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Soil transference patterns on bras: Image processing and laboratory dragging experiments

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ABSTRACT

In a recent Australian homicide, trace soil on the victim's clothing suggested she was initially attacked in her front yard and not the park where her body was buried. However the important issue that emerged during the trial was how soil was transferred to her clothing. This became the catalyst for designing a range of soil transference experiments (STEs) to study, recognise and classify soil patterns transferred onto fabric when a body is dragged across a soil surface.

Soil deposits of interest in this murder were on the victim's bra and this paper reports the results of anthropogenic soil transfer to bra-cups and straps caused by dragging. Transfer patterns were recorded by digital photography and photomicroscopy.

Eight soil transfer patterns on fabric, specific to dragging as the transfer method, appeared consistently throughout the STEs. The distinctive soil patterns were largely dependent on a wide range of soil features that were measured and identified for each soil tested using X-ray Diffraction and Non-Dispersive Infra-Red analysis.

Digital photographs of soil transfer patterns on fabric were analysed using image processing software to provide a soil object-oriented classification of all soil objects with a diameter of 2 pixels and above transferred. Although soil transfer patterns were easily identifiable by naked-eye alone, image processing software provided objective numerical data to support this traditional (but subjective) interpretation.

Image software soil colour analysis assigned a range of Munsell colours to identify and compare trace soil on fabric to other trace soil evidence from the same location; without requiring a spectrophotometer. Trace soil from the same location was identified by linking soils with similar dominant and sub-dominant Munsell colour peaks.

Image processing numerical data on the quantity of soil transferred to fabric, enabled a relationship to be discovered between soil type, clay mineralogy (smectite), particle size and soil moisture content that would not have been possible otherwise. Soil type (e.g. Anthropogenic, gravelly sandy loam soil or Natural, organic-rich soil), clay mineralogy (smectite) and soil moisture content were the greatest influencing factors in all the dragging soil transference tests (both naked eye and measured properties) to explain the eight categories of soil transference patterns recorded.

This study was intended to develop a method for dragging soil transference laboratory experiments and create a baseline of preliminary soil type/property knowledge. Results confirm the need to better understand soil behaviour and properties of clothing fabrics by further testing of a wider range of soil types and clay mineral properties.

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1. Introduction

In a recent homicide matter in Australia [1,2], the results of soil examinations were the only forensic science evidence obtained in the case. Despite burial for eight days in natural soil in neighbouring parkland, the mineralogy and descriptive characteristics of trace soil on the victim's clothing and shoes showed an extremely strong degree of comparability of originating from distinctly different anthropogenic soils from the victim's place of residence [1–4]. This forensic evidence indicated the victim could have been attacked at her home and then transported to the burial site. An important question that arose in the trial was whether the soil from the victim's residence had been deposited by the action of dragging the body across the surface. The trial was before a judge and he concluded that there was no clear evidence to support the dragging proposition and that casual transfer of the soil could not be excluded [1,2].

Current forensic soil examination has a range of sophisticated analytical techniques available to compare soil with possible places of origin and can provide compelling evidence for an association with a suspected source [5–13]. As documented by Sugita and Marumbo [14], variations in soil colour provide one of the most distinguishing characteristics of trace soil evidence.

However in the homicide matter referred to above, the important question was not about the complexities of soil science but the much more fundamental question of how the soil was deposited on the clothing. A search of the literature revealed an absence of any studies into this topic. Studies to date have mostly involved the transfer of manufactured materials [15] such as powder [16], glitter [17,18], glass fragments [19], acrylic and wool fibres [20–23]. There has been no recent research focusing on the transfer of soil particles onto textile fabrics since Locard [24]. This identified a need for systematic studies to be conducted to determine whether a range of soil types deposited by dragging produced characteristic features that would allow this mode of transfer to be inferred [25].

The dragging method of soil transfer to fabric alleged during the homicide matter inspired this paper's soil transference experiments. Relatively abundant soil deposits were on the victim's bra [1–4]. This item of clothing was therefore selected as the starting point for a series of soil transfer experiments (STEs) conducted on a range of natural and anthropogenic soils from Royal Tasmanian Botanical Gardens, Hobart, Tasmania, Australia [26].

