Fluorescence Microscopy*

ABSTRACT: In an attempt to maximize the yield of latent fingerprints from paper items, we conducted a study of a fundamental process between fingerprint deposits and paper. Fingerprint ridges have been observed in the cross section of paper by fluorescence microscopy. It was possible to see, for the first time, how residue from fingerprint ridges is embedded in paper. Undeveloped, latent fingerprints, as well as latent prints developed by the two fluorogenic reagents, DFO and 1,2-indanedione, have been examined. The shape and depth of penetration of fingerprints vary with different types of paper. An inverse relationship between the smoothness of the paper and the penetration depth was observed: higher smoothness values result in lower depths of penetration. High quality prints appear to correlate with an optimal penetration depth—between 40 and 60 microns.

KEYWORDS: forensic science, latent fingerprints, DFO, 1,2-indanedione, BY-40, paper, fluorescence microscope, smoothness, porosity

Paper articles are particularly important for fingerprint search in major crime investigations including terrorist activities, forgeries, and currency counterfeiting (1). Latent prints on paper are visualized by chemical methods, recorded, and further manipulated (2–4). Nevertheless, a considerable number of latent prints escape visualization, even by the DFO-ninhydrin sequence (5,6), which can seriously decrease the chances of solving serious crimes.

Fingerprint practitioners have known for a long time that porosity is not the only difference between paper and other smooth surfaces such as glass, metal, or plastic. The frequent appearance of background coloration and the remarkable differences in fingerprint quality on various papers indicate that there are factors other than porosity that are involved in the visualization process.

In an attempt to maximize the yield of latent fingerprints from paper items, we conducted a study of a fundamental process between fingerprint deposits and paper: the penetration of the fingerprint material into the paper. So far, the "third dimension" of latent prints in paper has been studied only indirectly (5), or postulated on theoretical grounds (7). To observe the penetration, we have devised a method for viewing fingerprint ridges along the paper cross section.

Paper samples representative of the types of paper encountered most frequently during investigations of serious crimes were used as substrates for fingerprint deposition. The depth and shape of the penetrating fingerprint material in 15 types of paper have been studied by fluorescence microscopy. Paper samples bearing "controlled" latent prints, made with fingers stained with a fluorescent dye, BY-40, and fingerprints developed by the fluorogenic reagents, DFO and 1,2-indanedione, have been observed along the Z-axis (the paper cross section), (Fig. 1).

The present work focused on an attempt to find a linkage, if there is any, between the quality of the developed prints and the depth of penetration. A spin-off from this study was an attempt to find a correlation between the depth of penetration and paper properties such as porosity, smoothness, and density.

Methodology

Paper Samples and Fingerprint Treatment

Fifteen different paper samples were used as substrate for fingerprints deposition, five of them were selected from the Sample Book of the Institute of Paper (8) and additional papers were selected from our local production (Table 1). Thirteen of the samples were uncoated paper and two were coated.

Because fingerprint secretion has almost no natural fluorescence, it was necessary to stain the fingers by a fluorescent dye, so that the latent prints could be observed by the fluorescence microscope. Clean fingers of two donors were smeared by 1% ethanolic solution of the fluorescent dye BY-40, dried in air and deposited on the paper samples. These prints provide an approximate measure of the natural penetration of fingerprint residue into paper, before chemical development. The same donors also deposited clean, unstained prints onto paper strips, which were subsequently processed by dipping in fluorogenic reagents, DFO and 1,2-indanedione. Both types of fluorescent prints have been observed by the cross section fluorescence imaging method.

The natural, unstained prints have been developed within one to eight days after they had been deposited. The paper samples were processed by dipping in one of the following reagent solutions:

DFO—0.025% solution in CFC113 also containing methanol and acetic acid. For processing, the articles were placed in a dry oven at 100°C for 30 min (3).

