

# The Silent Witness: Soil's Role in Forensic Investigation

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## ABSTRACT

Soil is primarily composed of various intricate natural elements, including inorganic and organic materials and a wide range of living organisms. Forensic soil scientists focus on analyzing soils that have been disturbed or moved, usually due to human activities. Each soil type has distinct characteristics, such as color, texture, and mineral content, and these variations in the soil make soil valuable evidence to prove the linkage between a suspect and a crime scene. Soil evidence acts as a silent witness even a suspect may be unaware that soil particles can get stuck on them (like shoes, clothes vehicles) or around them (like the carpet in the car). Techniques like microscopy (Stereo binocular microscopy, Scanning Electron Microscopy) help examine the physical properties of soil like color, and size while chemical analysis techniques like (X-ray powder diffraction) reveal its mineral composition. The main goal of forensic soil analysis is to determine whether the two sample sets came from the same location. This article explores various analytical methods for differentiating soils and offers a comprehensive overview of soil as trace evidence. It is intended to support academics, researchers, and forensic soil scientists in their investigations.

## KEYWORDS

• Soil • Trace evidence • Soil Composition • Microscopy • Identification

## INTRODUCTION

Soil is the uppermost layer of the Earth's surface. It is a complex mixture of minerals, organic substances, water, and air. The term "pedology," which is the study of soil, comes from the Greek word "pedon," meaning soil. Pedology is a branch of earth science that focuses on soil in its natural setting: its origins, chemical

and physical properties, mineral composition, classification, and distribution across different regions. Soil is primarily composed of various intricate natural elements, including inorganic and organic materials and a wide range of living organisms. These elements can either occur naturally or be introduced through human activities. Soil changes continuously

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due to various factors such as temperature, precipitation, pH levels, and the presence of macro- and microorganisms. These influences can vary based on the specific location. The physical, chemical, and biological properties of soil play a vital role in identifying soil types, proving to be significant in forensic investigations.

The term "soil forensics" was initially coined approximately 40 years ago. It can be defined as the on-site examination of soil within criminal investigations. This field encompasses the analysis of soil present on suspects, victims, or items linked to a crime, aiming to identify suspects and solve the crime. Over a century ago, the significance of soil evidence in criminal investigations was first portrayed. However, this portrayal was in a fictional narrative within the Sherlock Holmes series penned by Sir Arthur Conan Doyle. Around the same period, Hans Gross from Austria mentioned in his handbook on criminalistics that traces of soil on footwear could potentially provide valuable insights for criminal inquiries, though he didn't present any real case studies or practical techniques. As per a report by Murray, it's suggested that Georg Popp from Germany might have been the initial scientist to analyze soil evidence, leading to the resolution of a murder case in 1904.

Forensic soil scientists, also known as forensic geologists, focus specifically on soils that have been disturbed or moved, often due to human activities. They may compare these soils to natural soils or databases to help pinpoint crime scenes. They typically collect soil samples from crime scenes or contaminated areas, as well as from nearby suspected locations where soil might have been transferred, whether by vehicle, on foot, or using a shovel. The varied properties of soil allow forensic soil scientists to utilize soil as evidence more confidently in criminal and environmental investigations.

Soil can be easily transferred from one object or person to another, like from a crime scene to items such as shoes, clothes, or tires, and then to another surface. This transfer can be categorized as primary transfer when it moves from the crime scene to an item, and secondary transfer when it moves from that item to another surface. This concept is based on the Locard exchange principle, which suggests that when two objects come into contact, there

is an exchange of matter. In this case, soil, with its unique characteristics, can be traced back to the crime scene.

To use soil as evidence in a crime investigation, two types of samples are needed: questioned samples and control samples. Questioned samples are collected from objects like tires, wheel wells, garments, shoes, or tools found at the crime scene. Control samples, on the other hand, are deliberately gathered from the crime scene and its surroundings for comparison with the questioned samples. Different types of examination methods are used for soil sample analysis which may be simple or complex.

