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Comparison of Scanning Kelvin Probe with SEM/EPMA Techniques for Fingermark Recovery from Metallic Surfaces

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Highlights

- The Scanning Kelvin probe provides a fermi energy map revealing latent fingermarks
- Scanning Kelvin probe could pre-identify fingermark areas for targeted DNA recovery
- SEM/EPMA data was compared to Scanning Kelvin Probe images of fingermarks
- An increase in sodium, chlorine and oxygen coincided with a change in CPD
- Scanning Kelvin probe worked best on non-enhanced surfaces without VMD

Abstract:
Most traditional techniques to recover latent fingermarks from metallic surfaces do not consider the metal surface properties and instead focus on the fingermark chemistry. The scanning Kelvin probe (SKP) technique is a non-contact, non-destructive method, used under ambient conditions, which can be utilised to recover latent prints from metallic surfaces and does not require any enhancement techniques or prevent subsequent forensic analysis. Where a fingermark ridge contacted the metal, the contact potential difference (CPD) contrast between the background surface and the fingermark contact area was 10 - 50 mV. Measurements were performed on the untreated Brass, Nickel-coated Brass and Copper metal surfaces and compared to traditional forensic enhancement techniques such as vacuum metal deposition (VMD) using Au-Zn and Au-Ag. Using VMD, the CPD change ranged from 0 - 150 mV between the dissimilar metal surfaces affected by the fingermark. In general, SKP worked best without additional enhancement techniques.
Scanning Electron Microscope (SEM) scans were used to identify the fingermark contact areas through a Sodium, Chlorine and Oxygen electron probe micro-analyzer (EPMA). The fingermark was observed in the backscattered electron image as the carbon deposits scattered the electrons less than the surrounding metal surface. The fingermark is shown clearly in a Cathodoluminescence scan on the Copper sample as it blocks the photon emission at band gap (2.17 eV) from the underlying Copper Oxide (Cu_2O) surface. For the first time, SEM, EPMA and Cathodoluminescence techniques were compared to SKP data.
Visible and latent fingermarks were tested with latent, eccrinous fingermarks more easily imaged by SKP. Results obtained were very encouraging and suggest that the scanning Kelvin probe technique, which does not need vacuum, could have a place as a first stage analysis tool in serious crime investigation.

Keywords: Scanning Kelvin Probe, Fingermarks, Forensic Science, Metal Surfaces, Contact Potential Difference, SEM

1. Introduction:

As an important tool within criminal investigations, there are many existing methods of fingermark visualisation. Scientific developments over the past century have allowed latent fingermarks to be enhanced and visualised through a variety of techniques on many different porous and non-porous substrates.

Metal surfaces are of interest due to their common presence and the possibility of recovering evidence from gun cartridges involved in major crime. Recovery of fingermarks from metal surfaces has been observed to be more challenging than other non-porous surfaces, due to the metal chemistry and reactions that may be occurring at the substrate surface [1]. Within the Fingermark Visualisation Manual published by the UK Home Office Centre for Applied Science and Technology (CAST), the processes recommended do not utilise the surface metal reactivity and they note that 'no information is available on which processes are the most effective' [1].

Additionally, commonly used techniques, including powdering, vacuum metal deposition and cyanoacrylate fuming [2], contaminate the sample surface and may prevent or weaken further study. There have recently been some promising results involving new techniques for metal surfaces. Wightman et al. [3] investigated oxidisation and corrosion using thermal or chemical treatment and found that fingermark deposits may locally increase or prevent corrosion depending on their composition. Gun blue may also be used as a chemical agent to develop latent fingermarks with success ranging from mixed to excellent results depending on both the composition of the fingermark and method of application of the enhancement agent [4-6]. However, these improvements also contaminate or change the sample surface. With modern developments in forensic science including DNA recovery, the possibility of conducting multiple investigations on a single sample is increasingly important and, as such, a non-contact, non-destructive method of fingermark visualisation is highly desirable.

Most techniques focus on the fingermark chemistry or surface properties but when there is a conducting material, the interaction of the fingermark deposit with the surface and the subsequent changes in material energy levels may also be investigated. The scanning Kelvin probe (SKP) is used for surface analysis within metal and semiconductor research [7], measuring the contact potential difference (or volta potential / work function) between the vibrating Kelvin Probe tip and sample with the spatial resolution defined by the diameter of KP tip [8]. Recent applications of the Kelvin probe range from solar cell research [9] and diamond [10] to corrosion [11]. SKP was initially applied to the forensic science field by McMurray and Williams to recover latent fingermarks from Iron and Brass [12, 13]. The signal is derived from the capacitive interaction between the sample and Kelvin probe. When a finger touches the metal surface, the ridge contact changes the contact potential difference. SKP allows a reproduction of the original fingermark image from the difference in fermi energy levels. Most importantly, as a non-contact/non-destructive technique the scanning Kelvin probe does not prevent any subsequent Forensic analysis. Additionally, we propose that it offers the opportunity to pre-identify and, target one or more fingermarks before swabbing or lifting for DNA.

Despite the promising initial work on the SKP technique in forensic science, little investigation has been performed on the origin of the fingermark signal or on the relationship between this and other techniques. A better understanding of the science of the fingermark

and the information available from the SKP scan is required to develop confidence in the method prior to adoption in live criminal investigations.

We combine a scanning Kelvin probe study of fingermarks on Nickel, Brass and Copper flat metallic surfaces with Scanning Electron Microscope and EPMA data to investigate the properties of the fingermarks from chemical analysis and volta potential measurements of the surfaces. We study the quality of images obtainable from latent and visible prints. Additionally, SKP is combined with the VMD technique to allow comparison of the optical and fermi energy level mapping processes. This pilot study meets or exceeds the guidelines for the assessment of fingermark detection techniques of the International Fingerprint Research Group (IFRG) [14].

