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# Examination of Line Crossings by Scanning Electron Microscopy

A document examiner is often faced with determining the age of certain writing, whether done by ball-point pen, pencil, ink, typewriter, or something else; the problem is almost unsolvable because no method exists that yields reliable and direct results. Ways and means have often to be found that permit an indirect determination. One of the most important factors in this connection is the investigation of line crossings. If the writing sequence of two crossing lines can be determined, it is then possible to estimate accurately the age of one writing characteristic in relation to the other. For instance, the frequently posed question as to whether a signature on a contract was made before or after the text was written can be answered.

The difficulties that usually arise in the examination of line crossings are well known. The difference in quality of the two writing media used, the surface of the material bearing the script, and other factors such as impression, speed of writing, and position of the writing medium and pad all play an important part.

Determining the line sequence with conventional methods is possible only in exceptional cases. In previous crossing zone examinations, secondary characteristics such as line deviations, ink misplacements, and ink distribution gaps were sought. However, deposits of a second writing instrument on a first and the details of fine structures cannot be conclusively defined by a light optical microscope because as the limits of its resolving power are reached the depth of focus is considerably reduced by the increased magnification. Under high magnification it is impossible to get an optical image of the fissured surface of a piece of paper or of the deposits of a writing instrument on it. In the ultramicroscopic range interesting findings on ink deposits can be expected, especially in regard to line crossings. One realizes that the characteristics of the actual primary deposit can arise inside a crossing zone.

The only instrument suitable for such examinations is the scanning electron microscope (SEM). With a resolving power of approximately 5.0 nm (about ten times stronger than that of a light microscope), the SEM has about 1000 times better depth of focus.

## An Actual Case

The SEM was used for a case in which it was to be determined whether the signature "Schmid" was written before or after the typewritten text was made. Figure 1 shows how the length of the upper loop of the capital *S* crosses the typewritten *G* in two places (*arrow*). The signature was made with a ball-point pen; an IBM typewriter with plastic or carbon ribbon was used for the text. There are only fragmentary traces of ink on the crossing section. Examination of the two crossing points (*1* and *2*) with conventional, nondestructive, light optical methods led to no conclusive results. We then used the SEM for the first time to

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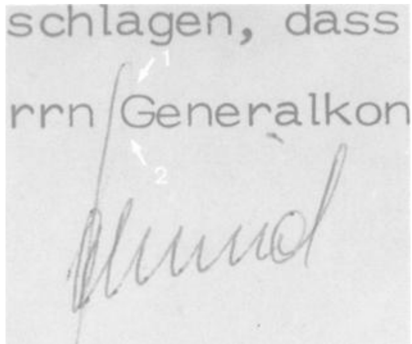


FIG. 1—*Crossing zones numbered* 1 *and* 2 *between ball-point pen stroke and typewritten letter* G.

obtain some information on line sequence. Results were checked by producing model crossing lines and comparing them with the same type of writing medium on similar paper.

Figure 2 (*left*) is a SEM picture showing the test sample of the cross sections in question. The ink trace of the ball-point pen and the imprint of the capital *G* (see dashed lines in Fig. 2 [*right*]) can be seen. The arrows point to the two cross sections (magnification, × 18, where the magnification quote refers to the size of the screen of the SEM, which is 120 by 120 mm). Figure 3 shows Crossing 1. The imprint of the *G* forms an arch from the lower left to the upper right. In about the center of the picture a slightly darker *S*-shaped fiber (magnification, × 92) can be seen. The arrow marks the spot of the crossing zone from which the next detailed shots were taken. In Fig. 4 (magnification, × 460) can be seen how the lower visible part of the fiber takes a downward course from right to left. In the center of the picture a dark spot on a paper fiber can be seen (*arrow*). These fibers are within Crossing 1. The dark, flat spots are deposits of ball-point pen ink. The granular substance spreading over the entire picture represents deposits of plastic ribbon dye (compare later descriptions of these writing media). Figures 5 and 6 (magnifications, × 1840 and × 4600, respectively) show the dark spot marked in Fig. 4. Here, the granular structure of the carbon ribbon dye covering a paper fiber that stretches diagonally across the picture is visible. These grains are,