Soil typically has a strong ability to transfer and adhere, especially the fine fractions like clay and silt, as well as organic matter. The bigger particles like quartz don't stick as well to clothes, shoes, or carpets. Fine soil material, like fractions less than 50-100 micrometers, might not be present in large amounts.

Soil evidence acts as a silent witness even a suspect may be unaware that soil particles can get stuck on them (like shoes, clothes, vehicles) or around them (like the carpet in the car). Forensic scientists can easily find and gather soil stuff when they check out crime scenes or look at evidence items.

**Lloyd Dudley 1976**, explored how particle size distribution in forensic soils can differentiate samples, linking them to specific locations.

**Michael Graves 1979**, discussed the mineral composition of soils and its role in connecting soils to geographical areas relevant to forensic investigations.

**Martin Junger 1996**, focused on soil color as a key feature for analysis, presenting methods for measurement.

Additionally, Kenji Sugita and Kenji Marumo emphasized the importance of particle size distribution in forensic applications, showcasing various analytical methods for better soil differentiation.

**John Smith and Emily Johnson 2000**, discussed foundational principles, focusing on soil collection methods and its role as evidence in criminal cases.

**Michael Brown and Sarah Davis, in 2001** explored methodologies for collecting soil samples from crime scenes, highlighting how soil properties can link suspects to locations.

**Lisa Taylor and Robert White 2002**, reviewed various analytical techniques for soil analysis, covering mineralogical and physical properties and their applications in investigations.

**Pye, Kenneth & Blott, Simon J. 2004**, focused on particle size distribution analysis, emphasizing its role in identifying soil types and differentiating samples while highlighting the need for strong analytical methods in forensic soil investigations.

**Ruffell, Andrew., et al.** discussed the significance of mineral composition, detailing methods like X-ray diffraction and scanning electron microscopy, of soil evidence and how these techniques can provide crucial evidence in forensic soil cases.

**Bull, Ian D., et al. 2006**, looked at how soil and pollen can still be found on clothes even after they've been washed. They found that trace evidence can stick around, showing how important soil and pollen analysis is in forensic work.

**Petraco, Nicholas D., Garrison, Robert., et al. 2008**, looked at ways to collect soil from objects and clothing in forensic cases. They talked about different testing methods and how these can help link or eliminate suspects based on soil evidence.

**Swindles, Graeme T., et al. 2009**, looked at how soil can be used as trace evidence. They focused on how different and unique soils are and talked about methods for analyzing soil that can help in forensic science.

**Fitzpatrick, R., et al.** highlighted the features of forensic soils and why they matter in criminal investigations. They suggested using standard practices for analyzing soil evidence to make the results more reliable and consistent.

**Murray, M., et al. 2016**, looked at how soil gets transferred from one place to another. They found that things like mineral types and soil makeup affect how easily soil moves to different materials. They also mentioned that more research is needed on how different clothing types of impact soil transfer.

**Levin, Eliezer, et al. 2017**, and his team focused on methods for transferring trace evidence that can be applied to soil analysis in forensic situations. They highlighted how important it is to understand these transfer mechanisms for better forensic investigations.

**Jessica Smith and Laura Taylor 2021**, reviewed new forensic soil analysis methods. They emphasized using GIS for mapping crime scenes and studying soil composition. They noted that soil texture, minerals, and organic matter help link suspects to locations and suggested using techniques like spectroscopy for better accuracy.

**Michael Lee and Kevin Robinson 2022**, reviewed techniques for soil evidence collection and analysis. They emphasized the importance of sampling methods, lab tests, and maintaining chain of custody. The authors called for better training for forensic professionals and discussed the role of soil evidence in legal cases, highlighting the need for clearer guidelines on its admissibility.

**Emily Parker and Daniel Ramirez 2023**, looked at new methods for analyzing soil particle size and shape, highlighting their importance in forensics. They shared case studies showing how these analyses can help tell apart soil samples from different places, which is crucial for linking suspects to crime scenes. The authors discussed improvements in imaging technology and statistical methods that make soil comparisons more accurate and suggested a way to include these techniques in forensic investigations.