2. Experimental Details

Materials

Metallic substrates were obtained from a variety of sources: Iron (25 mm x 25 mm) from Goodfellow Ltd., Cambridge, UK; Brass (25 mm x 25mm) 67% Cu 33% Zinc from Advent Research Materials, Oxford, UK; and CZ106 Brass (20 mm x 20 mm) 70% Cu 30% Zinc from Metal Sheets Ltd., Liverpool, UK. Nickel coating was applied to a subset of the CZ106 Brass by Flexible Surface Technology Limited, Livingston, Scotland, UK.
The CZ106 Brass and Nickel coated Brass were prepared by cleaning with diluted Teepol™ detergent (Teepol Products, Orpington, Kent, UK) and rinsed with water before being dried with tissue [15]. The protective seal on one side was removed using tweezers, the surface cleaned with ethanol (Sigma Aldrich Co. Gillingham, Dorset, UK) using clean tissue and left to air dry. The Brass from Advent Research Materials was wiped with IPA to ensure that any manufacturing or storage residue was removed before the fingermark was applied. Iron was cleaned using aluminium oxide lapping paper with particle sizes 30 µm and 1 µm in turn.

Fingermarks were applied using four different methods:

A) Unloaded samples – the hands were washed in soapy water and dried with paper towels. The donor waited 20-30 minutes whilst continuing normal activities before applying firm pressure to the metal with the index or middle fingers to create the fingermark sample.
B) Loaded samples - the index and middle fingers were dipped into a saturated saline solution (37 % aqueous sodium chloride solution) for two minutes. The fingers were removed and allowed to air dry. Once dry, the finger was placed onto the surface of the metal to create the fingermark sample.
C) Eccrinous samples – the hands were washed with soap and water and dried. Then blue powderless nitrile gloves (Marigold) were worn for 30 mins and then removed before firm pressure was applied to the metal with the index finger to create the fingermark as suggested by Sears et al [16].
D) Sebaceous samples – the hands were washed with soap and water and dried. Then the donor rubbed their index finger on the side of the nose before firm pressure was applied to the metal to create the fingermark.

Three different donors provided fingermarks and the age when analysed ranged from 1-48 hours to 9 months old. They were stored prior to measurement in laboratory conditions at 35-45% RH in a dust free container. We did our best to keep the metal surfaces dust free and used gloves to prevent duplicate fingermarks when handling the samples.

Methods

Scanning Kelvin probe (SKP)

The Kelvin probe is a non-contact capacitor device measuring the relative work function of a conducting material. There is a small voltage (Contact Potential Difference – CPD) between the Kelvin probe tip and the sample which is perturbed when the fermi energy level of the surface is altered, e.g. by finger ridge contact to a metallic surface (Fig. 1A). The spatial resolution of an SKP is determined by the tip diameter so different tip sizes from 50 µm – 1 mm were explored to ensure an appropriate resolution and signal quality. The measurement setup is demonstrated for a vibrating 100 µm tip in Fig. 1B with the SKP scanning at a fixed height 100 µm from the sample surface using a raster pattern (Fig. 1C). The metal samples were scanned using different scanning Kelvin probes, SKP5050 (KP Technology Ltd.) shown in Fig. 1D and for environmental stability/control, a RHC040 shown in Fig. 1E (KP Technology Ltd.). The Kelvin probe used in this study operates by the off-null Baikie method allowing highly accurate and automatically height-regulated measurements [7]. This technique removes the requirement to run an initial topography scan and allows easy transition to more irregular surface structures.

Samples were scanned with a 1mm tip to screen samples for the presence of a fingermark. These initial scans were completed in ~ 1 hour. For a 25 mm x 25 mm sample, it could be sampled with more than two measurements per 1 mm tip diameter for example with a 60 x 60 grid. At ~1 second per point, each line was completed in ~1 minute and the entire scan in ~ 1 hour. Once the location of the fingermark was known, a smaller tip was used to scan the fingermark area with a higher resolution to allow the recovery of unique identification points. Scans were taken with a 50 µm, 100 µm and 300 µm diameter tip. Due to the smaller tip, it is necessary to use higher averaging and a smaller grid spacing so these scans took longer. Each measurement takes 5 – 10 seconds per point, so for example with a 100 x 100 grid, each line takes 8 – 17 minutes and the entire scan between 13 – 28 hours. Larger scan grids correspondingly required more time and smaller area grids needed less measurement time.

