

Assessing the Unique Characteristics of Close-Proximity Soil Samples: Just How Useful Is Soil Evidence?

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ABSTRACT: An evaluation of current techniques used in the forensic analysis of soils and geologic evidence. Research was performed to determine the discriminative qualities of the various procedures to discern at what point soils become indistinguishable from one another. Included in this research is an assessment of the techniques from an analyst standpoint to determine what level of advanced mineralogical examination is required to segregate one sample from another.

One hundred samples were collected from three different sites; a beach, an island isolated by a river, and a bus parking lot. The samples were analyzed utilizing color determination, particle size distribution analysis and mineralogical profiles of the twenty-five most common soil minerals. Of the three hundred samples examined, over one-half could be discriminated by color alone, the remainder needing only particle size distributions analysis for differentiation, negating the need for lengthy mineralogical examinations. These examinations were conducted with very inexpensive equipment and calculations which could be used with a minimum of training and cost.

KEYWORDS: forensic science, forensic geology, soils, soil analysis, trace evidence

Throughout history people have used the earth in an attempt to unravel the mysteries and secrets that surrounded them and their world. People have looked to the soil for information on determining the right "color" for planting crops, or finding game and natural resources, trying to resolve the conflicts of science by observing natural events and interpreting them. The relationship between geology and forensic science (though not named) has been in existence for thousands of years in one form or another.

Forensic geology uses geological evidence, primarily soil samples, to analyze problems. This type of scientific inquiry, though very informative and useful, is rarely used in most forensic laboratories because of the perception that costs for equipment and training of personnel are too high,² given the (assumed) limited

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²Telephone survey conducted in April of 1992 by the author of twenty state and federal laboratories to determine whether soil analysis was performed and by whom. Eighteen of the laboratories sent their soil cases to the two laboratories in the survey that did do this kind of work.

practical use of such evidence. But is this form of scientific investigation worth the time and money that it takes to outfit a laboratory and train its staff members?

The aim of this research is to answer these questions: 1) can soils in close proximity to one another be separated from one another, 2) can these examinations be done using simple techniques performable by most analysts in forensic laboratories, and 3) can these procedures be made cost effective. To this end, a methodology was developed that is in keeping with current literature on forensic science and forensic geology and which is both cost effective and functionally useful.

Literature Review

The history of forensic geology, and the idea of forensic geology as a viable investigative tool has occurred to many other individuals, not the least of whom are the mystery writers. Sir Arthur Conan Doyle's character Sherlock Holmes is credited with being the first forensic geologist, even if a fictional character. Blau describes several cases in which this fictional supersleuth used deductive reasoning in dealing with geologic evidence found on victims or suspects, with surprising detail and accuracy (1).

Many recent cases exist in which murder or kidnapping charges were decided based on geologic evidence. Cleveland (2) describes how a kidnapper eluding police after a ransom delivery was later identified by a footprint made in the back seat of the kidnapper vehicle. This footprint was white, made after the kidnapper stepped into a pile of diatomaceous earth at a quarry where he kept his victim. Identification of the specific fossilized organisms and their distributions led to this quarry as a possible site of origin.

Pre-dating this case was the famous Lindbergh kidnapping. Eckert (3) describes how one of the pivotal pieces of evidence was a clay encrusted footprint left on the window sill of the baby Lindbergh's nursery. This soil was from the Lindbergh's flower bed, and was later identified as being similar to that found adhering to the shoes of Bruno Kauptman.

Rapp (4) describes a man who would marry women and then murder them (four in all); he was eventually apprehended after clastic material (fragments of rock mechanically broken) found in the floorboards of his car were linked to an oil drilling site where one of his victims' bodies was left. These cases and others point to the inherent value of geologic evidence as a viable form of evidence.

Forensic Geology by Murray and Tedrow (5) is an excellent book for investigators, lawyers, police officers and geologists who want to get specific information about forensic geology. This book put the broad study of geology into a forensic perspective, and poses many questions that could spur more research on the forensic applications of the earth sciences.

Fitzpatrick and Thornton (6) attempted to develop a forensic technique to identify and individualize sand particles. Sand is defined as any rock particle between 0.05 and 2.0 millimeters in diameter, usually composed of calcium carbonate (limestone), aluminum silicate (feldspar) or silicon dioxide (quartz). Quartz is so common that the phrase "sand" is usually applied to quartz sand grains. Fitzpatrick and Thornton recognized that the erosion of the surface facies of sand grains is a product of the transportation medium (water vs. air). The resulting fracturing of the mineral faces can be indicative of the transportation medium because the fractures on the crystal readily show characteristics specific to either water, chemical or air erosion. Also, measurement of the various surface structures of multiple grains may yield a tendency of a group of particles to display the same general markings, thus further aiding in the localization of the mineral's point of origin. The authors examined several techniques in use for particle size determinations and distributions and found many techniques suitable for forensic use. Notably, however, the authors did not prefer the use of sieve and weight techniques as these procedures require large samples (30 to 50 grams), which are rarely available in the forensic setting.