**Fiona Cooper and Jonathan 2024**, White discussed the legal challenges of using soil evidence in court, emphasizing the need for clear evaluation standards and strong validation studies to support its admissibility. They also highlighted the importance of effective communication of findings by forensic scientists.

**Benjamin Walker and Anjali Singh** explored future trends in forensic soil research, particularly the use of AI and machine learning to enhance the efficiency and accuracy of investigations. They suggested further research on soil databases and predictive modeling to improve forensic analysis.

### Steps of Examining the Soil Evidence

To ensure the integrity of soil samples, it is crucial to follow a systematic and organized approach during collection and preservation. The forensic analysis of soil typically involves four main steps: crime scene investigation, laboratory sample analysis, result comparison, and result evaluation and interpretation. (Table 1).

When examining a crime scene, the forensic examiner must gather both reference and questioned samples for later comparison. It is recommended to collect multiple samples from different points on the surface and various soil depths or layers, depending on the activities and soil characteristics at the scene. Following the scene assessment, the collected samples should be sent to the laboratory for further analysis to address forensic inquiries. Various techniques are employed to identify the components present in the soil, ranging from analyzing the entire sample composition to isolating specific components like clay fraction or microbial communities. After analyzing the samples, forensic examiners compare the results from questioned and reference samples using subjective (expert opinion), objective (statistical methods), or a combination of both approaches. Subsequently, examiners interpret the results and address any questions posed by the client, utilizing databases, reference materials, and geographic information systems for evaluation and interpretation.

**Table 1:**

<b>Step 1</b>	Investigation of Crime Scene
<b>Step 2</b>	Analysis of Sample in the Lab
<b>Step 3</b>	Comparison of the Result
<b>Step 4</b>	Result Evaluation and Interpretation

### Examination Methods

The passage highlights the importance of soil evidence in forensic science, pointing out its diverse makeup and the various analytical methods used to study it. Soil can consist of numerous natural and human-made materials, making it an essential source of evidence in investigations. The presence of different minerals, rocks, and artificial particles like plastics and metals adds to the uniqueness of soil samples. Forensic scientists use a range of instruments and techniques to analyze these materials, enabling them to compare questioned samples with known references. While the effectiveness of these methods can differ, they are all widely accepted practices in forensic analysis.

**Physical examination:** It involves analyzing the observable properties of soil, such as color, texture and particle size distribution. Physical examination is the easiest method to differentiate samples.

**Color:** The soil color method represents a pivotal technique in forensic science, employed to identify and compare soil samples based on their color attributes. The coloration of soil is shaped by various factors, including its mineral composition, organic matter, and the coatings that may be present on the soil particles. Minerals such as iron, manganese, and copper play a significant role in determining soil color. For example, iron-rich soils often display reddish hues upon oxidation, while manganese contributes to darker black shades, and copper-containing minerals can impart greenish tones. Organic matter, including decomposed plant material or humus, tends to darken the soil, often resulting in brown or black shades. Additionally, over time, soil particles may become stained or coated with clay, iron, or organic materials, further modifying their appearance.

To standardize the characterization of soil colors, forensic scientists employ the Munsell color system, which classifies soil color based on three fundamental parameters: hue (the prevailing spectral color), value (the degree of lightness or darkness), and chroma (the intensity of color). This methodology facilitates a consistent and objective delineation of soil color, which is essential for forensic comparison. Typically, soil samples undergo air-drying or oven-drying processes to eliminate moisture, as the presence of water can significantly influence color perception. Given that moisture amplifies the brightness and saturation of soil colors, it is imperative to document the moisture content of a sample during analysis. Moreover, lighting conditions exert a considerable influence on the perception of soil color; natural illumination is preferred for accurate observation, whereas alternative light sources such as fluorescent or incandescent lighting may induce variations in the appearance of the soil.