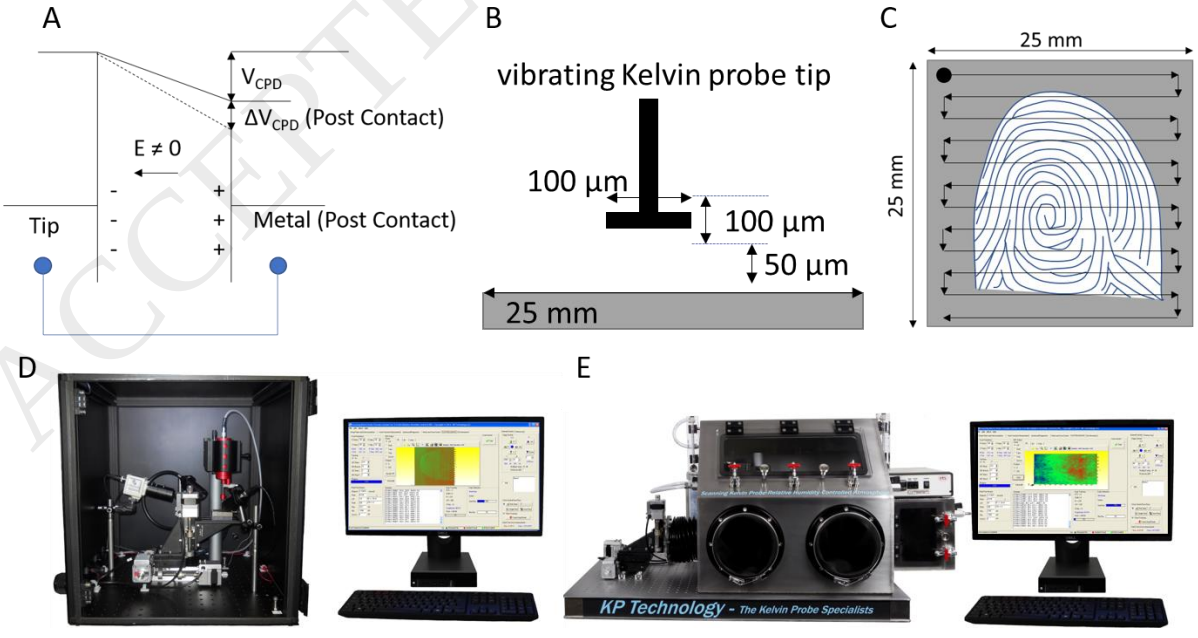

Fig. 1A. Kelvin probe measurement principle: electric field across tip/sample capacitor and potential difference due to material and fingermark ridge contact, **B.** Schematic diagram of 100 µm Kelvin probe tip operating at a distance of ~100 µm from the surface, **C.** Schematic diagram of fingermark sample scan with the Kelvin probe tip rastered across the surface, **D.** Photograph of scanning Kelvin probe ambient measurement system, **1E.** Photograph of relative humidity controlled enclosure for scanning Kelvin probe measurements.

Scanning Electron Microscopy/Electron Probe Microanalyser (SEM/EPMA)
The SEM/EPMA analysis was performed using SX100 with WDS (CAMECA, AMTEK, Inc.) with Sodium, Chloride and Oxygen detected simultaneously. Measurements were also conducted using backscattered electron and cathodoluminescence. The analysis was conducted under vacuum conditions with a minimum pressure of 6×10^{-6} Pa. The electron beam energy was 10 keV, the current 100 nA and the spot size 50 µm.
Cathodoluminescence was performed using a focussed beam of electrons to cause the sample to emit photons which are measured by a cathodoluminescence detector attached to the SEM. High resolution imaging was performed using a Quanta 250 Scanning Electron Microscope (ThermoFisher Scientific) under high vacuum.

Vacuum Metal Deposition (VMD)
Vacuum Metal Deposition (VMD) is a fingermark enhancement technique used on non-porous and semi-porous substrates, such as metal and plastics. The process involves the evaporation of metals to form a thin metal film on the surface under investigation [17]. Single metals, such as Gold (Au), Silver (Ag), Zinc (Zn), Copper (Cu) and Cadmium (Cd) or a combination of these may be used, common combinations include Au-Au, Au-Ag and Au-Zn. Firstly, Gold is deposited onto the surface being examined by evaporation of Gold wire under vacuum using a filament. The vaporised Gold coats the surface of the sample in a thin layer. Once this is complete, the second metal is vaporised and binds to the Gold nuclei on the surface, any Gold that has diffused into fingermark residue is not available for binding [17-19].

A subset of Brass CZ106 samples were treated with Vacuum Metal Deposition (VMD) using the VMD900 Through Wall system by West Technology Systems Ltd. with Au-Zn and Au-Ag. The samples were placed on the front loading stainless steel chamber of the VMD instrument with an acetate sheet covering one half of the fingermark and secured with small magnets. The metal boats were loaded with the metal being used for analysis. For Au-Ag, the Gold and Silver boats required 4mm of Gold and Silver wire respectively and for Au-Zn, 4mm of Gold wire was placed in the Gold boat and the Zinc boat was filled with Zinc pieces.

Optical Microscope
Optical images were taken, where possible, using a DinoLite 7013 Digital Polarising Microscope (AnMo Electronics Corporation, Taiwan).

3. Results and Discussion

SKP, VMD and Optical Study
Fingermark location could be determined using a more rapid screening scan with a 1 mm tip size when necessary. Whilst it is not possible to resolve individual fingermark ridges with this tip size, it does give the possibility of scanning a large area rapidly to identify the location of a fingermark. This may assist in identifying key areas to be swabbed for touch or contact DNA. This could allow differentiation between recovered marks which would be very relevant in situations where it could be assumed an object could have been handled by a number of individuals.

Optical images of fingermark ridge detail (measured using DinoLite Microscope) were studied and the ridge spacing defined as mostly 2 ridges per mm: with a fingermark peak (or trough) each spanning 250 µm. This is in good agreement to Moore's analysis [20] of ridge to ridge spacing with a range of 200 – 850 µm. Therefore, a tip with a smaller diameter should be able to fully resolve the fingermark ridge suggesting that the tip sizes of 50, 100, 300 µm were suitable. The 100 µm tip size was preferred; minimising the impact of external noise and simplifying control while allowing a good representation of the work function difference. The contrast could be improved further by taking a high-resolution scan with a higher point density.

As a standard forensic fingermark enhancement technique, VMD allows recovery of an unloaded fingermark by improving the otherwise poor optical contrast on the untreated surface. This is demonstrated in Fig. 2A as the fingermark may be clearly observed on the Au-Zn side but not on the untreated Brass side. The optical contrast is due to the Au atoms lying beneath the fingermark debris and the zinc atoms preferentially coating the Au particles on top of the untouched metal. The colour contrast between the two surfaces is then sufficient to recover the fingermark [21-23].

