The forensic analysis of soils and sediment taken from the cast of a footprint

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Abstract

The routine production of a cast of a shoe-print taken in soil provides information other than shoe size and gait. Material adhering to the surface of the cast represents the preservation of the moment of footprint impression. The analysis of the interface between the cast and soil is therefore a potentially lucrative source of information for forensic reconstruction. These principles are demonstrated with reference to a murder case which took place in the English Midlands. The cast of a footprint provided evidence of a two-way transfer of material between the sole of a boot and the soil of a recently ploughed field. Lumps of soil which had dried on a boot were deposited on the field as the footprints were made. Pollen analysis of these lumps of soil indicated that the perpetrator of the imprint had been standing recently in a nearby stream. Fibre analysis together with physical and chemical characteristics of the soil suggested a provenance for contamination of this mud prior to deposition of the footprint. Carbon/Nitrogen ratios of the water taken from the cast showed that distilled water had been used thus excluding the possibility of contamination of the boot-soil interface. It was possible to reconstruct three phases of previous activity of the wearer of the boot prior to leaving the footprint in the field after the murder had taken place. This analysis shows the power of integrating different independent techniques in the analysis of hitherto unrecognised forensic materials.

1. Introduction

Following Locard's general principle that 'every contact leaves a trace' [1] it would be tempting to consider that the analysis of sediments and soils taken from the soles and uppers of shoes would show much similarity with that of a specific crime site where the person wearing the shoes would be considered to have walked. However, when investigating the similarities or differences of materials found on shoes compared to the comparator site it is clear that the supposed simple relationship is not quite so straightforward [2].

The main problem encountered when analysing and interpreting material from shoes is that the shoes are worn for some designated period of time (often quite a long time) after the crucial event. Thus, materials may well fall off shoes, or indeed be added to by materials from elsewhere during subsequent activity. Compounding this problem is the fact that the shoes may have already had material adhering to them prior to the forensic event. Further, consideration must be given to the representative nature of the sample collected from the shoes and indeed the amount of material available for analysis.

Analytical techniques available to the forensic scientist are numerous if one considers the range of techniques available in geochemistry, sedimentology and botany. A crucial problem here is to employ techniques with forensic rigueur rather than using purely geological procedures of interpretation. So, given that there is enough material available for analysis, and given that the samples analysed are representative both of

the material found on the shoe and also representative of the source sample from whence they came, it should be possible to afford a meaningful analysis, comparison and interpretation of results.

Whilst it is possible to provide carefully controlled and repeatable experiments to determine the presence, persistence and final preservation of sediments on different types of shoes, under different climatic conditions, and utilising different geological scenarios ([3],[4],[5]) there is no real substitute for analysis of an actual forensic investigation albeit with all the logistical restraints that accompany such a scenario.

2. Case Background

A young woman was out walking her dog in the early afternoon on a hot summers day in a rural area in the midlands of England. The path she took crossed a small bridge which forded a trout stream and ran parallel with the raised embankment of a railway line. The woman was brutally attacked and dragged onto the railway embankment through a patch of thistles and it was assumed that the attacker had attempted to lay her inert body across the railway track. The embankment proved too steep and the young woman was left at the bottom of the slope later to be found barely alive. She was taken to hospital where she died six days after admission. Tracker dogs at the scene followed a trail from where the girl was left, across the railway line into a field that had been ploughed on that very morning. Footprints could be seen tracking across the field. Plaster casts were taken of the footprints, primarily to ascertain the size of the suspect's shoes (with the intention of excluding the farmer as being the originator of the footprints. Subsequently, it was shown that the farmer had feet far too small for the footprints).

Suspicion fell upon a man who lived in the area and who was seen a few hours before the attack standing in the trout stream, whilst illegally fishing. When arrested the following day in relation to the attack on the young woman, two pairs of his shoes and his clothes were seized. The investigation centred, in part, on whether materials found on the accused's shoes and clothing were similar or not to the materials found at the crime scene and in the ploughed field (he had burnt some of his clothing the previous evening). He was asked when he had last worn his shoes, and he stated that he had worn one pair of shoes the previous day when he had helped lay a concrete path. He denied having been in the location about the crime scene at any time in the past. Analysis initially centred about a comparison of the materials taken from both pairs of shoes with the crime scene and field from where the tracker dog found the footprints in the recently ploughed soil. Subsequent analysis involved investigation of the footprint casts themselves. Physical, chemical and biological tests were employed during the subsequent laboratory investigation. Finally, a number of samples were taken from nineteen surrounding fields to act as exclusion samples and to provide an indication of the variation (if any) in the nature of the soil in the whole of the surrounding area.