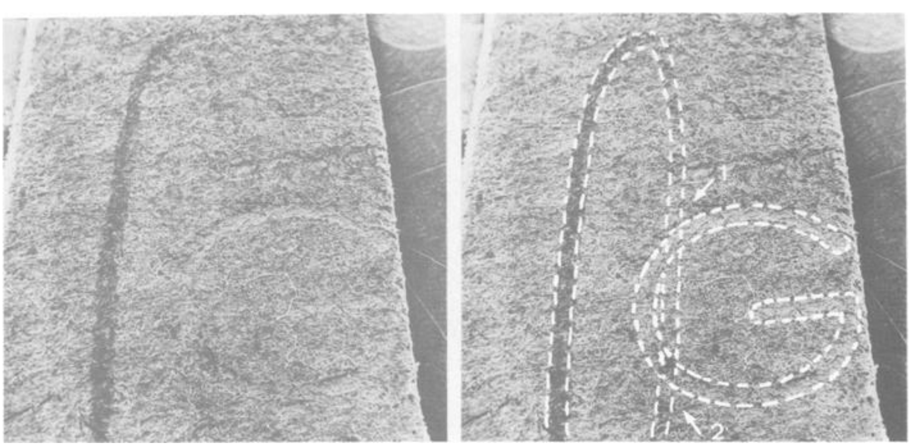


FIG. 2—(left) *The two crossing zones.* (right) *The dashed lines show the imprint of the capital letter* G *and the course of the ink trace of the ball-point pen stroke. Arrows* 1 *and* 2 *mark the two crossings.*

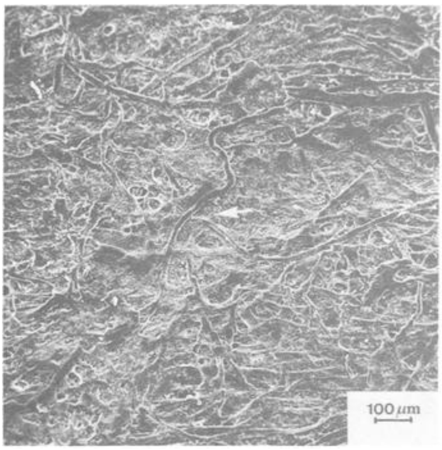


FIG. 3—*Crossing 1. The arrow points to the two fibers within the crossing zone that are detailed in the following pictures.*

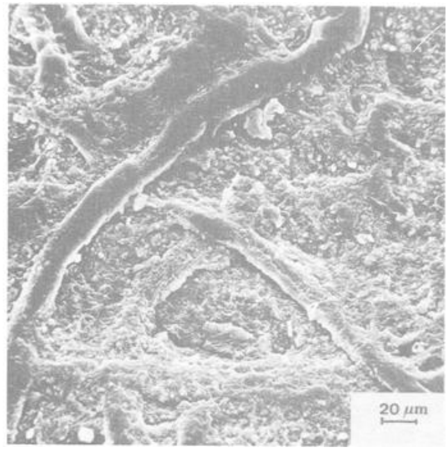


FIG. 4—*The two fibers shown in Fig. 3. The arrow marks a dark spot on top of one of these fibers.*