Fitzpatrick and Thornton also used scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to evaluate the surface markings of Littoral (beach), Eolian (deserts, dunes) and Glacial (mountain) sands and determined that the surface markings are very characteristic for each classification and that class identification is very easy using these techniques. They also discussed the segregation of "industrial" sand, or sand that is quarried rather than surface collected. The presence of pellicles of hematite and limonite indicates that the particles have been left underground and are not yet polished clean by surface erosion.

Nute (7) tried to simplify the tried-and-true technique of density gradient columns for discriminating soils. This process requires that soils be dispensed into columns filled with liquids of varying densities: the soil sample separates according to the specific densities of its component parts. Nute devised a wooden box with fixed columns mounted with spigots for draining the suspension liquids and samples in a controlled fashion, avoiding sample loss and further contamination from outside sources. The process of density gradient columns had been used for years prior to Nute's proposal but has become obsolete in the face of other instrumental and mechanical means. Density gradient columns required a relatively large sample to do the examination correctly and contamination of the sample by the suspension liquid often required cleaning with solvents that could be hazardous to the carbonate components in the sample. Side-by-side comparisons of known and unknown soils were at best approximations (useful for agricultural purposes, but not for forensic applications). Murray and Tedrow (5) have all but avoided the procedure, discussing it but advising against its use in forensic settings.

Thornton and McLaren (8) tried to demonstrate that soils are not inert collections of minerals as most people assume. Rather, soils support a huge biomass made up of fungi, microorganisms, plants and insects. Each of these organisms is responsible for depositing a massive variety of biochemicals into the soil mass, most of which can remain inert in the soil for some time before destruction by natural processes. Since these biochemicals are a product of the local organismal communities within the sample, it is possible that extraction and analysis of some of the more stable chemicals may give the soil a certain chemical "fingerprint."

While Brewer (9) recommended a strategy for performing soil analysis in the forensic setting, Graves (10) proposed a simplified

method that did away with much of the tedium normally encountered in soil analysis. Graves argued that the examiner should separate the soils into fractions and use a special reticle (a piece of glass with a counting grid etched onto its surface) within the optical field of the microscope to speed counting of individual mineral grains. Graves also discussed the possibility that the usual counting of 1200 mineral grains within a given sample was not statistically necessary. He argued that counting 1200 mineral grains would increase examination time to 15 hours, while counting 300 grains would take 2–4 hours. He showed that the statistical variation between 300 and 1200 grain counts was minimal and that 300 grains would give an adequate assessment of soil composition.

Graves also divided particles into 14 broad categories and used these classifications as he examined the 100-mesh fraction of a soil sample on the microscope slide. Graves' method is somewhat complicated and would take considerable practice to master, as the examiner must make a series of passes over the same optical field and only count elements that his checklist calls for at that moment. The examiner must then pass over the same fields to look for the next item, and so on. But use of this classification method can yield valuable data quickly, causing little confusion into which classification a particular particle should be placed into.

Janssen et al. (11) used a different approach to identifying soils, looking at the color of the sample's clay fraction. Since a sample's color is largely due to the clay fraction that coats the larger mineral grains, they argued that examining the clay fraction separate from the main mineral components will give excellent forensic data.

Wanogho et al. (12) theorized that a more thorough approach to soil analysis could be obtained through the use of statistical calculations of the individual soil fractions within a sample. Their procedure called for a thorough cleaning of the sample, lightly crushing it to break up the aggregated minerals, and then shaking the sample through a stack of five sieves. This produced six soil fractions that were used in calculating the median particle size. This value was then used to compare other samples in a collection to determine if distinctions could be made as to their identity.

Wanogho et al. (12) expanded on this area later by introducing particle size distribution analysis using wet sieving and automated instrumentation. The systems used were the Coulter Counter and Automated Image Analysis³ systems. They discovered that discrimination was somewhat better using these automated systems and that speed and efficiency were greatly increased. Analysts could perform the examinations without extensive training in microscopy, needing only to be familiar with the sample preparation. Since most examiners are hesitant to do soil analysis because of the perceived need for specialized training, these systems can go a long way in making the examination of soils in forensic cases more saleable. These studies are important in their assessment of the value of soil fractioning for discrimination purposes. Much of the particle size analysis in this project reflects the methods outlined by Wanogho and his colleagues. The addition of mean and dispersion values into my statistical assessment will make further discrimination possible.

Many researchers have endeavored to examine specific aspects of soil analysis or to exploit the instrumental examination of soils. Siegel and Precord (13) attempted to see whether soils could lend themselves to analysis using reverse phase-high performance liquid chromatography (HPLC) using wavelength ratioing. The technique of reverse phase high performance liquid chromatography was

³A system where particles are suspended in a solution and passed before a photo-detector that measured the particle counts and sizes.

modified to allow for detecting two different wavelengths within the ultraviolet spectrum to determine differences in the ratios of absorption intensities. Siegel and Precord recognized that soils can vary greatly in ratio both horizontally and vertically within very short distances. This experiment used standard HPLC methods of sample preparation while three channels were used to differentiate wavelengths. The channels were set at 254 nm and 280 nm to analyze the ultraviolet wavelengths. The outcome of the experiment was that the samples showed very good quantification from one to another but not all samples could be qualitatively differentiated based on their overall particle size distributions.