3. Results

3.1 Binocular Microscopy

Simple low powered binocular microscopy was undertaken on the samples taken from the field, the cast, two pairs of shoes and the nineteen exclusion samples. The results are provided in figure 1 (samples from both pairs of shoes (1 and 2) were taken from the left and right shoe respectively). Perhaps the most striking occurrences identified in this analysis were the presence of very many small fibres of a large number of

colours and from a variety of different material types found particularly in the mud sampled at the plaster cast/soil interface (underneath the footprint indent into the soil). Various fibres similar in colour and material type to those found in the cast were also found in the soil from both the left and right of the second pair of shoes. One similar type and colour fibre in the field was also found on the left shoe of shoe 1. Indeed the cast mud contained thirteen different colours of fibre comprising cotton, synthetics and wool.

Animal hair was also identified within the soils of the field, the plaster cast and both pairs of shoes (left and right), although what appears to be unusual is that the hair in the mud from the cast and both pairs of shoes was cut, some at both ends. From the nineteen samples taken from surrounding fields no hair (or indeed fibres) were identified.

The visual mineralogy obtained by binocular microscopy showed that the field, cast and both pairs of shoes contained angular quart silt, rounded quartz sand, calcite and mica. With the exception of the mud taken from the left and right of the first pair of shoes (shoe 1L and 1R), all samples also contained feldspar, crystals and iron nodules. The nineteen exclusion samples taken from surrounding fields contained this basic mineralogy but also exhibited rounded purple shale pellets, limestone fragments and weathered ooliths.

The simple microscopy therefore, identifies the presence of an unusually large number of different coloured and different fibre types, animal hair which was cut, sometimes at both ends, and a series of common minerals associated with deposits of

river terrace material overlying limestone shale substrate. Of particular note is the general accord of particulates found from soils taken from the second pair of shoes (2L and 2R) with that of the cast and field samples.

3.2 Grain Size Analysis

Soil samples collected from the underside of the plaster cast, the field from which the plaster cast was taken, both the left and right shoes of shoe 1 and shoe 2 and nineteen samples taken from surrounding fields were analysed for their grain size distribution characteristics using a CILAS 720 laser granulometer. The rationale behind this analysis was to see if any samples could be excluded from having derived the area around the plaster cast. Grain size analysis is a tool best suited for description and possible exclusion, rarely can it be used as a diagnostic tool [6]. Further, when grain size analysis is undertaken on soil taken from a suspect's artefacts (shoes, clothing, vehicles etc.) the very homogenisation required of the sample prior and during analysis (by whatever technique) prevents any idea of previous or post event contamination from being considered and inevitably leaves exclusion or association an untested result.

Grain size distribution curves and cumulative percentage curves of the relevant samples are presented in figure 2. Visual inspection shows that there is very little difference in the grain size characteristics for the field, cast and both pairs of shoes (1L and 1R, 2L and 2R). This simple unimodal distribution portraying a strongly modal fine sand size found in soils samples from both pairs of shoes, from the field and the cast suggests that no exclusion can be made between site samples (field and cast) and those of either pairs of shoes. In contrast however, two samples selected

from the exclusion samples taken from surrounding fields can be shown not to be the source of the mud found on either pair of shoes. In all, the nineteen exclusion samples contain two groups of grain size distribution pattern. In the first group eleven samples have patterns which exclude them from having been the source of the material found on either pair of shoes, and in the second group, eight samples have the simple unimodal distribution identified from both pairs of shoes, the field sample and the mud from the cast. Thus, it can not be stated with any certainty whatsoever that the materials found on either pair of shoes could only have derived from one local provenance, indeed it would appear that they could have derived from many different locations (with reference only to the grain size distribution characteristics of the samples).