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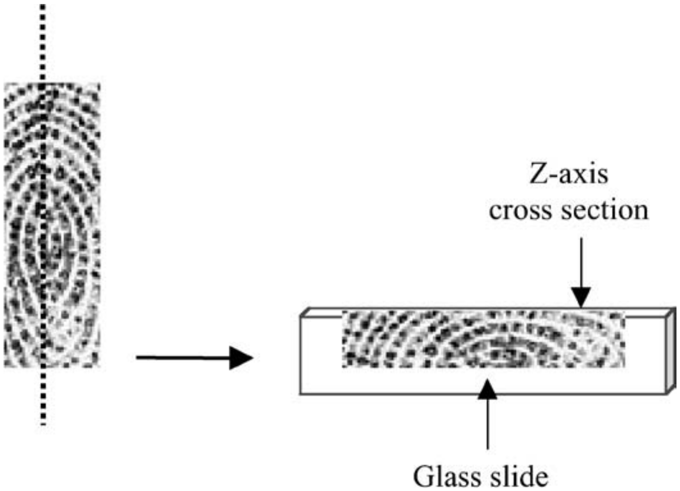

FIG. 1—*Paper sample with fingerprint, cut perpendicularly to the ridges and mounted on a glass slide.*

TABLE 1—*Types of paper examined in this study.**

Paper No.	Paper Description	Source/Reference
1	Brown packaging paper	Sample No. 33, (8)
2	High white smooth multi function office paper	Sample No. 6, (8)
3	White envelope type I, *inner side*	Dafron, Israel
4	White notebook paper	Daftar, Israel
5	White copier paper, brightness 112	American Israeli Paper Mills Ltd., Hadera, Israel
6	White copier paper	Sample No. 4, (8)
7	White envelope type I, *outer side*	Dafron, Israel
8	White copier paper, brightness 105	American Israeli Paper Mills Ltd., Hadera, Israel
9	White envelope type II, *outer side*	Dafron, Israel
10	White envelope type III, *outer side*	Dafron, Israel
11	White 100% cotton writing paper	Sample No. 7, (8)
12	White postcard board	Sample No. 27, (8)
13	Filter paper, grade1	Whatman
14	White light coated matt	Sample No. 24, (8)
15	Scangloss paper, 1-39-07984	Holmen Paper, Sweden

* All papers were uncoated except Nos. 14 and 15.

1,2-indanedione—0.025% 1,2-indanedione in HFE7100 also containing ethyl acetate and acetic acid. For processing, the articles were placed in a dry oven at 100°C for 10 min (9).

Sample Preparation

The paper strips bearing the fluorescent prints were carefully cut with a blade, perpendicularly to the ridges (Fig. 1), and mounted on a glass slide. A purpose-built sample holder designed to allow observation of the paper sample under the microscope objective, in the planar and perpendicular directions, held the glass slide. In this way, the details of a specific fingerprint could be viewed either as plane image (view from above) or along the cross section of the paper (view from the side).

Imaging System

The imaging system is based on the Olympus PROVIS AX70 microscope in the fluorescence mode of operation. The microscope is fitted with a mercury lamp light source and changing filter cubes system, allowing selection of excitation wavelengths (420–440, 470–490, 510–550 nm). A CCD camera is attached to the microscope and connected to an image recording and processing system. The fluorescent images are stored in a computer via ATI board as a pixel-to-pixel map of light intensity.

Depth of Fingerprint Penetration

The depth of fingerprint penetration into each paper was first measured as the relative fraction of the absolute thickness of the paper, as seen on the microscope image and then, calculated from the true measured thickness of each paper strip. For each sample, three to six measurements were carried out on neighboring ridges, as close to the center of the print as possible. The average value was then calculated.

Paper Features

Each paper sample was characterized in terms of grammage, thickness, density, smoothness and porosity. Grammage value (gr/m^2) was given by the paper manufacturer or calculated by

TABLE 2—*Paper features of the samples examined in this study.*

Paper No.	Thickness (microns)	Grammage (gr/m^2)	Density (gr/cm^3)	Smoothness (sec)	Porosity (sec/100 cm^3)
1	114.25	70	0.61	38	35
2	132.66	100	0.75	31	16
3	120	90	0.75	27	18
4	78.33	60	0.77	38	14
5	109	80	0.73	31	19
6	99.33	80	0.81	34	14
7	109	80	0.73	20	16
8	109	90	0.73	33	12
9	120	90	0.75	24	17
10	107.66	70	0.65	23	21
11	161.66	110	0.68	7	9
12	235.75	160	0.68	5	15
13	165.66	82	0.49	1	3
14	93	100	1.08	45.8	Sealed to air
15	74.5	80	1.07	Very smooth (out of scale)	Sealed to air