Marumo and Yanai (14) took a unique approach to the biologic fragment of soils when they examined the formation of opal phytoliths. They recognized that most soils are unique due to their mineralogical and biological diversity. What concerned them were those instances where the topsoil had only recently been formed by volcanic activity or alluvial deposits. These soils can develop rapidly (in the case of volcanic soils, several feet of material can be deposited in several hours), and their mineralogic profiles will be very homogenous because the normal sorting processes of erosion and deposition have not taken place. The authors decided to examine one aspect of soil particles that develop rapidly, opal phytoliths. These, in the words of the authors, "show more varied systematic morphological forms. . . ." Opals are formed from plants instead of by normal geologic processes. Opals are minerals, or mineral gels consisting of silicon dioxide and water.

Due to the youthful nature of the soils within the study area, mineralogical profiles were indiscriminate despite a change in elevation from 30 meters to 5 meters along the length of the study area. The authors then collected phytoliths from living plants as well as soil samples and were able to discriminate the phytoliths using a thorough classification system based on the taxonomy of the plants that formed them. The results showed that samples taken from the higher diluvial plateau were readily distinguishable from those from the alluvial plain, and that samples from within these sites had many similarities.

Thornton (15) provides an excellently written and very thorough examination of most of the current procedures used in forensic soil analysis, and introduces the idea of evaluating soils on the basis of their microbiological and enzymatic constituents. Rather than dividing soils into only their organic (leaves, roots, mulch) and inorganic (rocks and minerals) components, Thornton added a third classification, the biologic component, for microorganisms present in the soil. The rationale for this is quite logical: in one pound of soil there may exist up to one million different forms of fungi and bacteria, most of which are dependent on the inorganic matrix of the soil in which they reside. Thornton argues that these organisms, when viewed as a ratio of one community to another, can offer unique information about the specific local environment that sustains them. Thornton then went on to prove this assertion by examining a collection of soils using standard microbial inoculation techniques on culture plates. The resulting colonies of organisms demonstrated that the specific biota living in each sample was somewhat unique from sample to sample, and that the micro-environment of each sample helped to tailor-make the biology it supported.

In the history of forensic soil analysis, practitioners have moved from direct examination, statistical measurements and chemical assaying, to modern instrumentation methods and analytical component analysis. While these procedures may be very thorough and precise, the cost of the equipment and the training are often out of reach for a laboratory that is not primarily committed to

doing this type of analysis. A database that proves the discriminatory nature of soils in close proximity to one another and an analysis plan that is simple to perform by most analysts with minimal training, would make the practice of forensic geology an attractive technology for laboratories to include in their examination protocols. One of the first of these databases that needs to be developed is how much "virgin" soils (non-commingled) change over a short distance using readily available equipment and simple procedures. This is a necessary preliminary to assessing the separation of adulterated soils, such as those found on shoes or on a floorboard of a car.

Methods

We began by selecting three different geologic environments: a beach, a woodland area and a vacant lot in an urban setting. These sites were selected because of their similarity to locations where crimes are frequently committed or where criminal evidence is recovered. After the sites were selected, a one-hundred by one-hundred meter "box" was marked off and divided into a grid of ten meter sections. This size grid was selected because the closeness of the individual boxes could be useful in forensic work by isolating locations in close proximity to one another, yet not being so close that adulteration (when a suspect passes over several boxes enroute to the crime scene, and picks up elements from each) becomes a serious problem.

Each of these sections was numbered and a sample of the surface soil was collected from each "box." The samples were collected at a depth of $1/2$ to $3/4$ of an inch and stored in plastic Zip-loc bags. One hundred samples were collected at each of the three locations, resulting in a total of three hundred samples.

Site Descriptions

The three sites chosen for this investigation will be described so that readers can appreciate the topography, geology and amount of human interaction with the region.

Site 1: Seldene Island, CT—is a small island park situated ten miles inland from Long Island Sound on the Connecticut River. This small park is accessible only by boat and has a small picnic area and boat landing (a very small patch of beach area for canoes and small motorboats). Most of the island is flat with small undulations in the surface that are covered with shallow cedar swamps and grasses. There are some trails around the perimeter of the island, but strict preservation regulations and its isolated location have kept it relatively free from overuse and contamination.

The site selected for collection was bordered on one side by a grove of cedar trees and a cedar bog; the other side by a slight hill (5-foot mean elevation change) that contained more cedar and oak trees. The previously described grid pattern was established and coordinates were confirmed using a topographic map and lensatic compass. The "top" of the grid box (A1 through J1) was laid-out parallel to the edge of the cedar bog, with the "bottom" of the box ending on the crest of the small hillock. This site was selected to see what kind of impact the slight elevation change would have on the particle distribution over such a short distance.