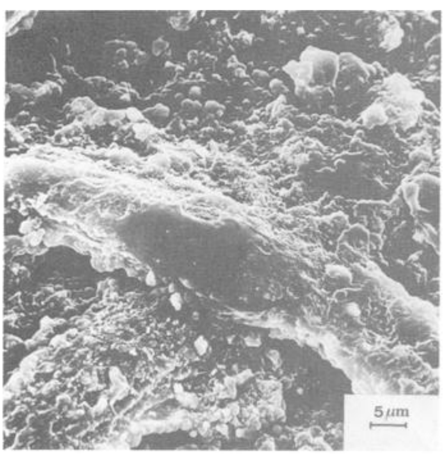


FIG. 5—*Detail of the spot shown in Fig. 4.*

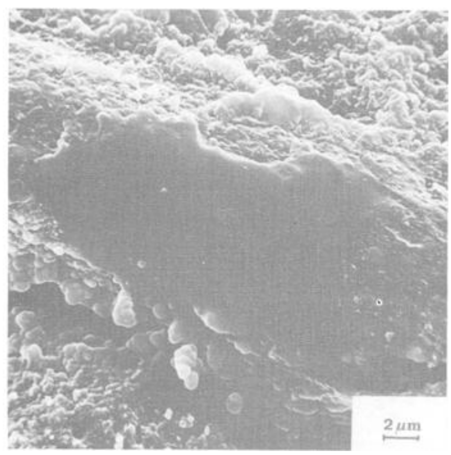


FIG. 6—*The spot shown in Fig. 5 represents deposited ball-point pen ink on top of carbon ribbon dye grains.*

in turn, covered by a paste-like substance (center of picture). As various model tests have proved, this substance is ball-point pen ink. On these and the following photographs the significant advantage the SEM has over the conventional light optical microscope can be recognized. Because of the powerful depth of focus the SEM provides, the fissured paper surface can still be seen despite the higher magnification.

Figure 7 (magnification, × 950) shows a selected part of Crossing 2. Here too the typically structured deposits of the carbon ribbon dye are sporadically covered by the ball-point pen ink. It should be mentioned here that Figs. 4 to 7 merely illustrate two selected spots. The examiner cannot, however, rely only on single characteristics; he must interpret and evaluate all the information accumulated from a crossing. Conclusions concerning the sequence of the strokes are possible only if no contradictory appearances are present.

*Comparative Photographs*

For comparative purposes the carbon ribbon, ball-point pen ink, and a portion of the blank paper surface outside the crossing zones were subsequently examined. Figure 8 shows the typical granular deposits of the ribbon dye (magnification is the same as for Fig. 6). On the left of Fig. 9 the blank paper surface is visible, while deposits of ball-point pen ink cover the paper on the right. Figure 10 clearly shows the transition zone of ball-point pen ink to paper.

*Model Crossings*

To compare established characteristics with models it is necessary that models be produced with the same or similar writing media. Optimal conditions for comparative purposes are given when a blank zone of the incriminating paper can be used. Figure 10 (magnification, × 1950) shows a detail of a model crossing where the stroke of the ball-point pen lies on top of the typewritten letter.

Figure 11 (magnification, × 2000) shows a model crossing zone where the dye of the typewriter ribbon lies on top of the line made by the ball-point pen. The layer of the typewriter ribbon dye on the right covers the trace of the ball-point pen ink.

## Other Writing Media

Since that first case we have examined various other line crossings from actual cases with the SEM. We are at present conducting examinations of different model crossings in which twelve different kinds of writing instruments were crossed on five distinct qualities of paper having surfaces of dissimilar structure. The second strokes for the model crossing samples were made two weeks after the first. To produce these models, we made a total of 720 different stroke crossings. The following writing media were chosen for these examinations: lead pencil, ball-point pen, ball-point pen ink, felt-tip pen, fountain pen, chinese ink, stamp pad ink, carbon paper, textile typewriter ribbon, IBM T III ribbon, IBM carbon ribbon, and IBM correctable ribbon. The following examples have been selected from the many model crossings produced with various writing media.