TABLE 3—*Average depth of fingerprint penetration for each type of paper and fingerprint treatment applied.*

	Average Depth of Penetration (microns)		
Paper Type	DFO	1,2-indanedione	BY-40
Uncoated paper			
No. 1	15	No prints	22
No. 2	18	22	36
No. 3	26	30	18
No. 4	38	36	14
No. 5	40	28	59
No. 6	44	33	36
No. 7	49	52	51
No. 8	55	38	42
No. 9	56	54	58
No. 10	60	50	49
No. 11	65	67	52
No. 12	85	84	82
No. 13	138	96	99
Coated paper			
No. 14	31	24	29
No. 15	4	No prints	5

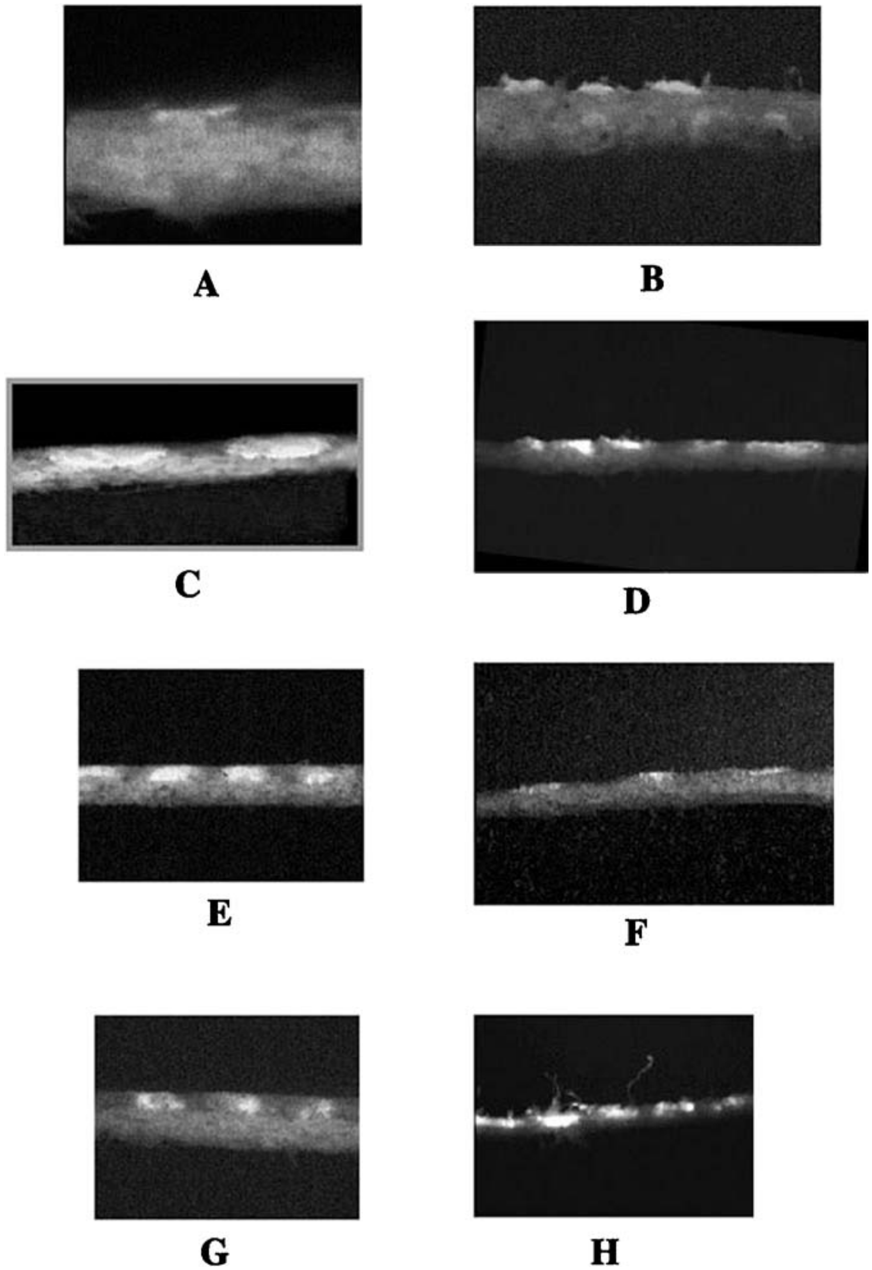

FIG. 2—*View from the side of fingerprint ridge penetration into several types of paper: (A) paper No. 15, DFO, λex = 470 nm; (B) paper No. 1, DFO, λex = 550 nm; (C) paper No. 8, DFO, λex = 420 nm; (D) paper No. 4, 1,2-indanedione, λex = 550 nm; (E) paper No. 7—outer side, DFO, λex = 420 nm; (F) paper No. 3—inner side, DFO, λex = 420 nm; (G) paper No. 12, BY-40, λex = 420 nm; (H) paper No. 13, DFO, λex = 420 nm.*

dividing the weight by the surface area. Thickness (microns) was measured with a Messner-Buchel micrometer. Paper density (gr/cm^3) was calculated by dividing the paper grammage by the thickness. Smoothness (sec) and porosity (sec/100 cm^3) were both examined by the Israel Institute of Standards according to Technical Association of the Pulp and Paper Industry (TAPPI) methods. Smoothness was determined according to Bekk (T-479) and the porosity according to Gurley (T-460) (10,11). The features of each type of paper examined in this study are shown in Table 2.