When the metallic surfaces are treated with VMD, the Kelvin probe may also be able to detect the fingermark due to differences between the dissimilar metal work functions. An SKP scan of the VMD treated sample for Au-Zn is shown in Fig 2B. There is a clear CPD contrast between the Au and Zn regions shown in Fig 2B. This agrees with the results obtained by Dafydd *et al.* [24]. The benefit of a high-resolution scan may be seen in the black border subsection of Fig 2B. Line scans are taken between i - ii and iii – iv (shown in Fig. 2C) showing a clear 150 mV CPD contrast between the Zinc background and the Au/fingermark deposit. The contrast is lower than expected from the individual metal work functions, probably as the Au diffuses sub-surface, so we recommend selecting deposition metals with a large ΔCPD if intended for SKP visualisation.

The fingermark on Brass treated with Ag-Au was visible optically on treated and untreated surfaces with ridge detail more distinct on the VMD side (Fig. 2D). There was no detectable SKP contrast (i.e. 0 mV) between Ag and Au regions on the treated side but some poor-quality ridge detail is observable on the non-treated Brass region in Fig. 2E and Fig 2F. Therefore, the combination of different VMD metals on Brass to enhance the SKP signal had mixed results. In the Au-Zn treatment an excellent CPD modulation was observed but the Ag-Au treated side did not allow any ridge detail to be detected.

An unloaded fingermark was visible on an untreated Brass sample (Fig. 2G) and the corresponding SKP image provided > 2/3 clear ridge detail from the analysed region (Fig. 2H). The line scans through the sample show a uniform change in CPD in the y direction but a notable trend in the 'baseline' in the x direction across the width of the fingermark (Fig. 2I). This may be attributed to greater central pressure when the print was applied and a contamination deposit across the fingermark [25]. The work function modulation was poorer than the photo at the edges of the fingermark in this example but similar information was provided for the central region. The SKP standard deviation across the measured region outlined with the black border was 26 mV. The SKP ridge detail on the untreated Brass in Fig. 2G is far superior to Fig. 2D suggesting that the vacuum processing of the VMD sample

may have degraded the achievable fingermark quality.

Table 1 shows analysis of these samples using a CAST 5-point scale (from [23] and listed in the appendix). The non-treated Brass sample (Fig. 2G/H) showed greater than 2/3 ridge detail in the photos and the SKP image for the measured region i.e. a grade 4 recovery. By contrast, the vacuum treated surfaces in Fig. 2A/B/D/E showed only some evidence of the fingermark, in both cases for the photo and once for SKP resulting in a score of 1. The VMD treated surfaces (Fig. 2A/B/D/E) were generally more successful optically than using SKP with grades of 3 and 4 for Au-Zn and Au-Ag treatments respectively. The SKP resulted in grades of 4 and 1.

The relative humidity control system was used to investigate the effect of changing the relative humidity (RH) of the environment surrounding the Brass sample shown in Fig 2G to determine whether this improved the contrast between the metal and the fingermark. It was studied for high and low RH from 85% to 25%. We observed (not shown) that the mean work function of the surface was altered but the overall contrast between the fingermark ridges and surface remained constant with the standard deviation at 27 mV ± 1 mV so no enhancement was achieved.