3.3   Chemistry

Chemical analysis of the eight soil samples taken was undertaken in order to determine the pH and conductivity of the soil samples together with atomic absorption spectrophotometry (AAS) and Dionex analysis (to identify cation and anion concentrations of the most common elemental types present in the soil). Results are presented in figures 3 and 4. Bearing in mind the general variability of soil within one distinct soil type, it is interesting to note that a hierarchical clustering technique which identifies an index of dissimilarity (figure 4) on the basis of simple chemical analysis provides compellingly simple interpretation of this data. The dendrogram demonstrates that both soil samples from the first pair of shoes (1L and 1R), whilst similar to each other, are very dissimilar to the soil samples taken from second pair of shoes (2L and 2R), the cast and the three field sample sites (which are themselves very similar to each other). The soil samples taken from the cast and the second pair

of shoes (2L and 2R) are in turn very similar to each other. The soil samples taken from the field are most similar to the soil samples taken from the cast and the second pair of shoes (2L and 2R). The soil samples taken from the first pair of shoes (1L and 1R) can be excluded from having the same provenance as the field sample sites, whilst the soil from the cast and the second pair of shoes (2L and 2R) can not.

3.4   Palynology

Soil was recovered from field sample 1, from soil adhering to the footprint plastercast and from both pairs of shoes belonging to the suspect (left and right). $1cm^3$ sub-samples were prepared for pollen analysis and counted using techniques outlined in Moore *et al.* [7] including the hydrofluoric acid and acetolysis stages. The pollen residues were stained with safranin and mounted in glycerol jelly. Counts were made using a Nikon Eclipse E400 light microscope under bright light with phase contrast being used for critical determinations. The pollen nomenclature is based on Clapham *et al.* [8]. The results from the six samples are presented below and summarised in figure 5.

3.4.1   Field Sample 1

On the whole the pollen was not in a good state of preservation. Many grains were degraded and crumpled. The sample was dominated by Gramineae (grass) with high numbers of Compositae Liguliflorae (dandelion family) present (figure 5). These grains are resistant to decay and have a very thick, distinctive exine. Also present were a number of Cerealia (cereal) pollen grains. These are large grains of the same family as Gramineae. They exceed 40μm and have a large annulus   (over 10μm). The majority of these grains were larger than 60μm which fall into the *Triticum/Avena* (wheat/oat) size class.

Low frequencies of tree and shrub pollen were present (figure 5). *Ilex* is relatively unusual in that it is insect pollinated and thus very low quantities are released, therefore the numbers encountered would suggest a very local origin. Non arboreal pollen over 1% of the Total Pollen Sum included Brassicaceae (brassica family) and *Trifolium* (clover).

3.4.2   Sample from cast

The sample taken was carefully removed from the soil contact with the sole of the plaster cast from all over the impression. In general the composition is very similar to that from the field soil sample i.e. dominated by grass, with high levels of Compositae Liguliflorae. On the whole, the grains were crumpled and degraded. The sample did however have a greater number of different taxa present (figure 5). This included three well preserved pollen grains from aquatic species (the highly distinctive *Nuphar* (water lily) see figure 6 and *Menyanthes* (bogbean)). Also present were Cereal grains mainly from the *Tritcum/Avena* size class, Brassicaceae and *Trifolium* as well as *Ilex*.

3.4.3   The second pair of shoes (2L and 2R)

The overall composition of these two samples is almost identical, with only very minor differences. The samples have the greatest number of different species present (figure 5). The samples were dominated by Gramineae with Compositae Liguliflorae and Compositae Tubuliflorae. Spines and a seed of *Cirsium* (thistle) were also recovered during the preparation stages. Also present were a large number of Cerealia grains (large size *Triticum/Avena* class). *Ilex* was again present in both of these samples, so too were a number of aquatic grains including *Typha* (bulrush), *Nuphar* and *Menyanthes*) which were in good condition.

3.4.4 The first pair of shoes (1L and 1R)

These two samples were similar to one another. They are dominated by Gramineae with Compositae liguliflorae present at fairly high frequencies (figure 5). Unlike all the other samples examined they contained no *Ilex* or Brassicaceae. Between them they only contained three Cerealia grains. They were only just over 40 μm and not in the 60μm category as many of the other grains encountered in the other samples were. No aquatic pollen was found.

3.4.5 Discussion

The pollen diagram (figure 5) shows the close resemblance between the soil from the field and those adhering to the plastercast. However the plastercast had a number of unusual grains that were not found within the field. These include pollen grains from aquatic and waterside plants including *Nuphar* and *Menyanthes.* These were considered important given that the footprint was located some distance and uphill from the river. The samples from the first pair of shoes (1L and 1R) vary considerably from the soil in the field and the plastercast, note for example the high values of Pinus. The second pair of shoes (2L and 2R) exhibit a resemblance to the field sample (Field sample 1) and plastercast (designated Cast). Of importance is the presence of *Nuphar* and *Menyanthes* from this pair of shoes, both of which were found in the plastercast sample.