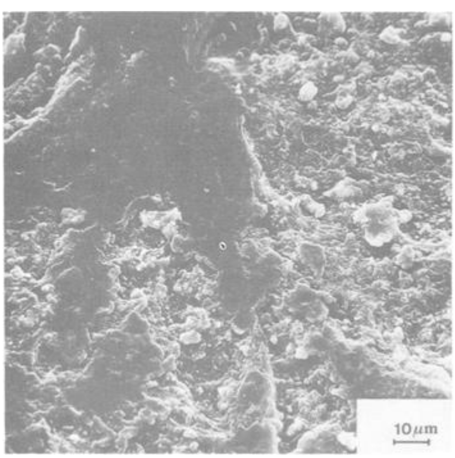


FIG. 7—*Selected part of Crossing 2 (see Fig. 1) illustrates the dark deposits of ball-point pen ink lying on top of the grains of the carbon ribbon dye.*

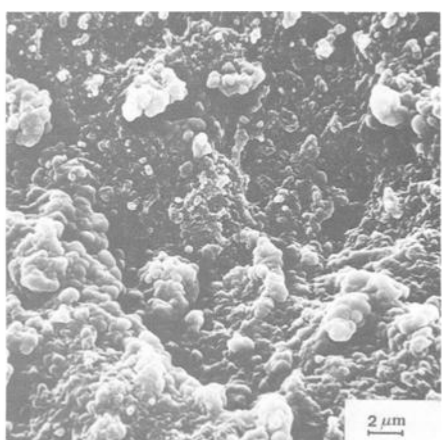


FIG. 8—*Sample of carbon ribbon dye of the letter G beyond the crossing zones. Typical grains of carbon ribbon dye can also be seen.*

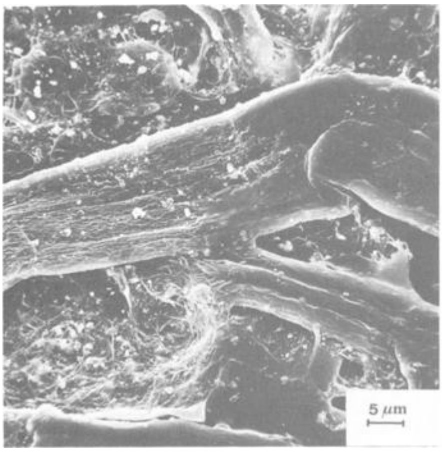


FIG. 9—*Sample from outside the crossings. On the left is a blank paper fiber; on the right are deposits of ball-point pen ink.*

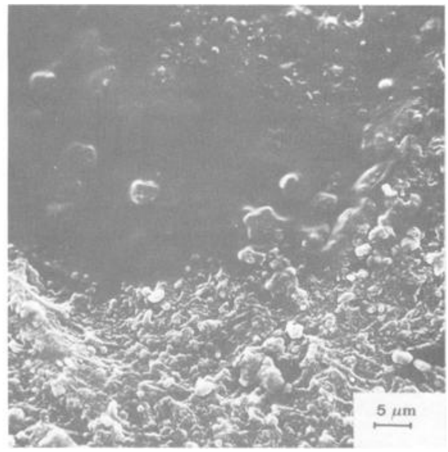


FIG. 10—*The upper part of the photo shows how the granular deposits of the carbon ribbon dye are covered by the ball-point pen ink.*

### *Textile Ribbon on Top of Ball-Point Pen Ink*

The following case illustrates the examination of a stroke crossing between a ball-point pen line and a type imprint made by a textile ribbon. Figure 12 shows how the signature crosses the bottom line of the typewritten text in three places (*arrows*). Crossings 2 and 3 were examined with the SEM.

Figure 13 (magnification, × 1950) shows Crossing 2. The granular structure of the deposited dye of the textile ribbon and, again, the the typical ball-point pen paste deposits can be recognized. The arrow points to the zone enlarged in Fig. 14. On the left of Fig. 14, the grains (in fact, soot particles) of the typewriter ribbon can be seen (magnification, × 19 500). On the right, the spread-out covering of the ball-point pen paste is visible. This picture clearly shows how the particles of textile ribbon dye lie *on top* of the ball-point pen