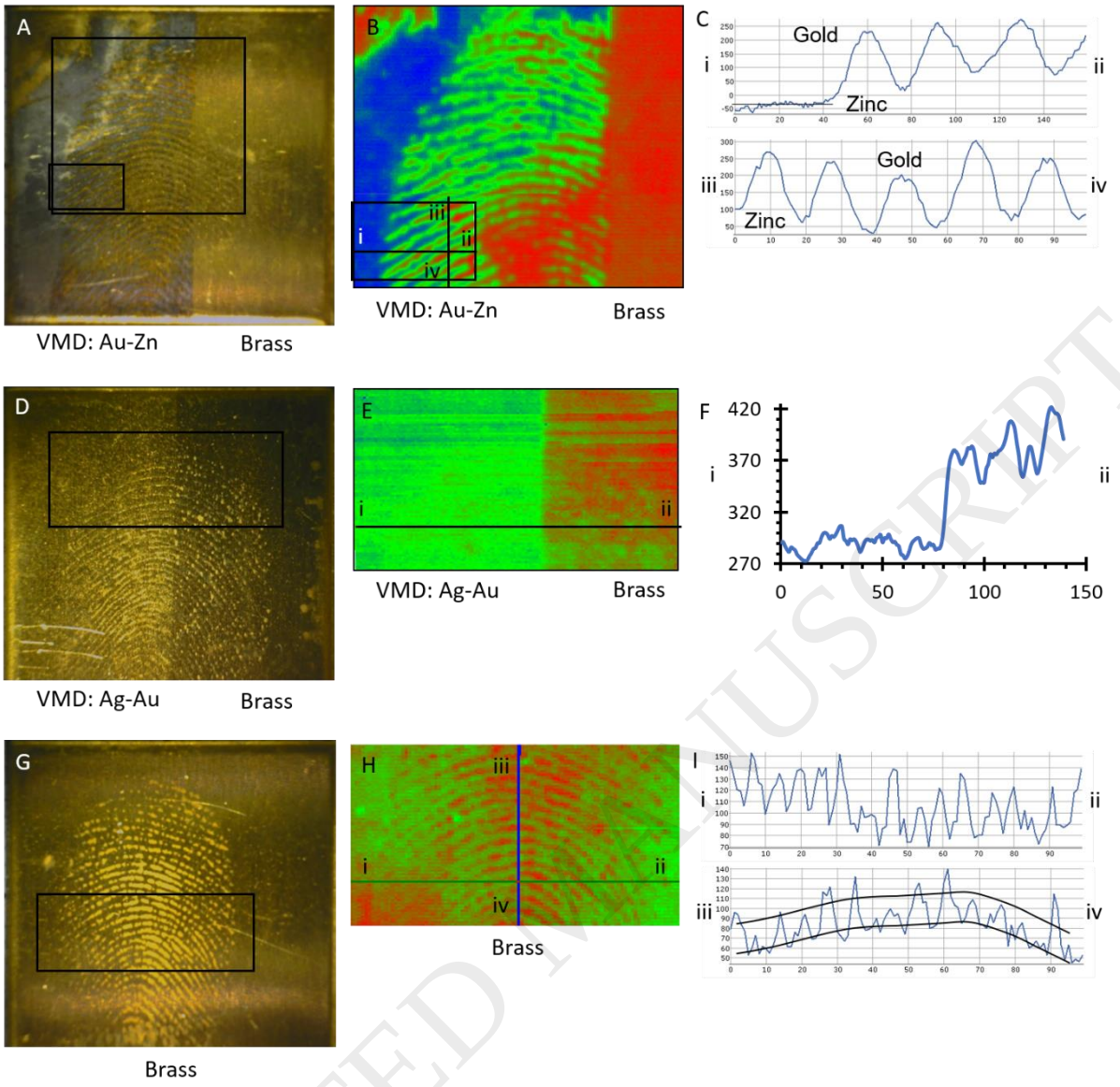

Fig. 2A. Optical (20 x 20 mm square) image of unloaded fingermark treated by Au-Zn VMD with untreated Brass on right side and SKP subsection shown by black border, **2B.** SKP image of unloaded fingermark with Au-Zn VMD and untreated Brass on right with region shown by black border in 2A and subsection, high-resolution SKP scan, **2C.** 150 mV CPD contrast (y) between fingermark ridges for i-ii and iii-iv labelled in 2B vs measurement points (x), **2D.** Optical (20 x 20 mm square) image of unloaded fingermark treated by Ag-Au VMD with SKP subsection shown by black border, **2E.** SKP image of Ag-Au VMD showing ridges visible on untreated Brass side. Region shown by box in 2E, **2F.** CPD (mV) contrast (y) between treated and untreated regions of 2D showing some small fingermark ridge variation on the Brass side vs measurement points (x), **2G.** Optical image of unloaded fingermark on untreated Brass surface with SKP subsection shown by black border, **2H.** SKP image of fingermark on Brass surface from region shown by black border in 2G, **2I.** CPD (mV) contrast (y) between fingermark ridges for i-ii and iii-iv labelled in 2H vs measurement points (x).

Figure	L Surface	Photo	SKP	R Surface	Photo	SKP
2A/B	VMD - Au Zn	3	4	Brass	1	0
2D/E	VMD - Ag Au	4	0	Brass	4	1
2G/H	Brass	4	4	Brass	4	4

Table 1. CAST scale (described in appendix) assessment of optical and SKP (Left and Right) fingermark

images

Different surfaces and fingermark types
Optical and SKP images (Fig. 3 top and bottom respectively) from eccrinous, unloaded and eccrinous/sebaceous fingermarks (3-4 months old) were measured on untreated Copper, Nickel and Brass surfaces. The CPD contrast between the fingermark and metal surface was 10 - 50 mV and is in this case a non-contact, non-destructive measurement method. Where fingermarks were visible optically, the scanning Kelvin probe image provided similar information with a lower spatial resolution determined by the tip size. However, in the case of the latent fingermark (Fig. 3, right), there was no optical information and the SKP measurement provided a clear fermi energy map of the surface.
It is important to note that all the SKP images presented are entirely unprocessed with no optical enhancement, filters, scaling or average functions applied to the measurement data. It should thus be possible to further improve the image quality with such functions if this is required or necessary. Each material is described in detail below:

Cu/CuO Eccrinous/Sebaceous Sample – 9 months old (Fig. 3A)
This sample had a mixture of eccrinous and sebaceous components. The SKP data was in good agreement with the optical image and has sufficient CPD contrast for at least 8 ID points to be identified (not shown). In this case, the light areas on the optical image correspond to the dark areas in the CPD image. The application of the fingermark caused a decrease in the work function of the material across the entire fingermark suggesting spreading of contact debris or a general corrosion effect on the metallic surface [25]. The work function modulation of the fingermark on the Cu/CuO is 10 – 20 mV p-p which is realistically the smallest difference that can be expected to be reliably detected.

Nickel Unloaded Sample – 6 months old (Fig. 3B)
The fingermark was visible optically and there was clear CPD / work function modulation by the fingermark ridges on this sample between 50 – 80 mV p-p. There is a correlation between the optical features of salt corrosion and peaks in the SKP image. The dark areas of the scan indicate ridge modulation and the light areas the flat metal background with no evidence of a change in work function across the entire fingermark area.

Brass Unloaded Sample – 4 months old (Fig. 3C)
The fingermark could be clearly identified and matched the optical image with the light areas corresponding to the ridge detail. There were some artefacts of the background material visible in the scan in addition to the work function modulation by the fingermark. The peaks corresponding to the fingermark ridges are well defined in the scan data with a clear work function modulation by the fingermark ridges between 30 – 50 mV p-p.

Brass Eccrinous Latent Sample – 1-60 hours old (Fig. 3D)
This latent fingermark was invisible under normal lighting conditions and SKP provided a very clear fermi energy map of the surface with 19 unique identification points (marked by red circles). This was the same information as is available from an ink fingermark covering the same area. The ‘speckle’ features on the background surface in Brass are due to grain boundaries within the metal corresponding to the Copper and Zinc components in the metal alloy. Fortunately, this does not impact on the recoverable information from the print. This scan was performed slowly on an initially fresh print over 60 hours. There was no difference in the SKP fingermark recovery performance over this time.