Results and Discussion

By staining the palmar sweat with a fluorescent dye, and the use of a fluorescent microscope, it was possible to observe how fingerprint ridges are actually embedded in paper. The application of fluorogenic fingerprint reagents such as DFO or 1,2-indanedione to the latent prints enabled us to watch also the developed prints in the depth of the paper, compare the penetration in various papers and try to correlate between the depth of penetration and various features of the paper.

The experimental results are presented in Table 3 and Figs. 2–6. Figure 2 presents the cross sections of eight types of paper bearing fluorescent prints, "natural" (BY-40) or developed by DFO and 1,2-indanedione, as seen under the fluorescence microscope. The fluorescence intensity of the ridges corresponds to the amount of fingerprint deposits at each point. Table 3 shows the average depth of penetration of undeveloped prints (BY-40), and of prints developed with DFO and 1,2-indanedione, for each type of paper. Figure 3 plots the depths of penetration of fingerprints developed with DFO and 1,2-indanedione in all the uncoated

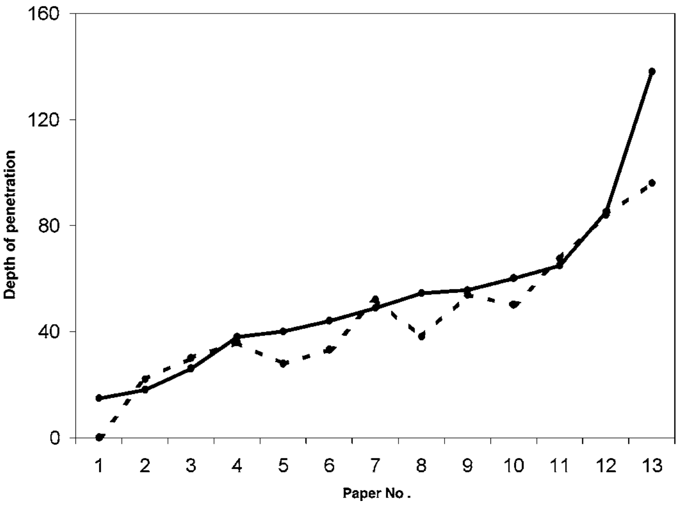

FIG. 3—*Depth of penetration (microns) of DFO and 1,2-indanedione-treated prints, for 13 uncoated papers (—) DFO, (----) 1,2-indanedione.*

