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Forensic Geology: Earthly Crimes Solved with the Microscope

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ABSTRACT

Soils are excellent as trace evidence; there are nearly an unlimited number of identifiable soil varieties based on the content of rocks, minerals, fossils, man-made particles and chemicals that may make up a sample. Forensic examination commonly yields the original source location of rocks and minerals associated with a crime. In addition, studies of the samples associated with both a suspect and a crime scene can produce evidence that the samples do or do not have a common source. Fraud involving mines, gems, or art is often detected based on the identification of the mineral components. The primary tool of the forensic geologist used in such forensic exams is the petrographic microscope.

MULTITUDE OF SOIL SAMPLES

Soils and related material have great value as trace evidence. This value flows from the fact that there is nearly an unlimited number of identifiable soil varieties. Soils are made up of many different kinds of minerals, rocks, man-made particles and chemicals. As anyone who has taken an elementary geology or earth science course knows, there are many varieties of rock, minerals and fossils, and each of these has many subforms. Man-made particles such as glass, abrasives, plastics, concrete, brick, plaster, and other types of trace evidence, including fibers and paint, commonly find their way into soil. Furthermore, soils change rapidly and unsystematically over very short distances both horizontally and vertically (1).

The earliest recorded case in forensic geology occurred in Prussia in 1856. Barrels of silver coins were shipped via a railroad, but upon arrival it was discovered that the coins had been removed and replaced with sand. Substitution of sand or rock of the same weight as valuable cargo is still a common crime today. In the Prussian case, authorities sought the advice of Professor Ehrenberg, a well-known Berlin microscopist of the time. He asked for sand samples to be collected from each railroad station where the train had stopped. After examining the samples with the microscope, he was able to identify the station that had sand similar to that in the barrels. Armed with this information, the authorities were able to identify the culprit from the few employees at that station.

Forensic examiners are often asked to aid an investigation by answering the question, “Where did this soil or rock come from?” Perhaps the most famous case in which forensic geology provided the key to an investigation was the 1985 murder of Enrique Camarena Salazar, an agent with the U.S. Drug Enforcement Agency (Figure 1). Camarena was abducted in broad daylight on a street in Guadalajara, Mexico. During the following month, the White House, the U.S. State Department, and other Washington D.C. law enforcement agencies put great pressure on both the

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U.S. Drug Enforcement Agency

Figure 1. An FBI forensic geologist compared soil and rock samples in solving the 1985 abduction and murder in Mexico of Enrique Camarena Salazar (above), an agent with the U.S. Drug Enforcement Agency.

Mexican government and the Mexican Federal Judicial Police to solve the case. In response, Mexico's federal police force, the Federales, raided a farm in the state of Michoacán owned by the Bravo family, who were known small-time drug runners. The mother, father, and three sons were killed, as well as a Mexican federal police officer. The Federales recovered the bodies of Camarena and his pilot, Alfredo Avelar, from the farm. The story made news around the world.

FBI forensic geologist Ron Rawalt suspected that the bodies of Camarena and Avelar had been exhumed from another location and placed on the farm as part of a cover-up. He arranged for samples of soil to be collected from the body. Upon examination, Rawalt established that the collected samples were of a different rock type than those found on the Bravo farm. Rock fragments collected from Camarena's body were an unusual type of phyolitic volcanic ash. An intensive search was made of published rock descriptions from northern Mexico, and geologists familiar with the area were consulted. Eventually, rocks identical to the fragments on Camarena's body were found in an area near Guadalajara; this had been the original burial site. Rawalt's work and forensic geology exposed the cover-up.

DOES THE MINERAL MATCH THE CRIME?

Forensic geologists are often asked to examine samples associated with a suspect in comparison to those collected from the crime scene. Finding an unusual mineral or rock material naturally strengthens the value of the evidence. In one such example, the presence of bentonite clay, a natural clay that is often used to line ponds, proved to be the key in solving the murder of John Bruce Dodson. This case is one of the most interesting in the history of forensic geology, because the geologic evidence unequivocally tied the suspect directly to the crime and eliminated the suspect's alibi. Most importantly, the investigator of the crime recognized the potential significance of the geologic evidence and arranged for its examination. The testimony of the forensic geologist was critical to the prosecution of the case.

The case began on October 15, 1995, on a crisp autumn morning high in the Uncompahgre Plateau Mountains of western Colorado. During a hunting trip, John Dodson was shot and killed by Janice Dobson, his wife of three months. Some might argue that the case really began three months earlier, when Janice Dodson began accumulating life insurance on John, as well as making other financial arrangements to her benefit in the event of his death.