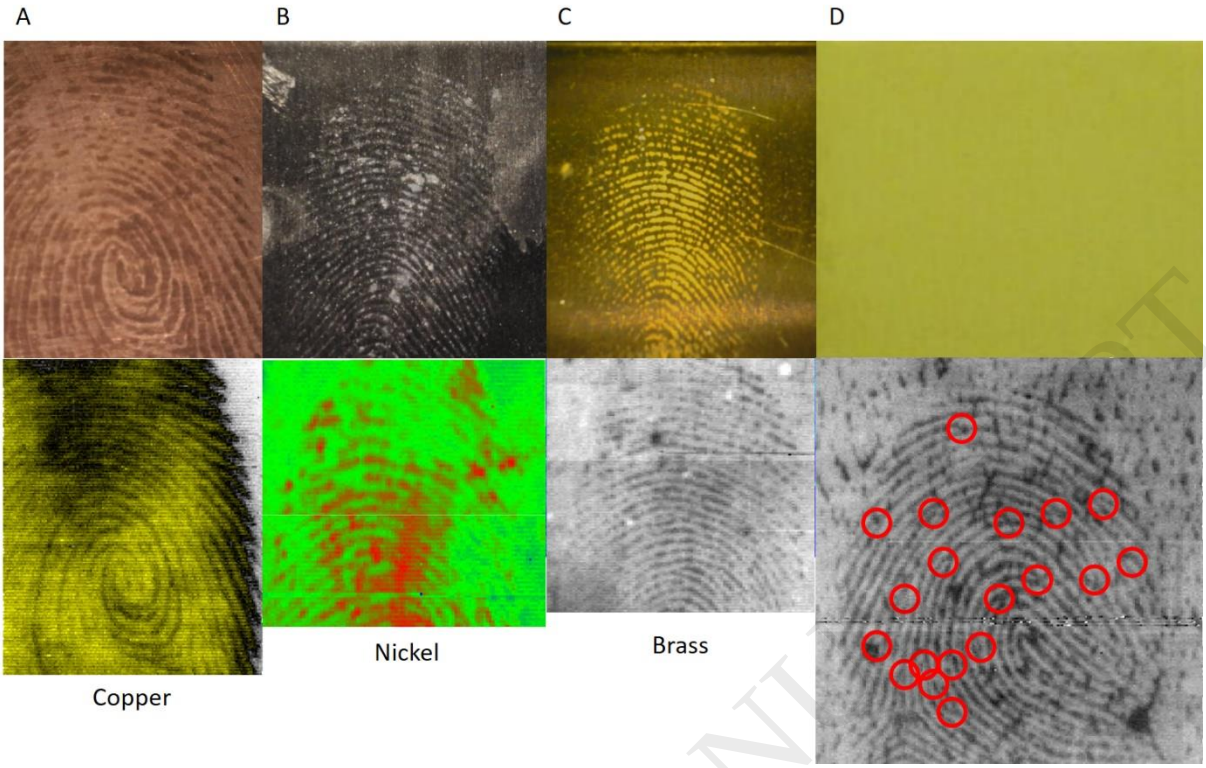

Fig 3. Top figures show, from left-to-right, A. Optical images for Copper (eccrinous/sebaceous fingermark), B. Nickel (unloaded fingermark), C. Brass unloaded fingermark and D. Brass eccrinous fingermark metal surfaces. The bottom images show the corresponding scanning Kelvin probe images of the fingermarks.

Sebaceous, unloaded and eccrinous prints were investigated to compare the SKP utility on different fingermarks. All sebaceous prints were visible optically and eccrinous fingermarks were found to be more commonly latent as previously observed on highly reflective surfaces [25, 26]. Ridge detail on the sebaceous prints was not visible using SKP (not shown).

Figure	Surface	Photo	SKP
3A	Copper	4	4
3B	Nickel	4	3
3C	Brass	4	4
3D	Brass	0	4

Table 2. CAST scale assessment of photo and SKP fingermark images (shown in appendix)

The fingermark SKP scans and corresponding photos from Fig. 3 were analysed using a CAST scale (shown in appendix) and results summarised in Table 2. The SKP images measured on Copper (3A) and Brass (3C/D) had a grade of 4 with greater than 2/3 clear ridge detail. The Nickel SKP scan was less effective resulting in a grade of 3. The photos were in general excellent with Copper (3A), Nickel (3B) and Brass (3C) having a grade of 4 but the last Brass sample (3D) was latent and had a grade of 0.

SKP works well on untreated fingermarks as we are imaging the direct effects of the fingermark on the metal surface. Therefore, unless the treatment increases this contrast, any

treatments may reduce the observable change on the metal surface. Therefore, within the forensic workflow, we would recommend that SKP is used at the start. As a non-contact, non-destructive technique a rapid scan with a larger tip could be performed prior to other tests and may offer the possibility to target areas for DNA recovery. If there is a possible fingermark contact region identified this could then be scanned with a high-resolution SKP to search for ridge detail. It may be possible to conceive of technical developments for typical metal object and likely fingermark areas e.g. a Kelvin probe on a robotic arm that could scan an object.