Site 2: Ocean Beach, New London, CT—is a public beach located in New London, CT. The beach area is bordered by a wooden boardwalk that runs along its northern edge, and has a variety of stands and shops, a water slide amusement area and a children's

play area. The beach area itself is approximately 150–200 meters in width and about 1000 meters in length. The beach has an incline from wavefront to boardwalk of about 10 to 15 degrees, with two areas having a slope of about 25 degrees. This had a direct affect on the local particle size distribution of the samples taken from this area due to early deposition after loss of current velocity. Simply put, the steeper the slope of the beach, the shorter the distance particles will travel before losing their energy and becoming deposited, causing poor sorting of particles by their size. The boardwalk is restricted to foot traffic and bicycles, with no vehicular traffic on the sand areas of the beach. Add to the effects of wind and wave action the human interaction of beach patrons who can affect the local deposition profile in such a way as to make beach environments very dynamic and varied in their makeup.

As was the case with Seldene Island, the prescribed area was marked off with stakes and samples collected in order. The “top” of the box ran parallel to and immediately adjacent to the boardwalk, with the “bottom” of the box ending at about the low tide waterline. Classic sedimentology suggests that beaches naturally sift sands by the wave action of the ocean: as the velocity of the waves decrease, progressively lighter particles will “settle out,” with the largest particles immediately next to the waterline, and the finer particles deposited further up the beach by the farthest-reaching waves (not to mention wind, which will further deposit the lighter and finer particles up the beachfront). This concept has been considered in terms of the large-area model; this study considers the small-area model. If the theory is true in the small-scale, then all samples that are collected and analyzed will show the same particle size distributions in relation to those in a line that runs parallel to the waterline, with decreasing sizes the further you go up the beach.

Site 3: George’s Garage, Center Groton, CT—This site was selected because it has had a long history of adulteration. Behind the garage area proper is a large, 500 meter by 150 meter dirt lot that was cleared many years ago. This lot had been used as a parking area for school buses until a large brush fire burned its perimeter two years ago, and it is now unused. Unlike the Seldene Island site, it has seen much contamination and soil movement by human interaction.

The terrain can be described as essentially flat with some minor depressions. The surface geology ranges from a fine clay to large cobbles in a hardpack soil that is almost like concrete. In many areas there are small bushes scattered around, and there is a distinct perimeter where the lot joins the surrounding woods. The majority of the area studied has been compacted by years of vehicular use, whereas areas immediately adjacent show almost no signs of use whatsoever, presumably because of the clay-rich soils quicksandlike potential for vehicles after a rain.

The samples collected were analyzed using *color determination*, *particle size distribution*, and *mineralogical profile*. These three techniques are the standard practice of laboratories that perform forensic geologic analysis and are part of the routine used by the Mineralogy Section of the FBI Laboratory.

Color Determination

First the individual samples were “debrided”: minerals and soil particles were separated from leaves, twigs and other detritus using tweezers and low power magnification. The samples were heated to 105 degrees Fahrenheit for twenty minutes to drive off excess water. Soil scientists will often look at soils when they are wet,

but for forensic applications the samples are kept dry because a better spectrum of colors is visible in the dry samples. After drying, the soils were examined for their color characterization using a Munsell Soil Color Chart to determine hue, value and chroma. The use of the Munsell Chart, a series of colored chips covering the entire spectrum of visible light which identifies all of the colors that the human eye is capable of detecting, controls the subjective elements involved in the assigning of color values to a sample; color by itself can often be a very good indicator of the geographical origin of the soil.⁴ The use of the Munsell Color Chart is an accurate way to identify colors and allow reproduction of the color if needed, especially when following protocols as established by McCrone and Delly (1973) in their work *The Particle Atlas*. The Munsell Chart thus serves as an excellent discriminatory tool that can eliminate extra steps in analysis. The Munsell Chart shows correlation between the color and the chemical composition of the soils, that is, the hue value has a high correlation to the percent of titanium and ferrous iron, while the clays and organic matter are recognized in the value component of the Chart.

After the samples were all examined for color, those samples that did not have another sample(s) with a matching Munsell Color Designation were removed from any further testing, as they were sufficiently differentiated from the remaining samples and did not require further examination.

Particle Size Distribution

The soils were prepared for mineral examinations and particle size determinations by first removing any surface coatings of fine silt, clay or humus. Three grams of sample were added to 25 mL of 0.1% sodium hexametaphosphate in distilled water, placed in an ultrasonic cleaner for several minutes, and the resulting supernatant was then pipetted off. The procedure was repeated until the fluid was clear. This procedure was not used in the case of beach-collected samples, as the need to remove clay components for visualization was not necessary.

