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Forensic Importance of Soil Evidence: A Review

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Abstract

Soil is a heterogeneous mixture of inorganic minerals, organic materials and biological matter the consistency of which varies horizontally and vertically along the surface of earth. This inconsistency arises because the factors which influence the formation of soil - temperature, rainfall, humidity, atmospheric pressure and composition of parent rocks - differ from place to place. It is therefore pertinent that the soil of one location is different from that of another location not only in its chemical constituents like ions, polymers and carbonaceous deposits, but also in physical parameters like color, texture and density. Such diverse characteristics serve as identification markers for different units of landscape and make soil a valuable evidence to link a suspect to the crime scene.

Keywords: Soil analyzes; Soil comparison; Soil density; Soil evidence; Soil particles.

Introduction

Soil is a biogeochemical material that forms the top layer of earth's crust. Its composition, however, is not uniform in all segments of the land's surface. The heterogeneous composition is attributed to climatic, weathering and anthropogenic factors which show marked variations with respect to distance.[1] This means that soil in a specific area shows unique physical, chemical and biological characteristics vis-a-vis its counterpart in an adjacent area.[2] If one or more of these unique characteristics of soil gathered from a site of criminal activity matches with soil retrieved from a person or an artifact, then that person or that artifact stands associated with the crime scene.

The significance of soil evidence in solving crime cases is reviewed in this communication.

Soil as Forensic Evidence

Its complex heterogenity notwithstanding, the natural state of soil is in form of particulates. On the basis of the size of particles, three broad components of soil may be identified: Clay, silt and sand. Clay particles have the smallest grain size and sand particles have the largest. The fine clay particles, the coarse sand particles and the moderate-size silt particles, when taken together, define the texture of soil.

Due to its particulate nature, soil gets easily transferred from object to object, person to person or object to person[1]. The transfer may take place from the crime scene to items like shoes, garments or tires and subsequently from that item to another surface. The former is called primary transfer, the latter secondary transfer. This transfer-ability brings to the fore the Locard exchange principle[3],

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which states that when two objects meet there is an exchange of matter. The matter being exchanged in this case is soil, the individualistic character of which can be traced back to the crime scene.

To validate soil as crime scene evidence, two sets of samples are required: Questioned samples and control samples. The questioned samples are those which are collected from an evidentiary object like tire, wheel well, garment, shoe or digging tool. The control samples are those which are intentionally picked up from and around the crime scene for comparison with questioned samples. The objective of the forensic soil analyzes is to ascertain whether or not the two sets of samples originated from a common location.

The degree to which the questioned samples adhere to an artifact depends on the nature of soil particles, nature of host surface and environmental conditions. Fine particles of clay and silt have a better capacity to stick to an object than the coarse sand particles. Dry soil has a better tendency to get retained on fleece clothing material due to electrostatic attraction, while wet soil adheres to almost all types of garments with equal ease.[4] Likewise, humid soil transfers to a greater extent to shoes than dry soil. The shoe profile, shoe size and the walker's weight too influence the quantum of soil transfer, but to a lesser extent.[5] Morgan et al.[6] studied the amount and persistence of soil in relation to the shoe profile. It was observed that while walking, the sole retained lesser amount of sediments from earlier locations and greater amount of sediments from later locations. However, the arch area of the shoe retained a higher proportion of soil particles from previous locations. The high relief soles that incorporate recessed areas too retained a higher amount of soil transferred from earlier locations. The inner lining of the shoes had deposits of soils from multiple locations.

Comparison of Soil Samples

The questioned and control sets of soil samples may be matched by a host of qualitative and quantitative techniques. At times, one technique may prove insufficient and further corroboration may be required for final validation. For example, optical microscopy may shed light on the color and texture of coarse sand particulates, while clay minerals may have to be analyzed by X-ray diffraction patterns. What is important is that the methods should be accurate, cost-effective, practical and applicable to both trace and bulk amounts of samples.[7]

If unique particulates, aggregates, rock fragments or biological matter are spotted in soil samples, these should be isolated from the bulk material. In case these constituents are found in both sets of samples, then greater emphasis should be placed on their analyzes. On the other hand, if examination under a low-powered microscope reveals marked differences between questioned and control samples then further comparison tests may be ruled out.[8]

The following are the common techniques that are used for matching or discriminating questioned and control soil samples.

Color comparison. Soils at different locations contain variable minerals and hence show distinct color. For example, lime-rich soils are white or gray; humus-rich soils are black or dark; iron oxides impart yellow or brown color to soil. It is therefore possible to associate the questioned samples of soil to a specific area. The comparison is carried out on the basis of Munsell systemwhich is based on three parameters:Hue (base color), chrome (color intensity) and value (lightness).[9] Thus it is possible to carry out side-by-side comparison of soil samples with standard colored chips.[10]

However, for meaningful discrimination of soils, color comparison should not be carried out on raw samples, but on pre-treated ones. For example, Dudley[11] compared the color of soil samples after air-drying, after moistening and after ashing at 850°C for 30 minutes. In this study comparison after ashing was most fruitful, that after moistening least. Sugita and Marumo[12] advocated that due to the presence of organic matter and iron oxides the actual shade of the soil gets masked. Therefore, in addition to air-drying, moistening and ashing, they suggested two more pre-treatment steps: Decomposition of organic matter and removal of iron oxides. This study concluded that ashing or moistening did not enhance discrimination of dark colored soil samples. Nevertheless, a combination of air-drying, decomposition of organic matter and removal of iron oxides enabled 98% of soil samples to be discriminated. Likewise, Janssen et al.[13] suggested that color comparison should be made only among the clay fraction of soil samples after isolating these from rest of earthy material.