The examination process includes looking at the soil sample and comparing it to the Munsell color chart under good lighting. This visual check is improved by looking at different sizes of soil particles like sand, silt, and clay one at a time, since different sizes can show different colors. For example, smaller particles often look red, while larger grains usually appear gray or yellow. Sometimes, organic coatings on the particles can be taken off to show the real mineral color underneath.

Besides looking at soil color by eye, using tools like the Minolta CM-2002 photo spectrometer gives more exact and repeatable color measurements. This tool measures the color of the soil by checking the light that bounces off the sample, giving objective data that is more accurate than what the human eye can see. Combining both visual checks and tool measurements helps forensic scientists compare soil samples accurately and connect them to specific places or crime scenes.

In the end, the soil color method offers a fast and reliable way to tell different soil samples apart, which helps link suspects to crime scenes and locations in forensic investigations.

### Particle Size Distribution

Particle Size Distribution (PSD) serves as a pivotal analytical framework in the realm of soil science, particularly within forensic investigations, as it elucidates the relative proportions of various particle sizes namely sand, silt, and clay contained within a soil sample. This granular information is indispensable for

Forensic scientists, enabling them to conduct comparative analyses and differentiate soil samples sourced from disparate geographical locales. The predominant methodologies employed for particle size analysis are sieve analysis and hydrometer analysis.

Sieve analysis involves the systematic passage of soil through a series of sieves, each characterized by progressively diminishing mesh sizes, facilitating the segregation of larger particles, such as sand and gravel. The mass of soil retained on each sieve is meticulously recorded, allowing for the calculation of the proportionate representation of each particle size. This technique is optimally suited for particles exceeding 0.075 mm in diameter, encompassing the sand and gravel fractions.

Conversely, for the assessment of smaller particles, such as silt and clay, hydrometer analysis is employed. This technique is predicated on Stokes' Law, which articulates the principles governing the rate at which particles settle in a liquid medium. A hydrometer is utilized to gauge the density of the soil-water suspension at specified intervals, with the sedimentation rate of the particles providing insights into their respective sizes. Hydrometer analysis is particularly adept at discerning particles smaller than 0.075 mm.

The outcomes derived from both analytical approaches are combined to construct a particle size distribution curve. This curve graphically represents particle size on a logarithmic scale against the cumulative percentage of soil particles. Such a representation is instrumental in classifying the soil and identify its texture, thereby determining whether it is predominantly sandy, silty, or clayey in nature. The morphology of the curve can further indicate whether the soil is well-graded characterized by a broad spectrum of particle sizes or poorly graded, where particles exhibit homogeneity in size. Within the forensic domain, PSD is utilized to compare soil samples extracted from crime scenes with those collected from suspects or associated objects. Distinctive particle size distributions can serve as a forensic link, establishing connections between soil and specific geographic regions. Nonetheless, the accurate interpretation of PSD necessitates a high degree of expertise, and it is frequently augmented by complementary methodologies, such as mineralogical analysis, to enhance the fidelity of forensic soil comparisons.

**Microscopic examination** It involves the examination of soil sample with the help of different types of microscopes. It is used to analyze the tiny, often invisible components of soil. There are several types of microscopic techniques used in forensic soil analysis, each offering different levels of magnification and detail, allowing for a comprehensive understanding of the soil's characteristics.

**Stereo Binocular Microscopy** Stereo binocular microscopy is a crucial tool in forensic soil examination, providing a three-dimensional view of samples that enhances the understanding of their physical characteristics.

**Basic Structure:** A stereo binocular microscope consists of two optical paths, one for each eyepiece. This dual-path system allows the user to see a three-dimensional image of the sample. Each eyepiece has its own objective lens, which provides a slightly different angle of view, mimicking human binocular vision.