After cleaning, the samples were poured through a stack of sieves that were nested together. The sieves were made of U.S. Standard Mesh sizes 18, 20, 35, 40, 60, 100, 120 and 230, (.100, .075, .050, .0425, .0250, .0150, .0125 and .0063 mm. in diameter, respectively) the recognized standards used by the U.S. Geological Survey. The samples were then flushed through the sieves using Ethanol (ethyl alcohol).

After a generous rinsing the sieves were gently heated to accelerate evaporation of the ethanol. When the sieves were dry the contents of each fraction was carefully weighed, and the fraction retained in the 120 Mesh was saved for possible mineralogical profile assessment. The particle size distribution was calculated as follows: Each of the fractions within a sample was weighed and the values totaled. The sample’s total weight was divided by 5%, 16%, 50%, 84% and 95% of the original 3 grams (.150, .480, 1.500, 2.520 and 2.850 grams) after the equations established by Krumbein and Pettijohn (1938).⁵ These percentage values were then used as a target value; the weight of each fraction was added together until it reached a specific target value (some fine soils would require the combining of several fractions just to reach the

⁴There are several types of Munsell Color Charts, from paint hues to textile dyes, but in geologic work there are the Munsell Rock Color Charts and the Munsell Soil Color Charts.

⁵Several rapid and highly accurate methods of particle counting have been developed since the inception of these calculations, but these values were employed because they did not require expensive equipment and were simple to calculate.

.150 gram value). Then a statistical value (a “Phi number”), was given for each of the percentages by taking the total number of sieves it took to reach the target weight and dividing the largest and smallest mesh sizes in half (*the weight of the combined sieves had to be within + or - 100 mg of the target weight*). Phi numbers are logarithmic constants that express the average diameter of a variety of particles within a collection, and as such their degree of significance is greatly increased as the Phi values increase, even when dealing with numbers of .01 to .001. The difference between Phi values of 0.00 and 0.01 can be as much as an 8 millimeter variation in diameter between the two samples. The resultant numbers were entered into formulas that determined the median, mean and dispersion (sorting) values of each sample as described by Krumbein and Pettijohn (1938). The median, mean and dispersion values were then used as a comparison factor to discriminate between samples of the same color. These comparisons proved to be very reliable and are a mathematically reproducible set of factors that greatly serve to individualize each sample from one another.

To illustrate this procedure, let’s take the values found in sample #C-1 from Ocean Beach and see how the calculations are made. The values for the different fractions are as follows:

18 Mesh	0.209 Grams
20 Mesh	0.060 Grams
35 Mesh	0.845 Grams
40 Mesh	0.110 Grams
60 Mesh	1.278 Grams
100 Mesh	0.390 Grams
120 Mesh	0.020 Grams
230 Mesh	0.015 Grams
<230 Mesh	0.073 Grams

The aim is to determine how many fractions it will take to equal the target values needed for the calculations. The target weights are 150 mg, 480 mg, 1,500 mg, 2,520 mg, and 2,850 mg. Each fraction is simply added, starting at the 18 mesh screen, until we are at the desired target value (+ or - 100 mg). In this case, the 18 mesh fraction contains 209 mg, which fits the 5% value. The Phi value for an 18 mesh screen is 0.00, so this is the number to use in the equation needing the 5% Phi value.

The next value needed is the 16%, or 480 mg. Adding the 18 and 20 mesh screens gives 269 mg, but the 35 mesh would give 1,114 mg, so stay with the lower value of 269 mg. When multiple screens are involved, take the minimum and maximum diameter of the screens and divide it by two. In this case, the 18 mesh screen size is 1.00 mm, and the 20 mesh size is .850 mm. Therefore, 1.850 mm, divided in half is 925 mg. This amount is then referred to the Phi chart, and a Phi value of 0.25 is used for the 16% value. The process is continued for each desired target value, starting with the 18 mesh screen and adding screens until within the limit of the target amount.

When all of the Phi numbers are calculated, they are placed in the following calculations to determine their Mean, Median and Dispersion values:

Mean: $Mz = \frac{16\% + 50\% + 84\%}{3}$
 Median: $Md = 50\%$
 Dispersion: $Di = \frac{84\% - 15\%}{4} + \frac{95\% - 5\%}{6.6}$

Or, in the case of our example:

Mean: $Mz = \frac{0.01 + 0.48 + 0.66}{3}$ equals 0.38
 Median: $Md = 0.48$
 Dispersion: $Di = \frac{0.66 - 0.01}{4} + \frac{0.8 - 0}{6.6}$ equals .284

These three values (mean, median, and dispersion) then become the comparison values for the particle size distribution. When the samples are similar in both color and particle size distribution, then a mineralogical profile must be performed.