Comparison of Particle Size Distribution. Gauging the relative abundance of mineral particles of different sizes in questioned and control soils is yet another way of linking the two samples to a common location. Particles of the same size may be matched visually with the aid of a hand-held lens or a low-powered microscope and there after their relative abundance in soil samples may be elucidated. However, before undertaking this exercise, it is first necessary to segregate the soil particles on the basis of their size. This is done by straining the soil through sieves of different pore diameters (Fig. 1). Straining may be carried out by two modes: Dry sieving and wet sieving.[14]

Fig. 1:A set of sieves mounted on a shaker for straining soil

Dry sieving is a simpler method, but requires a relatively large amount of sample.[15] Moreover, if the soil is rich in clay fraction, the results of dry sieving are erroneous. The reason being that the fine clay particles easily coalesce to form lumps and defy straining. Nevertheless, these are easily segregated and strained by wet sieving since on shaking with water the aggregates break down.[16]. Even otherwise, wet sieving gives better results, although it is more complicated as compared to dry sieving.[14,17] Marumo and Sugita[18] recommended wet sieving for fine fractions and dry sieving for coarse fractions in soil samples. Particle size distribution was examined by Dudley[19] using coulter counter technique and by Wanogho et al.[20] using laser diffraction technique.

Comparison of densities. Since soils collected from different locations have diverse mineral content, their densities vary. This factor assists in comparing the questioned and control sets of soil samples.

When soil particulates are placed in a liquid medium, either of the following phenomena will occur.

(a) The particles will waft on the surface if their density is less than that of the liquid.

(b) The particles will sink to the bottom if their density is more than that of the liquid.

(c) The particles will float in the middle of the column if their density is equal to that of the liquid.

In the density gradient method a mixture of two liquids, having a wide difference in their densities, serves as the medium. Commonly used liquids are bromoform (density = 2.89 g cm-3) and bromobezene (density = 1.5 g cm-3). Several aliquots of mixtures containing variable proportions of these chemicals are prepared. Each aliquot has a different density. These aliquots are then added to tubes of 25-40 mm length and 6-10 mm diameter in such a manner that a density gradient is created. The bottom most layer is of the aliquot having highest density, while the topmost layer is of the aliquot having lowest density. The intermediate layers are so arranged that each has a density less than the one below it and more than the one above it.[21] When the questioned soil sample is added to the density gradient tube, it will float in that layer of aliquot with which its density matches. If the control soil too floats in the same layer, then there is a likelihood that the two samples have a common origin.

Although density gradient column is a traditional method, it is beset with shortcomings and therefore for final validation the results of this test must be corroborated with those of other comparison procedures. For example, Chaperlin and Howarth[22] held that the comparison of density gradient patterns is dependent on the observer so that the consistency of results becomes questionable. In an endeavor to improve the performance of this method, Petraco and Kubic[23] replaced the bromoform/bromobenzene pair by Clerici's solution (saturated solution of thallium malonate-formate)/distilled water pair. The density gradient range increased from 1.50-2.89 g cm-3 to 1.00-4.24 g cm-3 thereby covering the densities of all mineral constituents of soils.

Comparison of organic matter. The most straightforward way of elucidating the proportion of organic matter in soil is to heat the sample in an electric furnace. The loss of weight on combustion reflects the total organic content.[7] Alternately, the organic compounds may be decomposed oxidatively by hydrogen peroxide and the loss in weight recorded.[24] It is also possible to extract the organic matter in non-polar solvents and carry out the high performance liquid chromatography of the dissolved phase.[25,26] The chromatograms of the questioned and control samples may then be compared. Pyrolysis gas chromatography, in concert with mass spectrometry, may be used to fragment the organic derivatives in soil. The resulting pyrogram of questioned and control samples may then be compared peak-by-peak.[27]

Comparison by microscopy techniques. Examination of soil samples under a binocular microscope provides an accurate means of mineral identification in the questioned and control evidence. Presence of identical rock particles not only assists in sample-to-sample association, but also predicts the geological location of the crime scene.[28] Similarly, mineralogical information on sand particles can also be obtained by examining soil samples under binocular microscope. This information, in turn, may be extrapolated to elucidate relationship between questioned and control sets.[29,30] Likewise, thin sections of soil when mounted on a glass slide and visualized under a petrographic microscope, reveal important information on rocks and minerals, as well as on biological matter.[31] For more sophisticated work, a scanning electron microscope or a transmission electron microscope may be used to magnify mineral particles and pollen spores by almost one lakh times, thus paving the way for identification, discrimination and comparison.[32-34]