3.5 Carbon Nitrogen ratio analysis

Because there were many different types of deposit found at the interface between the field soil and the plastercast of the footprint, a method was needed to determine whether there had been an accidental introduction of particulates (particularly palynomorphs) when water was added to the plaster at the site of the footprint where

the cast was taken. Although training manuals determine that scene of crime officers used only distilled water to produce plaster, the distance that the water had to be carried from the police vehicle, past the river and on to the field approximately 1000m away, necessitated that a check be taken to determine whether river water had been inadvertently introduced by either the scene of crime officer or even the police dog.

Samples were prepared for carbon nitrogen ratio analysis in order that comparisons could be made between land derived carbon and nitrogen (which would be relatively low) with aquatic derived carbon and nitrogen (which would be relatively high in comparison; for example [9]). Analysis of mud from the cast would also show if there had been any contamination of the soil by materials derived from aquatic sources (introduced by the scene of crime officer or the police dog). The CN ratios of the mud from the cast approximated 7.0, whereas the CN ratios of the field mud (sample 1) approximated 7.1. In contrast, the CN ratios of shoe 2 left and shoe 2 right were 10.6 and 8.9 respectively. These higher numbers may be explained by the addition of river or lake water onto the mud on the shoes or conversely from mud found in river or lake water. The conclusion of this analysis suggests that the water used to make the plaster cast did not contaminate the field mud at the interface of the plaster cast.

4.   Synthesis

The results of this case study involving the analysis of mud blocks found at the plaster cast/soil interface have provided some most interesting corollary results very reminiscent of Locard's 'every contact leaves a trace'. Although with hindsight, it

seems obvious that a two-way transfer of materials will take place when a person runs across a muddy field, actual case work examples are few and far between.

The main problem of forensic geoscientific investigation of a footprint or footwear, either in a field or on the sole of shoes or boots is that of 'contamination'. In order to compare two samples, assessment has to be made of the material which exists on the shoe prior to the forensic event and indeed material found on the shoe immediately after (and in some cases much later than) exit from the crime scene. Any analysis which involves the bulk collection of material from a shoe or from a forensic site will inevitably incorporate various stages of contaminants. Analysis of the bulk material by chemical means (or particle size analysis) in effect homogenises the sample and produces, unknowingly the possibility of false-positive or even false-negative results. This case enabled specific targeted collection of discrete materials which themselves could be compared to known provenances from where, for example, the footwear had been prior to the forensic event (home garden, river and field). Thus, comparison could be successfully undertaken. The results of analysing the discrete mud lumps have shown that, by binocular investigation, various materials were present both on the plaster cast and on the footwear. Such materials included multi-coloured fibres, animal hair (some of which was cut), a discrete suite of minerals (albeit common minerals to the area), a range of particle size distributions which failed to exclude the comparison between plaster cast mud and footwear and a large range of pollen grains which provided an extremely significant distribution of exotic subaqueous palynomorphs both on the cast and one pair of shoes (2L and 2R). Indeed, pollen analysis together with chemical elemental analysis was able to exclude the first pair of

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shoes (1L and 1R) as having derived their mud from an area similar to that where the plaster cast was taken.

Surface texture analysis of quartz grains provided a quartz grain assemblage from the materials taken from the plaster cast which could not be excluded from having derived from the same area as that of the suspect's primary shoes. However, it was not possible to develop this investigation any further given the paucity of grain size available for analysis.

Checks were made to determine whether the assemblage of distinctive subaqueous derived pollen grains which were found rather surprisingly on the plaster cast/soil interface, could have derived from river water which may have been mixed with the plaster in order to make the cast. CN ratios identified that the plaster cast was indeed made from water derived from laboratory sources rather than lakes, rivers or other sundry sources.

Perhaps the most important thing which derives from this study is the necessity for sample analysis by independent analytical techniques. It would be foolhardy to consider the colour of a sample and also investigate its mineralogy and bulk chemical composition since all three techniques will have results dependent upon each other to a greater or lesser extent. Here we have used physical characteristic techniques together with chemical and biological forensic techniques to build a picture of the provenance of the mud found at the plaster cast/soil interface. Given the number of techniques employed, it may be significant that it was still not possible to exclude the mud lumps from materials found on the shoes of the suspect. These results may be

considered surprising since the suspect denied ever having been at the field site, or indeed having made the footprints in the field.

5.   Acknowledgements

List of Figures

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