Mineralogical Profile

If the questioned samples could not be differentiated on the basis of color and particle size distribution, then a comprehensive mineralogical inventory looking at the twenty-five most common soil minerals was conducted; unique minerals were also counted, as their presence can be very distinguishing within a specific sample. The soil sample was separated by placing the sample in a high-density liquid and mounting the resulting “light” and “heavy” fractions. If available, the 120 mesh fraction of the sample was mixed with 5 cc of sodium polytungstate, a laboratory “heavy-liquid” with a specific gravity of 2.89. Sodium polytungstate is also water soluble, so cleaning of the particles after separation only required distilled water. There may be instances where the 120 mesh fraction may not be present, either due to small sample sizes or where the depositional environment is such that particles of this size are not represented. In this case, the 100 mesh fraction would be used for the profile.

The light mineral fraction was then mounted on slides in a Cargille refractive index mounting liquid of 1.54, the heavy fraction in 1.66 mounting medium. The minerals would then be identified by their morphology, birefringence, color, refractive index and optical sign using standard microscopy, polarized light microscopy, crossed polar examination and dispersion staining. If a principal mineral could not readily be identified, a description of its characteristics would be recorded (shape, color under crossed polars, inclusions) and then given a letter designation prior to counting. The following is a list of the common minerals that were routinely checked:

SPECIFIC MINERAL TYPE COUNTS

Apatite	Hornblende
Augite	Microcline
Barite	Monazite
Beryl	Muscovite
Calcite	Olivine
Corundum	Opal
Dolomite	Pumice
Epidote	Quartz
Flourite	Rutile
Feldspar	Sphalerite
Garnet	Spodumene
Glauconite	Tourmaline
Gypsum	Zircon
Hematite	

The total number of grains in each fraction was examined and the number of each of the target minerals was noted. This is a

tedious statistical task using quantitative microscopy. Five hundred grains were counted, a particle size distribution (simple weight/ratios) was performed and a percentage of particle composition was developed for that sample. An individual analysis sheet was made for each sample and the data correlated from these sheets.

After each site was completed a random collection of thirty samples were re-examined by 2 additional individuals, a forensic scientist familiar with soil analysis and a sedimentary geologist who is well-versed in the subject of forensic geology. The data from each of these samples were cross-checked against the original results to verify that variations between examiners were minimal.

Data Analysis

To aid in the comparison process, the data collected for each section was entered into a spreadsheet used in the Quatro-Pro Data Management System. This database made the sorting of samples by color, weight and statistical values very simple and extremely fast. It allows for the production of various easily understood graphs and other displays that make interpretation of results very effective and simple.

Findings

Seldene Island—When the 100 samples from Seldene Island were examined for color determination using the Munsell Soil Color Chart, 89 samples could be segregated, leaving 11 samples needing particle size distribution and mineralogical profiles. Table 1 depicts the distribution of color values in the Soil Color Chart. Of the 11 samples remaining, 7 of them were within the 10YR (“YR” meaning yellow-red) category, the other 4 samples in the 5Y category. In fact, 80% of all the samples within the Seldene Island collection area were within the 10YR category, while the other 20% showed a widespread distribution of color.

Of the eleven samples needing particle size examinations, none of the samples was immediately adjacent to another at the collection site. Eight of the eleven samples had no particles within the 20 mesh screens, but each sample had varying amounts in the 40 mesh and smaller screens. Table 2 depicts the particle size distribution analysis including the Mean, Median and Dispersion values for each sample. Figure 1 shows how the comparison of the particle size distributions have no distinct depositional characteristics (in other words, there is a random arrangement of deposition, without subtle changes from one histogram to the next). There was a trend noted in the region which will be discussed later. Figure 2 shows the ten samples that comprise the “top” of the collection site.

TABLE 1—Color Determinations of Site #1 (Seldene Island CT)
Specimens with Soil Color Charts.

Sample	Color
B-9	10YR 4.5/2
J-7	10YR 4.5/2
E-7	10YR 4.5/2
E-3	10YR 5/2
H-2	10YR 5/2
B-5	10YR 5/2.5
F-3	10YR 5/2.5
E-5	5Y 5.5/3
E-1	5Y 5.5/3
A-7	5Y 5/3
F-6	5Y 5/3

Because the color determination and particle size distribution analyses were able to discriminate the original 100 samples, no mineralogical profiles were necessary. Most of the minerals were spread between silicate and non-silicate minerals, with large quantities of biotite and muscovite micas. There was little contamination from man-made materials, with only occasional fly-ash and rubber particles. The mineralogical profiles were used to confirm the discriminations already made by color determination and particle size distributions.

Ocean Beach—Because this site consisted of a beach environment, it was believed that the color examinations would be much less specific due to the homogenous mixing of particles that wave action can produce in these environments. As was anticipated, of the 100 samples examined from Ocean Beach, 29 samples could be excluded from further examination on the basis of their color. Of the remaining 71 samples, virtually all of the samples were clumped together in groups of two to three, with the exception of the 10YR group, which had a total of ten samples within it at varying chroma values. In this collection of samples there were many groups of colors that contained “neighbors,” or samples that were very close to one another at the collection site. This was especially noticeable in those samples collected close to the waterline. It is believed that this could be due to both the wave action along this area and also the reduced foot traffic that would normally aid in mixing the various particles together. Samples that were in close proximity to one another and displayed similar colors also had very different particle size distributions, while samples that were widely spread along the site’s area with divergent color values have very similar particle distributions.