Comparison by instrumental methods. The clay minerals present in soil are too small to be examined by optical microscopy. Hence when soil rich in clay component is encountered at the crime scene, one has to take recourse to instrumental methods of analyzes. The most commonly used technique is the X-ray powder diffraction or XRD. Prior to using XRD, the organic matter and iron oxides are removed and the remnant soil sample is crushed to a very fine powder. When X-rays are impinged on the powder, a diffraction pattern, specific to each mineral, is produced on a film. The questioned and control samples may be matched or discriminated on the basis of their diffraction patterns.[35]

Diffuse reflectance infrared fourier transform or DRIFT method is non-destructive in nature and identifies organic matter, clay minerals and quartz in soil by virtue of the peaks of vibrational frequencies pertaining to the functional groups present in these naturally occurring substances. These peaks occur in the mid-infrared region of the electromagnetic spectra.[36,37] Magnetic susceptibility determination is useful to detect magnetic minerals like magnetite and maghemite that are present in soil in such trace amounts that these defy detection by XRD or DRIFT.[31]

Collection and Preservation of Soil Evidence

Although soil is essentially non-biodegradable, yet when encountered as forensic evidence, its collection and preservation must be prioritized since its integrity is compromised either due to natural phenomena like rainfall and wind or due to anthropogenic interventions like trespassing or overstepping.[2,38] As is the protocol, before packaging the soil samples, the scene should be properly documented by way of photographs and sketches.[2,31] Each evidentiary item bearing soil should be photographed and its location should be duly indicated. Wherever relevant, the depth of the location should also be recorded. The impression evidence should be documented before and after casting. The geographical coordinates of the site, along with its topography should be noted. The sites from where control samples are collected should be marked on the map.

The commonly used tools for collecting questioned soil samples are (a) dental pick; (b) microspatula; (c) forceps; (d) soil corer; (e) trowel; and (f) artist's palette knife. These are depicted in Fig. 2.

Fig. 2: Tools for collecting soil samples

Since control samples are required in larger amounts, garden trowels, spades, spoons and spatulas may also be used in addition to the tools required to pick up questioned samples. The smaller tools (Fig. 2) may be of disposable or non-disposable types. The disposable varieties are generally made of plastic, while their non-disposable counterparts are made of steel. After each collection, the non-disposable tools should be cleaned with pre-moistened wipes. Alternately, these may be rinsed with water and dried with a lint-free cloth. If required, these may be decontaminated with alcohol or bleach. The investigator entrusted with picking up soil samples should wear talc-free gloves. Talc, being a silicate mineral, is likely to contaminate the evidence.[31]

A spatula is suitable for dislodging questioned soil from upholstery, whereas a razor blade is suitable for removing deposits from a vehicle. While scraping, it should be endeavored to keep the lumps intact. If thin layers of mud are to be sliced then artist's palette knifes are deemed useful.[31]. The removal of soil sticking to shoes or garments should not be attempted; rather these items should be submitted as such to the forensic laboratory.[39]

Several aliquots of control samples should be collected after ascertaining visual similarities in color and texture of questioned samples[40] Each aliquot may contain approximately 30 mL of the material. The location of collection should include the entry and exit points of the crime scene, burial sites and areas of disturbance.[41] Soil samples from four compass points (north, south, east, west) in close proximity to the crime scene should also be collected.[2]

Wherever a footwear or a tire mark is found, tire control sample should be collected from as close an area to the impression as possible.[42] In such cases samples should also be taken from a depth of about 2 cm.[43] After the impression has been documented, soil particles should also be picked up from within the mark with the aid of tweezers (Fig. 3).

Fig. 3: Control soil samples need be collected from (a) just outside the impression and (b) from within the impression.

Once the soil samples are collected, these should be packed in such a manner that there physical state undergoes a minimum alteration. If the questioned and/or control samples are moist, these should first be air-dried at room temperature. In order to prevent contamination by foreign particles, the container should be covered with a thin sheet of paper44.

The samples should be packed in screw-top plastic containers or screw-top centrifuge tubes 45 (Fig. 4). Glass containers may also be used, but only after proper padding so as to avoid breakage during transportation.

Paper envelops should be avoided since these easily tear off. Polythene bags too are not suitable since a portion of soil becomes adhered to their inner surface and is lost. Moreover, the aggregates tend to break during transportation.[31]

Every container should be sealed by a tamper-evident method and assigned a unique identification number. The date and time of collection, as well as the name of individual who picked up the sample should be stated on the container. This will maintain the inviolability of the chain of custody.

Fig. 4 Containers for packaging soil samples

Conclusion

Soil is ubiquitous and due to its particle nature possesses a high degree of transfer-ability to objects or persons. Its constituents, whether inorganic, organic or biological, vary from place to place, both in proportion and nature. Herein lies the evidentiary value of soil in that it connects an object or a person to a particular location. There are a host of methodologies that can qualitatively and/or quantitatively analyze one or more constituents of soil so that the questioned sample collected from a suspect or an object removed from the crime scene may be matched with or distinguished from the control sample collected from the scene itself. All that is required is a circumspect handling of the soil evidence.

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