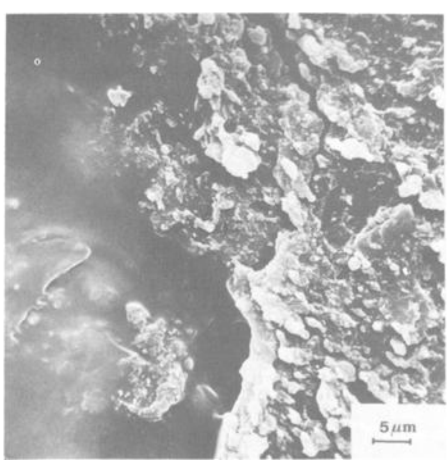


FIG. 11—*Transition zone between carbon ribbon dye on the right and ball-point pen ink on the left. The grains of the carbon ribbon dye lie on top of the ball-point pen ink.*

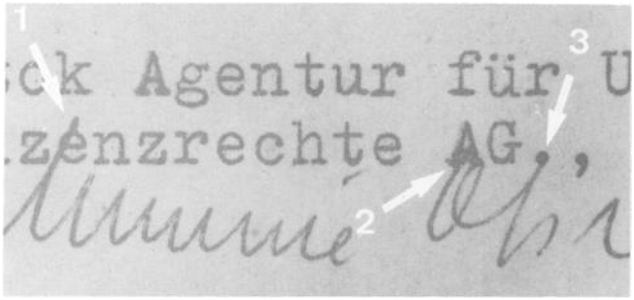


FIG. 12—*Crossings of typewritten text produced with a textile ribbon and ball-point pen writing. Crossings 2 and 3 were examined with the SEM (see Figs. 13, 14, and 15).*

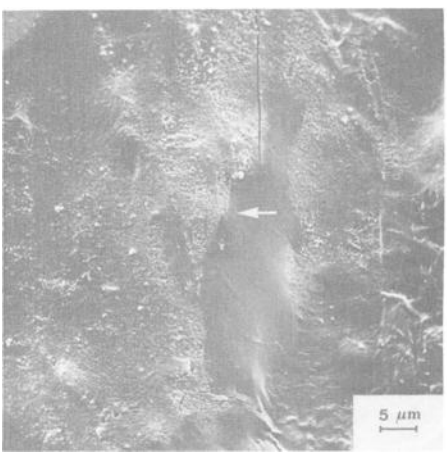


FIG. 13—*Section of Crossing 2 (see Fig. 12). The arrow marks the transition zone of textile ribbon dye to ball-point pen ink, which is shown in detail in the following picture.*

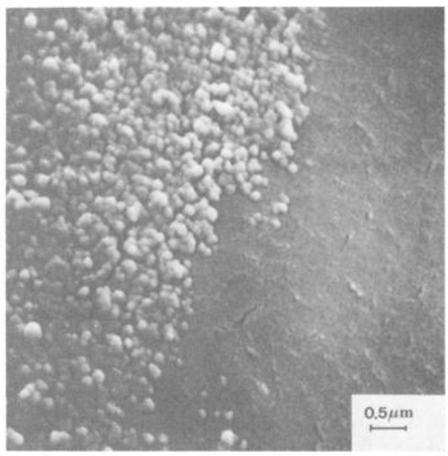


FIG. 14—*Transition zone of textile ribbon dye on the left and ball-point pen ink on the right. From this picture it can clearly be seen how the grains of the textile ribbon dye lie on top of the deposited ball-point pen ink.*

paste in the transition zone of the ribbon/ball-point pen. The SEM examination of Crossing 3 led to the same results. In comparison, Fig. 15 shows the deposited textile ribbon dye beyond the crossing zone. Again the typical granular structure is visible. Figure 16 (magnification, × 20 000) is also a comparative shot from outside the cross zones. The spread-out deposits of the ball-point pen paste are again apparent.