As in the Seldene Island samples, no mineralogical profiles were required. Twenty samples were profiled and the results were markedly different from those found at Seldene Island. While Seldene Island showed a good variety of silicate and non-silicate minerals, the Ocean Beach samples were almost exclusively quartz, rutile, plagioclase and feldspar minerals (90% of the minerals present were in this category). Without the discriminating nature of the clay minerals, these samples were very close to one another in their composition ratios. There was very little contamination noted in these samples in terms of paper, rubber or other debris. The mineralogical profiles were used to confirm the discriminations already made by color determination and particle size distributions.

George’s Garage—Of the 100 samples examined from George’s Garage, 52 samples could be discriminated on the basis of their color. Of these samples, 26 fit into the 10YR classification, while 14 samples fit into the 2.5Y classification. The overriding color is yellow, often causing the entire sample to have a yellow cast, with the individual grains themselves completely coated with clay. This coating was responsible for making individual discriminations very difficult and therefore made particle distribution analysis necessary.

The remaining 48 samples demonstrated a very broad distribution within the collection. Many samples had the majority of their weights in the 20–60 mesh range, while others were almost completely 100–230 mesh fractions. There is a certain mechanical function going on here, as many of the samples with the larger sized fractions were clustered around one another, which will be discussed later. In George’s Garage samples the individual fractions within two samples could be so alike that distinguishing them by weights ended up using measurements as small as 5–10 milligrams.

TABLE 2—Particle Size Distribution of Site #1 (Seldene Island CT) Specimens.

Sample	Color	Grams	20 Mesh	40 Mesh	60 Mesh	100 Mesh	120 Mesh	230 Mesh	<230 Mesh	Median	Mean	Dispersion
B-9	10YR 4.5/2	3.0	0.001	0.067	0.441	0.650	0.175	0.560	1.106	1.270	1.243	0.253
J-7	10YR 4.5/2	3.0	0.000	0.081	0.318	0.730	0.243	0.871	0.757	2.070	2.020	0.286
E-7	10YR 4.5/2	3.0	0.000	0.075	0.770	0.413	0.130	0.530	1.082	2.070	1.860	0.406
E-3	10YR 5/2	3.0	0.000	0.005	0.578	0.635	0.093	0.405	1.284	2.070	2.047	0.318
H-2	10YR 5/2	3.0	0.000	0.112	0.860	0.553	0.203	0.700	0.572	1.990	1.833	0.406
B-5	10YR 5/2.5	3.0	0.004	0.040	0.520	0.770	0.202	0.455	1.009	1.270	1.243	0.162
F-3	10YR 5/2.5	3.0	0.000	0.041	1.170	0.600	0.108	0.330	0.751	1.730	1.747	0.406
E-5	5Y 5.5/3	3.0	0.000	0.115	1.649	0.459	0.055	0.090	0.632	1.250	1.587	0.406
E-1	5Y 5.5/3	3.0	0.000	0.023	1.025	0.791	0.215	0.280	0.666	1.730	1.747	0.406
A-7	5Y 5/3	3.0	0.041	0.025	0.196	0.350	0.150	0.549	1.689	1.390	1.327	0.129
F-6	5Y 5/3	3.0	0.000	0.052	1.520	0.364	0.080	0.246	0.738	1.730	1.747	0.406

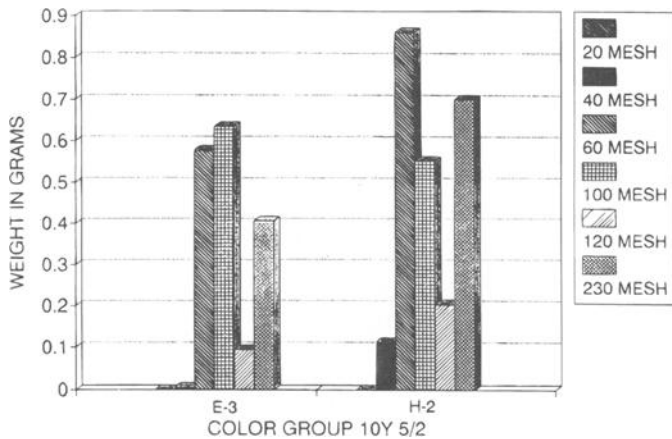


FIG. 1—Comparison of particle size distributions from samples of the same color group in Site #1 samples.