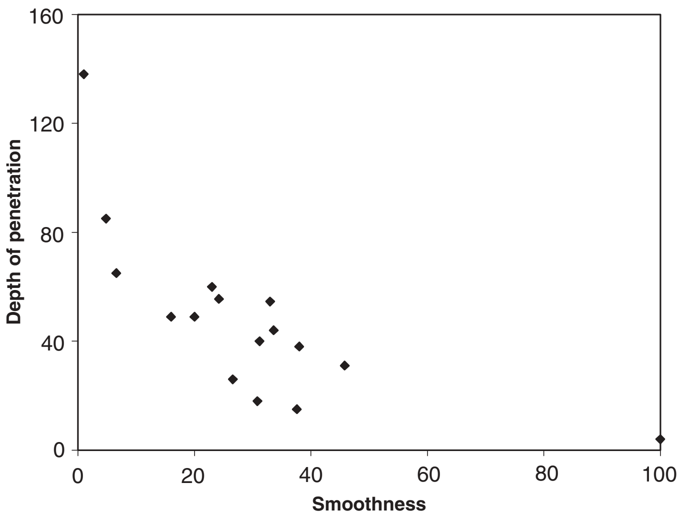

FIG. 4—*Depth of fingerprint penetration (DFO, microns) vs. paper smoothness (sec), for 13 uncoated papers.*

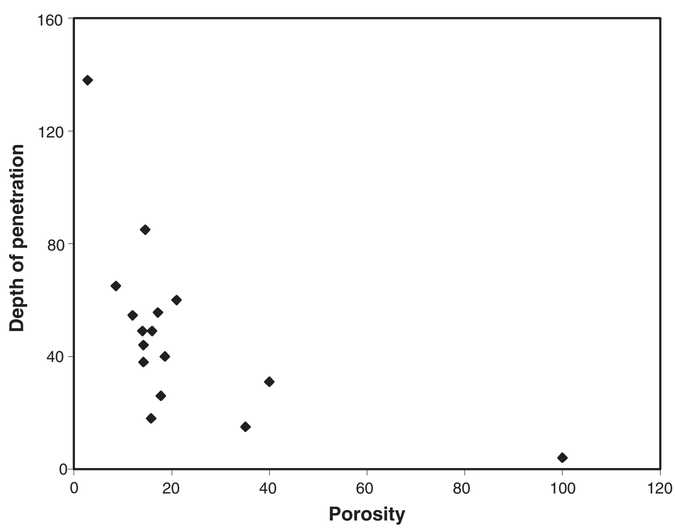

FIG. 5—*Depth of fingerprint penetration (DFO, microns) vs. paper porosity (sec/100 cm^3) for 13 uncoated papers.*

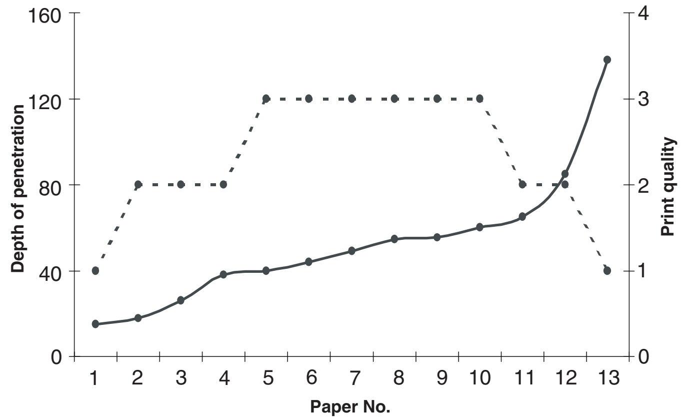

FIG. 6—*Developed prints quality (DFO) vs. depth of fingerprint penetration (microns). (—) depth of penetration, (----) print quality.*

papers (Papers No. 1–13). Under the microscope, the fluorescence of DFO and 1,2-indanedione-treated prints was much more intense than that of BY-40 "natural" prints, rendering the depth of penetration easier to evaluate. Consequently, the reproducibility of BY-40 results was lower than that of DFO and 1,2-indanedione.