Comparison with SEM / EPMA Data

Copper

The Copper eccrinous/sebaceous fingermark was analysed using SEM and EPMA techniques to compare with the scanning Kelvin probe measurements. The regions where ridges contacted the metal surface show higher Oxygen, Chlorine and Sodium content than the background metal (Fig 4) and coincide with the CPD change observed using the scanning Kelvin probe (Fig 3). An increase in Sodium and Chlorine content on ridge contact is anticipated due to fingermark composition [27, 28]. There is additionally an enhanced higher Oxygen content suggesting that there is an acceleration of corrosion and an oxidation reaction in these areas. This provides confidence that the CPD measurements produce a 'true' fingermark image by unequivocally identifying the contact areas. The peaks in work function corresponded with the peaks in intensity of the Sodium, Oxygen and Chlorine images. The background substrate has a lower but non-zero Oxygen content indicating the existence of a natural oxide on top of the metallic Copper. Copper oxide is a semiconductor which allows the possibility of additional analysis methods, such as cathodoluminescence.

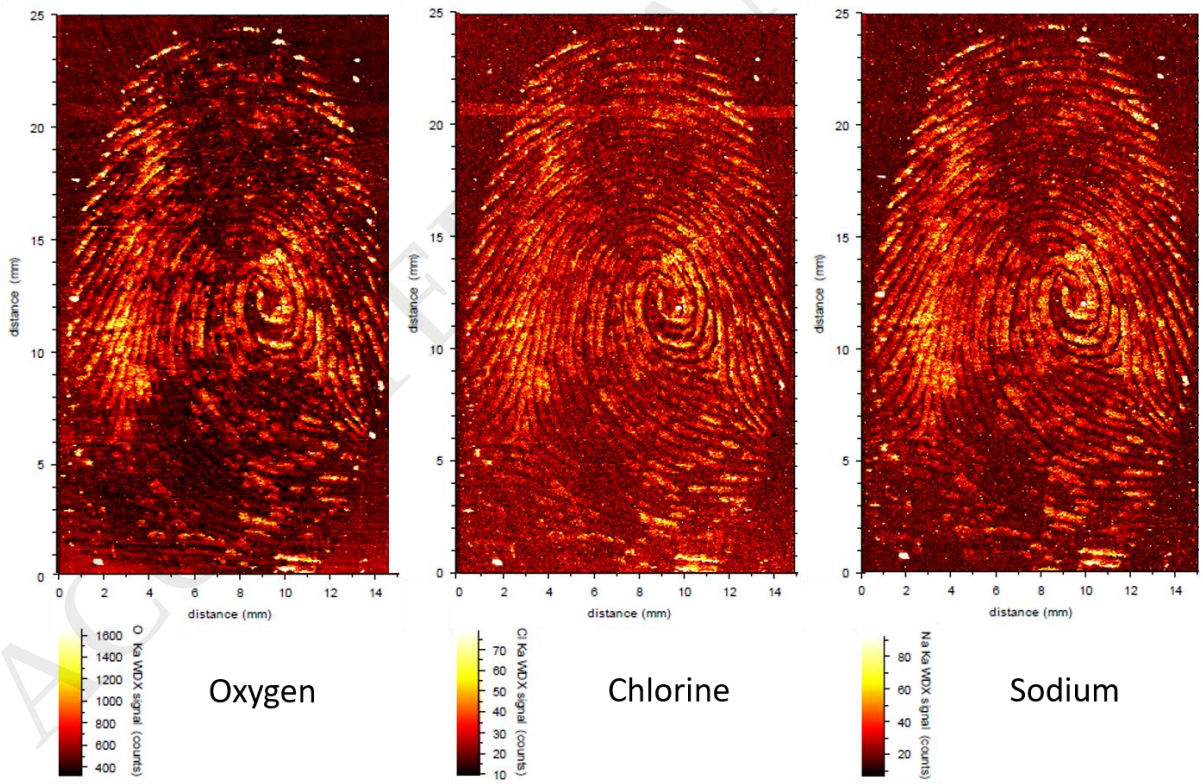

Fig 4. SEM/EPMA images for the Copper eccrinous/sebaceous fingermark also shown in fig 3 (left). The area contacted by the fingermark ridges shows a clear increase in Oxygen, Chlorine and Sodium components compared to background metal surface.

Brass

There is an increase in the Oxygen content at the fingermark ridges for the loaded Brass sample (see Fig. 5). The unloaded Brass sample showed a similar increase in Oxygen, Sodium and Chlorine content also (not shown). The carbon residue deposited on the surface by the fingermark ridges scatters the electrons less than the surrounding clean metal allowing a backscattered electron image to be measured (Fig. 5). The quality of the scans is excellent and the SEM/EPMA images the fingermark very effectively but, unlike SKP measurements, these techniques require a vacuum and high energy electron bombardment, which restricts later analysis.

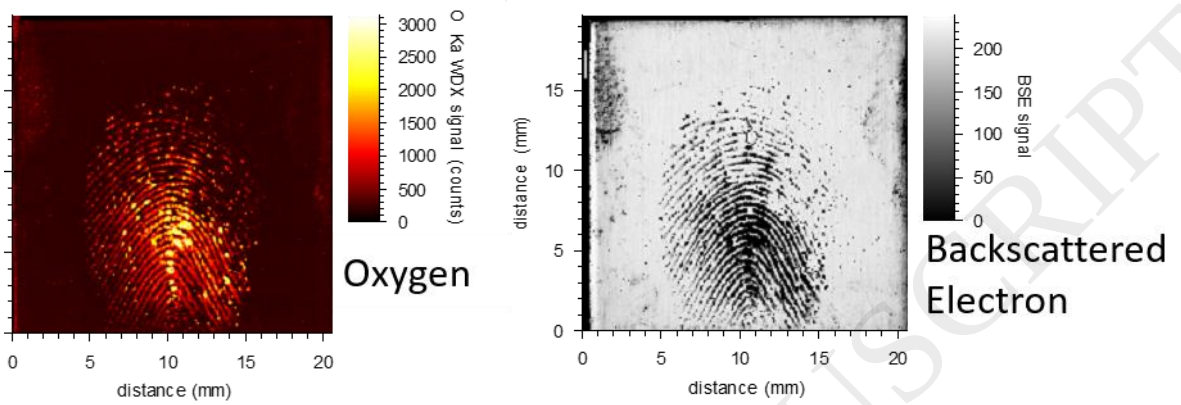

Fig 5. The SEM/EPMA Oxygen signal peaks in contact regions for fingermark on Brass (left). The fingermark is also observed in backscattered electron image (right) as the carbon deposits from the fingermark scattered the electrons less than the surrounding metal surface.