### *Ball-Point Pen Paste on Top of Textile Ribbon Dye*

For comparison's sake, samples were made with the same quality writing material but with the ball-point pen paste on top of the ribbon dye. Figures 17 and 18 show a sample of such a crossing (magnifications, × 4750 and × 19 000, respectively). The granular structure of the ribbon dye and the paste-like ink of the ball-point pen are visible. Along the border zones can be seen how the color particles of the ribbon dye are covered by the paste of the ball-point pen.

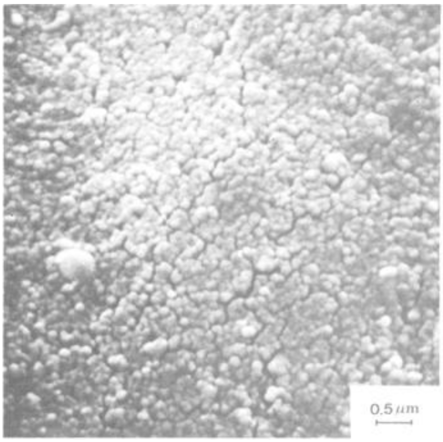


FIG. 15—*Deposited textile ribbon dye outside a crossing zone.*

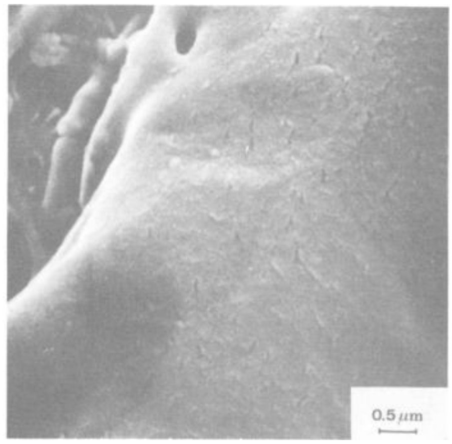


FIG. 16—*Deposited ball-point pen ink outside a crossing zone.*

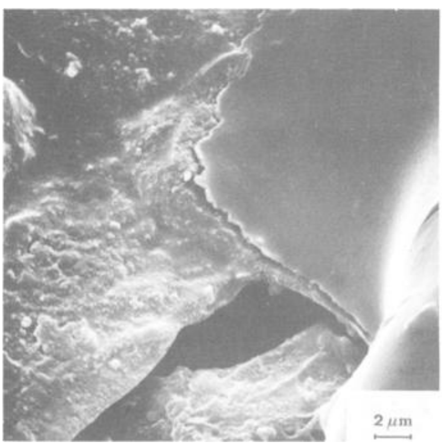


FIG. 17—*Crossing zone where the ball-point pen ink is deposited on top of the dye of the textile ribbon. On the right is the ball-point pen ink, on the left the dye of the textile ribbon.*

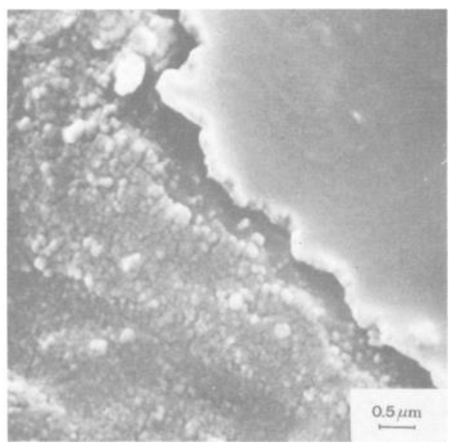


FIG. 18—*Center of Fig. 17 in detail. It is clear that the ball-point pen ink lies on top of the textile ribbon dye.*

### *Lead Pencil Stroke on Top of Lead Pencil Stroke*

Figure 19 shows the crossing of two lead pencil strokes. For this test pencils of medium hardness were used. The typical flaky deposits and scratches that run in the strokes' courses can be seen. From the positions of the deposited layers it is evident that the stroke that goes from the lower left to the upper right lies on top.

### *Ball-Point Pen Line on Top of Carbon Paper Dye*

On the left of Fig. 20 the well-known deposit characteristics of ball-point pen paste are shown. On the right are the granular deposits of carbon paper. This picture clearly shows how the dye of the carbon paper is covered by the paste of the ball pen.