**Magnification:** The magnification range for stereo microscopes typically varies from 10× to 100×. This level of magnification is ideal for observing larger particles and structures in soil, such as grains, aggregates, and organic matter. The lower magnification allows for a wider field of view, which is useful for examining the

overall composition of the sample. **Illumination:** Stereo binocular microscopes often use both transmitted and reflected light sources. Transmitted light passes through the sample, which is beneficial for observing transparent or translucent materials. Reflected light, on the other hand, illuminates the surface of opaque samples, making it easier to see textures and surface features. Some microscopes come with adjustable lighting, enabling users to manipulate the angle and intensity of the light for optimal viewing. **Depth of Field:** One of the significant advantages of stereo binocular microscopy is its greater depth of field compared to other types of microscopes. This means that more of the sample remains in focus at once, allowing forensic scientists to observe the three-dimensional structure of soil particles and aggregates without constantly adjusting the focus. In forensic investigations, stereo binocular microscopes are used to analyze soil samples for various characteristics. For example, scientists can assess the size, shape, color, and texture of soil particles, which can help in distinguishing between different types

of soil. They can also identify the presence of organic material, such as roots or leaves, which can provide additional context about the soil's origin. It provides a general impression of the soil's composition and can highlight the presence of unusual or foreign materials in the sample. After examining the soil samples under the stereo binocular microscope, forensic scientists can compare the characteristics of the soil from a crime scene with samples collected from potential sources. This comparative analysis is crucial for determining if there is a match between the soil found on a suspect and that from the crime scene.

**Scanning Electron Microscopy (SEM)** - The scanning electron microscope (SEM) offers an extensive range of magnification options, typically from 25 $\times$  to more than 650,000 $\times$ , allowing it to capture details as small as 1.5 nanometers. This advanced instrument became commercially available in the mid-1960s and has quickly gained popularity in forensic applications, particularly for analyzing gunshot residues and other minute particles.

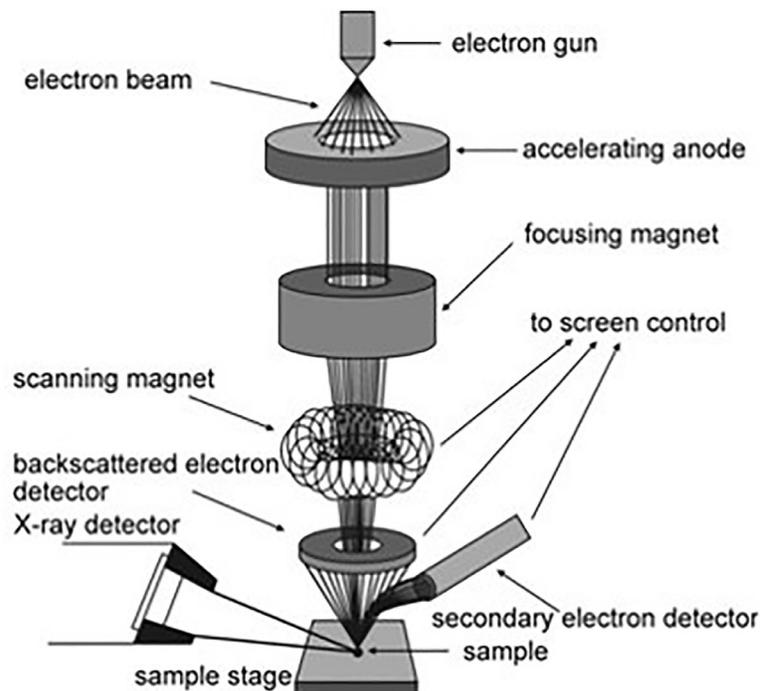


Figure 1: Scanning Electron Microscope

SEM can detect unique features in soil samples, such as the presence of specific minerals, organic matter, or anthropogenic materials (like glass or metal fragments). These unique features can serve as critical evidence in linking a suspect to

a crime scene. Scanning electron microscopes can identify the elemental composition of the particles under examination. This capability arises from the production of x-rays when the microscope's electron beam hits a target.