Cathodoluminescence

The fingermark on the oxidised Copper surface may be clearly observed in the cathodoluminescence scan (Fig. 6A) as the metal background is bright from the photon emission and the fingermark ridge contact areas are dark indicating no photon emission. The band gap of the semiconducting copper oxide surface may be observed in Fig. 6B as there is cathodoluminescence emission from Cu_2O at 2.17 eV from the background region. Interestingly, this provided the clearest data for this sample. Unfortunately, this cathodoluminescence technique is specific to the substrate surface of Copper and relies on the surface oxide signature. Also, unlike SKP measurements, the cathodoluminescence techniques require a vacuum and high energy electron bombardment, which restricts later analysis.

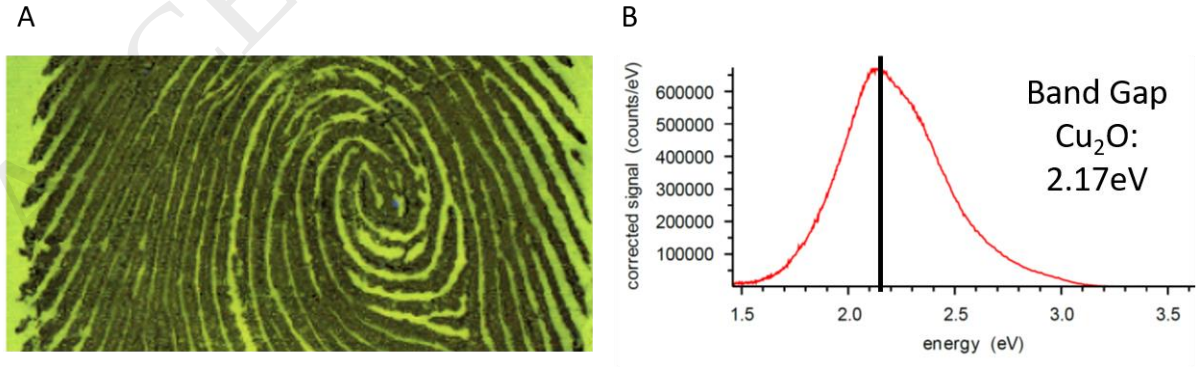

Fig 6A. Cathodoluminescence scan for Copper (eccrinous/sebaceous) fingermark shown in fig 3 (left) and fig 4. The fingermark ridges (dark regions) block the photon emission from the Copper oxide surface so imaging the print. **6B.** Analysed at a section well removed from the fingermark, the background oxidized metal surface emits light peaking at 2.17 eV, the band gap of Cu_2O.

4. Conclusions

A variety of scanning Kelvin probe tip sizes were investigated with a 1 mm - diameter tip found to allow the rapid screening of a metallic surface to discover areas of a fingermark and possible areas for DNA recovery before taking a longer scan to recover ridge detail and identification points. The ability to scan, pre-identify and then target fingermarks before processing for DNA allows an informed decision to be made as to the origin of each fingermark. The great advantage SKP offers here is an ability to differentiate between recovered marks and swab separately. This would be very relevant in situations where it could be assumed an object could have been handled by a number of individuals. To randomly swab the object would render interpretation of a resulting DNA mixture difficult if not unachievable. The scanning Kelvin probe technique worked best on non-visible eccrinous prints. Therefore, as a non-contact, non-destructive technique, we would recommend that a rapid screening scan could be undertaken at the start of the forensic workflow.

For the first time, SEM/EPMA was used to confirm that there was an increase in Sodium, Chlorine and Oxygen in the fingermark contact areas coinciding with a change in contact potential difference. This provides evidence of localised corrosion from a fingermark deposit. RH control was not found to increase the contrast of the sample. Use of SKP in conjunction with VMD provided mixed results with Au-Zn increasing the CPD contrast and Au-Ag removing the CPD contrast although both fingermarks were visible optically.

Although, metals may be a challenging surface for fingermark recovery, clean polished metals are ideal for SKP. Studies several months after the initial fingermark placement and scan showed the same details so we do not believe that time is a major factor providing that the relative humidity is not too high. It would be difficult to recover SKP scans from patterned metal surfaces but in principle there is no obstruction to the type of clean metal provided it was flat. We cannot comment on anodised or painted materials from the measurements undertaken in this pilot study.

Cathodoluminescence measurement could also be used to identify the fingermark on the Copper/Copper oxide surface due to the emitted photons being blocked by the fingermark. This emphasises the importance of considering the substrate material when analysing evidence.

In general, from the results of this phase 1 pilot study, scanning Kelvin probe worked best on untreated, non-visible, mainly eccrinous fingermarks and does not require vacuum or prevent further forensic analysis. This is encouraging evidence to suggest that the ambient scanning Kelvin probe, could provide a non-contact and non-destructive measurement technique for first stage analysis in serious crime investigation.

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6. Appendix

Grade	Detail Visualised
0	No evidence of a fingermark
1	Some evidence of a fingermark
2	Less than 1/3 clear ridge detail
3	Between 1/3 and 2/3 clear ridge detail
4	Over 2/3 clear ridge detail

Table 3: CAST assessment scale for grading developed fingermarks from [14, 23] used for analysis tables.