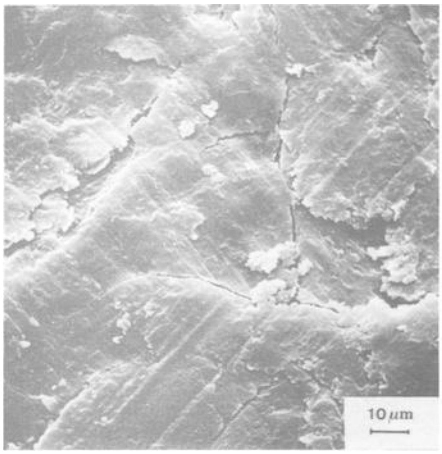


FIG. 19—*Crossing zone of two lead pencil strokes. The strokes run diagonally; the stroke that proceeds from top right to bottom left is on top. There are typical flaky deposits and scratches in the direction of the stroke.*

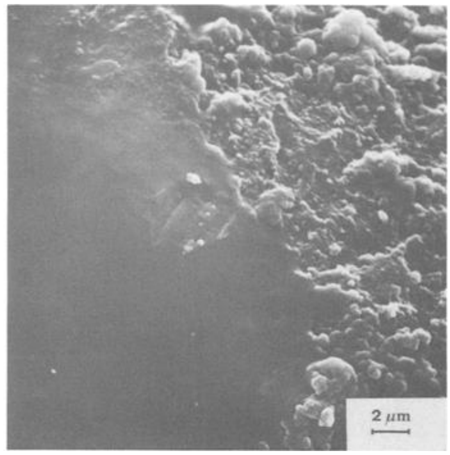


FIG. 20—*Ball-point pen stroke on top of carbon paper writing. On the left is ball-point pen paste, and on the right, granular structure of the deposited carbon paper dye.*

### *Carbon Paper Dye on Top of Ball-Point Pen Ink*

Figure 21 shows the structures of the pen paste and carbon dye shown in Fig. 20 and how the grains of the carbon paper dye lie on top of the pen paste.

### *Lead Pencil on Top of Ball-Point Pen Ink*

Figure 22 shows again the smooth deposits of the ball-point pen paste. On the left are the typical flaky deposits and scratch traces of the lead pencil. These deposits are on top of the ball-point pen paste.

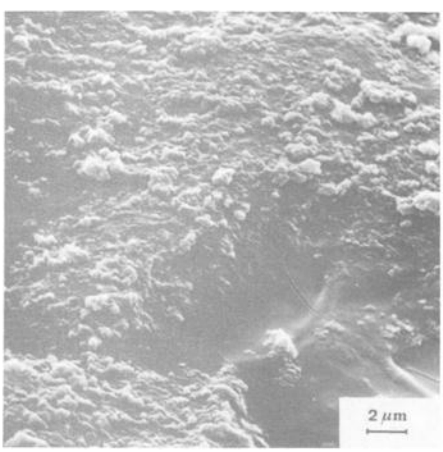


FIG. 21—*Carbon paper writing on top of ball-point pen stroke. The particles of the carbon paper dye are on top of the ball-point pen ink.*

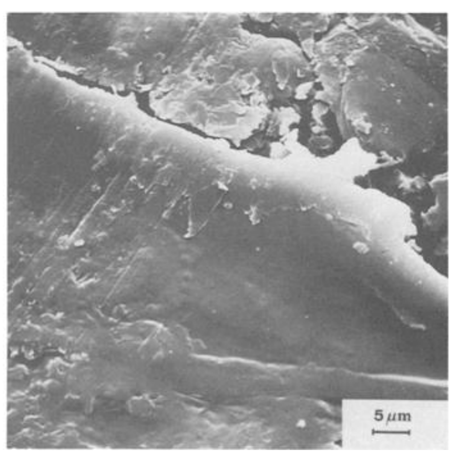


FIG. 22—*Lead pencil on top of ball-point pen ink, showing the typical scratches of the pencil stroke and the flaky deposits on the spread-out ball-point pen ink.*

*Ball-Point Pen Ink on Top of Lead Pencil*

On the left of Fig. 23 is shown how the scratch traces that proceed from top left to bottom right and the flaky deposits of the lead pencil are covered by the ball-point pen paste.