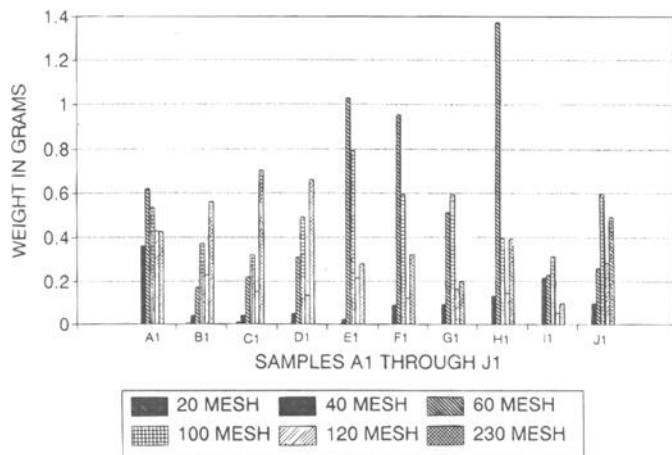


FIG. 2—Particle size distributions of ten adjacent samples in Site #1.

Although no samples needed to be segregated using mineral profiles, the tendency of many samples to differ only by very slight measures prompted an examination of the compositions of twenty samples. The samples showed a strong homogenous composition, as if the samples were somehow mixed before dispersion across the area of the parking lot. This mixing was recent (in terms of geologic time) and has not allowed for much separation and individualization of various sections by normal geologic processes. What was apparent was the high level of contaminants

within the soils. Many samples contained huge amounts of glass, flyash, tar and asphalt, rubber particles, paint debris and other man-made materials. The distribution of these contaminants was greater than the underlying minerals themselves. This may become very important when future research attempts to individualize samples that are comingled, such as on the bottoms of shoes and tirewells. As with the Seldene Island and Ocean Beach samples, the mineralogical profiles from George's Garage were used to confirm the discriminations already made by color determination and particle size distributions.

Discussion

After reviewing the findings some judgements about this research, its methodology and its conclusions can be made. On the whole, the data developed here has gone a long way in demonstrating that soils in close proximity to one another can be separated from one another, and that these examinations can be done using simple techniques performable by most analysts in forensic laboratories. It should be noted that the average analyst with no training in this kind of would require specialized training (approximately one full week of hands-on practical and didactic exposure) to carry on these types of examinations. This training is readily available from several organizations at a minimal cost and is easy to acquire.

While these results seem very specific and individualistic, one needs to remember that these samples are unadulterated collections and not the kind that are scraped from shoes, floorboards and tirewells. Fragmented samples encountered in actual casework should be put through all three examinations to insure unique minerals and components are not missed.

To address the question of whether the procedures are cost effective, the total cost of screens, collection bags, suspension liquids, color charts, mounting media and sampling tools was approximately \$250.00 in 1990. The single most expensive item needed for forensic soil analysis is a polarized light microscope, which is often already part of a forensic laboratory's equipment inventory. After this initial outlay of expenditures for equipment there are no maintenance costs, provided the equipment is not damaged from overuse. This does not include the cost of the instrumental analysis equipment that many organizations purchase when designing a laboratory. However, in a comparison of the data that has been gathered from using this simple equipment to the data gathered from some of the more complicated instrumental techniques, the value of this inexpensive examination protocol becomes very attractive. On the basis of expense in relation to quality of data derived, the procedures used are cost effective.

The actual examination process is relatively easy. The most difficult part of the process is not executing the mechanical procedures but rather understanding the statistical computations needed in the particle distribution calculations. Considering the exceptional discriminatory value of this procedure, it is well worth the time and effort it takes to develop an understanding of the process. Of added value is that this database can be used for all samples regardless of size and at all types of sites, regardless of composition.

Future research needs to be done so that this field of study can be fully explored. This study has pointed out that geologic change is a random event and not a linear progression. Differences exist in close-proximity samples that are specific enough for examiners to identify, which suggests that sites far removed from the three selected for this study can also be discriminated using the methodology described previously. These sites, however, do not represent every possible geologic site one can encounter in actual casework and some sites may be much more difficult to profile than others.

There are two future projects that would help in refining the results of this research. The first is the analysis of samples within a smaller environment: since soils can be differentiated at ten meters, can they be at one meter? The second is the analysis of commingled or incomplete samples: since evidence collected from a suspect is actually a collection of soils against a contact surface, then the depositional quality of these soils on the collection surface (shoes, tires, etc.) needs to be examined. This subject will be complicated by many factors, but if successful will yield the greatest forensic value. This project has established a baseline; now what is needed is to apply this data into the "real world." This experiment design is not what is found in real investigations, with some rare exceptions.

There is a need for better collection practices and for visualization techniques that will allow examiners to view soils in their micro-layers before being separated for analysis. This could establish the sequence of events when the subject travels from one scene to another. This is a crucial piece of research that needs to be done to advance the field of forensic geology.

Conclusions

As demonstrated by these findings, soil samples from diverse sites could be collected and analyzed with relative ease, yielding

viable results for identification and possible individualization. The methodology used in this research project is manageable and could be easily performed by analysts with minimal geological training. These techniques have been used in several cases since this methodology was developed and has met with excellent results.

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