The scanning electron microscope can be connected to an x-ray analyzer. The x-rays emitted are categorized based on their energy or wavelength values, which correspond to specific elements, allowing the analyzer to provide information that identifies the elements present in the observed material. The concentration of each element is assessed by the intensity of the emitted x-rays. Consequently, the examiner can ascertain the chemical makeup of the individual particle or particles being analyzed. Using the elemental makeup of individual soil particles can be examined, which helps in identifying specific minerals or contaminants present in the soil sample.

SEM gives in-depth details about the form, dimensions, and surface characteristics of soil particles. For instance, sand grains might display signs of wear or abrasion that suggest if they have been moved by wind, water, or other natural forces. SEM is especially useful for investigating small particles like sand or silt that may have distinct surface features revealing their origin. It can also identify the presence of industrial pollutants, which can help differentiate soil samples from various locations. The ability of SEM to analyze chemical elements provides an additional layer of forensic information, assisting in the comparison and matching of soil samples.

### Advanced Analytical Techniques

**X-ray powder diffraction (XRD)** - is a powerful analytical technique used in forensic soil analysis to identify and characterize the mineral composition of soil samples. The process involves directing X-rays at a powdered sample, which causes the X-rays to scatter in specific directions based on the arrangement of atoms in the minerals present. **Sample Preparation:** Soil samples, which can be very small (often between 0.5 and 5 mg), need to be prepared for analysis. Because of their small size, standard methods like pressed powders may not be suitable. Instead, samples can be deposited onto low-background holders or loaded into thin glass capillaries. For extremely small specimens, such as single mineral particles, they can be attached to glass fibers for analysis. **X-ray Diffraction:** When the X-rays hit the powdered soil sample, they interact with the crystalline structures within the minerals. Each mineral has a unique arrangement of atoms, which leads to a distinct diffraction pattern. This pattern is recorded

and can be analyzed to determine the mineral composition of the sample. **Comparison and Analysis:** The resulting XRD patterns can be compared to known reference patterns to identify the minerals present in the soil. In forensic investigations, this can help link soil samples from a crime scene to a suspect or a location by revealing similarities or differences in mineralogical composition. **Evidential Value:** The significance of the similarities in XRD patterns depends on the number and types of minerals present. If two soil samples contain only common minerals, such as quartz, the evidential value of their similarity is low. However, if the samples contain several uncommon minerals, the degree of similarity is considered high, making it more likely that the samples originated from the same location.

**Mass and Volume Magnetic Susceptibility Method** - are essential tools in forensic soil analysis. These techniques help in identifying and characterizing soil samples by measuring their magnetic properties. In forensic investigations, soil samples can provide crucial evidence, and the mass and volume susceptibility techniques allow forensic scientists to detect and quantify magnetic minerals, such as magnetite and magnetite, which may be present in small amounts. By analyzing the magnetic susceptibility of soil samples, forensic experts can differentiate between various soil types and potentially link a suspect to a crime scene. This method is particularly useful because it can uncover magnetic materials that might not be detectable through other techniques like X-ray diffraction (XRD) or diffuse reflectance infrared Fourier transform spectroscopy (DRIFT). In summary, mass and volume susceptibility techniques play a significant role in forensic soil examinations by providing valuable insights into the composition and origin of soil samples, aiding in criminal investigations.

### CONCLUSION

In conclusion, soil forensic analysis plays a important role in linking suspects to crime scenes and providing crucial evidence in criminal investigations. The different analytical techniques available, from microscopy to geochemical fingerprinting, increase our understanding of soil properties and their implications. Despite existing challenges, such as variability and contamination, recent

technological advancements hold promise for improving accuracy and reliability. The ongoing commitment to research, innovation, and collaboration will ensure that soil evidence remains a cornerstone of forensic investigations, aiding law enforcement in the pursuit of justice and. As we move into 2024, the integration of artificial intelligence and machine learning stands poised to revolutionize the field, enabling faster and more precise identification of soil types and their geographic origins.

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