## Preparation and Technical Aspects

All the examined crossing zones were cut out and mounted on a normally used test plate with double-sided transparent tape (Fig. 24). Because our samples in all cases were charged by the electron beam of the SEM it was necessary to make them conductive. With the sputtering method the samples have to be coated with a metal layer. In our case, we used a gold or gold/palladium layer of about 20.0-nm thickness. With this preparative coating the samples will become obliterated, and therefore it is impossible that these line crossings be examined again with other methods. For this reason, not all the crossings in a case where two writings cross at several points should be taken for SEM examination.

The instruments used were a Cambridge MK II and Cambridge Stereoscan S4. For practically all samples the normal working acceleration voltage of 20 kV was applied. For the photographs, Illford Pan F roll film Type 120 and Illford FP 4 Type 120 were used.

## Conclusions

Samples have shown that reliable and conclusive results can be obtained in examinations made with the SEM. However, extensive basic research is a necessary factor in achieving correct evaluation and interpretation of the great amount of new information yielded. Only the operator examining the whole crossing zone gets the entire picture. The accompanying photographs represent only a view of selected zones that are necessarily of coincidental character. Thus, within small areas, the surfaces of paper with sporadic impressions of the writing media can be subject to considerable deviation. However, as the examinations have shown, the SEM will be an indispensable instrument for examinations of questioned documents, as has already been found in the various other laboratories of the forensic sciences. The examination of line crossings represents only one small part of the numerous possibilities in this field.

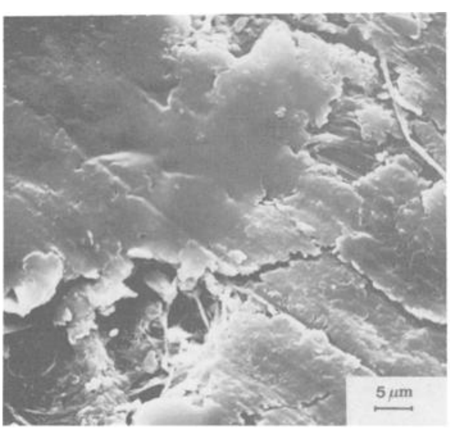


FIG. 23—*Ball-point pen ink on top of lead pencil stroke. On the left is shown how the sharp-edged scratches of the lead pencil deposits are covered by the ball-point pen ink.*

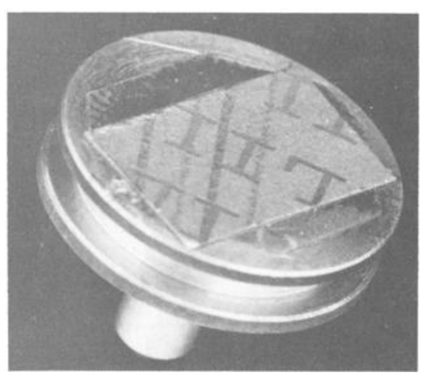

FIG. 24—*Sample attached to a normal specimen stub.*

**Summary**

In this study line crossings of various writing media were examined with the SEM. Examinations were carried out in actual cases on line crossings with unknown sequence and on model crossings where the sequence of the crossed lines was known. These model crossings were produced under diverse conditions. Not only were different types of writing media and paper surfaces taken into consideration, but factors such as depth of impression, writing pad, and the length of time that had elapsed between writing were also studied. Magnifications of approximately × 1000 to × 20 000 established the character of the deposits and the fine structures of the writing media on the crossings. On the whole, such observations permit conclusive data on the sequence of strokes to be obtained.

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