As seen in Fig. 3 and Table 3, the penetration depth varies considerably from paper to paper, i.e., from a few microns or even less in brown wrapping paper to 138 microns in a filter paper sample used as an extreme example. Following the brown paper in the lower part of the scale are the luxurious, smooth copier paper, the inner side of the envelope, the writing paper, the copier paper, the outer side of the envelope, a cotton paper, the postcard board, and finally the Whatman filter paper. In general, similar results were observed for DFO and 1,2-indanedione-treated prints (Fig. 3).

Prints developed with DFO and 1,2-indanedione on the coated paper No. 14, were almost invisible, and only a few ridges could be revealed. The cross section picture (Fig. 2*A*), shows that the print residue stays almost entirely on the paper surface and does not penetrate inside. On a different coated paper (No. 13), however, the print deposit did penetrate into the paper, despite the coating. The coating composition of both papers is unknown. Since only two coated papers have been tested, it is impossible at this stage to draw conclusions regarding the role of the coating on fingerprint penetration. This issue will be addressed in a following study.

In addition to the variability in the depth of penetration, the shape and distribution of the ridges inside the paper also vary, as seen in Fig. 2. On some types of paper, like copier papers (*C*) and white envelopes (outer side) (*E*), the ridges are very regular, "like pearls on a string". On the other hand, on white notebook (*D*) and Whatman filter paper (*H*), even neighboring ridges have an irregular appearance. In the case of the white envelope, fingerprints on both sides of the same paper, (samples No. 3 and 7), behaved in a totally different manner. The difference in penetration depth and shape can be clearly observed in Fig. 2 and Table 3.

In this preliminary study, paper properties such as thickness, grammage, density, smoothness and porosity were recorded for each one of the samples. The depth of penetration was plotted against each of these properties to reveal possible correlations. As shown in Fig. 4, there is generally inverse relationship between the smoothness of the paper and the penetration depth (DFO): higher smoothness values result in lower depths of penetration. A similar trend was observed with 1,2-indanedione. The porosity, which is the basis for the surface classification for fingerprint development, was also considered to be an important factor. However, the porosity of most of the papers examined in this study is very similar. As seen in Fig. 5, for papers with a high degree of porosity, the depth of penetration is large. On the other hand, when the porosity is very low, the prints hardly penetrate into the paper. No clear or specific relationship is observed between the grammage, the density or the thickness and the depth of fingerprint penetration.

An interesting relationship was observed when the quality of the developed prints was plotted against the depth of penetration (Fig. 6). The general quality of the prints was evaluated in terms of sharpness, clarity, contrast and uniformity of the ridges (rated from 0 to 3). No quantitative yield comparisons were carried out in this experiment. A bell-shaped curve was obtained, indicating that an optimal depth of penetration in the range of 40–60 microns correlated with high print quality. On the other hand, very shallow or very deep penetrations correlated with lower print quality.

It is assumed that papers that lie on both ends of the correlation curve, namely those characterized by very low or very high penetration may require different techniques for fingerprint development. For instance, techniques used for smooth, non-porous surfaces would seem to be appropriate for papers with very low penetration; furthermore, it might be worthwhile to seek sweat constituents that do not migrate as much as amino acids for the very absorbent filter-type papers.

Conclusions

By applying fluorescence microscopy to fingerprint cross section on paper, we were able to show that latent fingerprints on paper do not remain on the surface but are absorbed into the paper, becoming like inclusions within the substrate. The chemical reaction used to visualize them takes place within the paper. The shape and depth of penetration vary with different types of paper. On very smooth paper, there is hardly any penetration, which offers an explanation why chemical development techniques using reagents in solution tend to fail on such papers.

A good correlation was found between the depth of penetration and the quality of chemically developed prints. High quality prints appear to correlate with an optimal penetration depth—between 40 and 60 microns. It is assumed that papers that lie on both ends of the correlation curve, namely, papers that are characterized by very low or very high penetration, may require different techniques for fingerprint development. It is also assumed that the depth of penetration may serve as a preliminary test to predict fingerprint quality in actual investigations.

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