One of the earliest studies into transfer and persistence was that of Pounds and Smalldon [20–22] who investigated the transfer of textile fibres. They achieved fibre transfer by pushing a weighted fabric across an underlying fabric. This methodology was adapted for our studies for a range of soil transference experiments (STEs) where weighted bra-straps and cups were used to simulate a victim dragged across soil. Image processing software was adapted to analyse digital photographs of the soil patterns produced in the STEs to provide an objective methodology for determining the characteristics caused by dragging.

Classifying soils for a particular purpose involves the ordering of soils into groups or types with similar properties and for potential end uses. In general, soil classification systems currently used in most countries involve the use of the following three broad approaches [27].

- General-purpose broad soil classifications such as World Reference Base [28] or Soil Taxonomy [31], which communicate soil information at international scales; and national scale classifications, such as Australian Soil Classification [29], shown in Table 1.
- State, provincial or regional soil classifications, which are designed both to assist with "user-friendly" communication of soil information and to account for the occurrence of soils that impact on existing and future industry development and prosperity [27].
- Special-purpose and more technical soil classification systems, which are used for local or single-purpose applications such as in Soil Forensics [27]. These special-purpose systems generally involve using plain language names for soil types (e.g. anthropogenic, gravelly sandy loam soil or natural, organic-rich soil) for users such as police [27] but must also correlate with the general-purpose international and national classifications.

The soil classifications used in this paper incorporate international and national general-purpose classifications as well as a local special-purpose soil classification system as shown in Table 1; to be of global relevance to the greatest number of forensic investigators and researchers.

2. Materials and methods

2.1. Soil samples

Forensic soil examination is complex because of the diversity and heterogeneity of both naturally occurring soils (e.g., crystalline minerals, organic matter) and anthropogenic soils that often contain very small, sometimes even trace amounts of manufactured materials such as brick fragments and road gravel. Such diversity and heterogeneity have enabled forensic soil examiners to distinguish between soils, which may appear to be similar [5–11].

Murray et al. [26] contains detailed soil morphological descriptions and classifications on the 5 anthropogenic soils (Technosols, Anthrosols or Human-altered and Human-transported (HAHT; [31] soils) and 2 natural soil samples, which are summarised in Tables 1 and 2. Five anthropogenic and two natural soil samples originated from the Royal Tasmanian Botanical Gardens (RTBG) in Queens Domain, Hobart, Tasmania, Australia (Fig. 1). The natural soil type in the RTBG classify as Dermosols (a light clay over heavy black clay) [29] or Cambisols [28]; but the majority of these grounds in the RTBG (green cross-hatched area) have been radically modified to create roads, walls, specialty gardens and smooth flat lawn surfaces [30] (Fig. 2). As a consequence, the dominant soils in the RTBG and on Hobart's waterfront as shown in Fig. 1 (shaded a purple colour) comprise the following anthropogenic soil types:

- Anthroposols in accordance with the Australian Soil Classification [29] or,
- Technosols and Anthrosols in accordance with the World Reference Base [28].
- Human-altered and Human-transported material (HAHT) as defined in Soil Taxonomy [31].

Five samples were classified as Anthroposols, with four containing high amounts (90%) of gravel (>2 mm); including one with brick fragments (Table 1). Anthroposols are characterised by a strong spatial heterogeneity (Fig. 2) and usually contain a large array of known historical information such as brick fragments, which has been proved very useful in understanding and quantifying soil differences in forensic soil comparisons [6–13]. Two natural soil samples were taken from distinct horizons of one soil profile on the SE boundary. The top horizon consisted of undecomposed leaf matter, taken from 5 to 0 cm above the soil surface; with a second horizon of underlying mineral soil.

Analysis of carbon contents (by NDIR) and mineralogy (by X-ray diffraction) was undertaken on all soils except a non-mineral based horizon consisting of undecomposed leaves, because it did not