Initially, the shooting appeared to be a hunting accident. However, the autopsy revealed two bullet wounds to the body and one bullet hole through John's orange vest. The ensuing investigation noted that the Dodsons were camped near other hunters, one of whom was a Texas law enforcement officer. He responded to Janice's screaming call that her husband had been shot. He found her standing about 200 yards from the camp in a grassy field along a fence line. Once the officer determined that John was dead, he went to get help.

Prior to this, Janice had returned to her camp and removed her hunting coveralls, which were covered with mud from the knees down. She later told investigators that she had stepped into a mud bog along the fence near the camp. Investigators later found a .308 caliber shell case approximately 60 yards from the body. They also found a .308 caliber bullet in the ground on the other side of the fence, directly beyond the location of the bullet case to the body.

Photo courtesy of Raymond C. Murray

Figure 2. Soil evidence can be an extremely powerful component in a murder investigation. Mud samples collected from this pond lined with bentonite clay at a campsite in western Colorado matched the dry mud on a murder suspect's overalls. This finding, aided by forensic geology, led to the conviction of Janice Dobson in the slaying of her husband in 1995.

J.C. Lee, Janice's former husband, was also on a hunting trip and camped three quarters of mile from the Dodsons. Janice knew from past hunting trips that this was Lee's favorite annual camp location; therefore, he naturally came under suspicion. However, at the time of the shooting, Lee and his boss were hunting far away from camp. Most importantly, Lee also told investigators that his .308 rifle and a box of .308 cartridges had been stolen from his tent while he was out hunting.

Investigators Bill Booth, Dave Martinez and Wayne Bryant returned during the following summers of 1996, 1997 and 1998 to search for the rifle and other evidence. Using metal detectors, they scoured the entire area, including various ponds, but the rifle was never found. During their final search of the pond near Lee's camp, Al Beiber of NecroSearch International, a nonprofit consulting company for law enforcement agencies, noted that the mud in and around that pond was bentonite. Bentonite is a clay that is often used to line the bottom of man-made ponds in order to keep the water from seeping out of the bottom (Figure 2). Camped near the crime scene that evening, Booth and Martinez were discussing the evidence in the case when Booth suddenly exclaimed, "the mud!" He was referring to the dried mud that was found on Janice Dodson's coveralls. If she had obtained the rifle from Lee's camp, she would have most likely stepped in or fallen into the bentonite clay.

Janice had stated that while returning to camp on the morning of October 15, 1995, she stepped into a mud bog. Booth and Martinez therefore decided to obtain dried mud samples from the bog near the Dodson camp, the area around a pond near the Dodson camp, and the man-made pond and run-off near Lee's camp.

The mud samples collected from Janice Dodson's clothing had been held at the sheriff's office evidence room since 1995. The mud from each pond and bog sampled from the scene, along with the dried mud that had been recovered from Janice Dodson's coveralls, were sent to the Laboratory of Colorado Bureau of Investigation in Denver for examination. Jacqueline Battles, a

Photo courtesy of Raymond C. Murray

Figure 3. After examining the oily particles from an indoor parking garage floor such as this one, a forensic geologist helped track down the murderer of a young boy in Scarboro, Ontario.

forensic scientist and lab agent, examined the material. She concluded (and later testified in court) that the dried mud found on Janice's clothing matched the dried mud recovered from the pond near Lee's campsite, and did not match the mud bog or the pond near her camp. This finding was a breaking point in the case. The discovery placed Janice Dodson in her ex-husband's camp around the time Lee's rifle had been stolen. Because there are no other bentonite lined ponds or bentonite deposits in the area. Janice Dodson was extradited to Colorado, tried, and convicted of the murder of Bruce Dobson. The jury understood the results that followed Booth's insightful exclamation: "the mud!"

Even without unusual circumstances, soil evidence can be extremely powerful. A Canadian homicide case illustrates the value of careful examination. The body of 8-year-old Gupta Rajesh was found beside a road outside of Scarboro, Ontario, in 1982. The back of his shirt had a smear of oily material, and the preliminary conclusion was a hit and run accident, because the oily material potentially came from the undercarriage of a vehicle. However, an examination of the oily substance and its particles by forensic geologist William Graves of the Centre of Forensic Sciences in Toronto told a different story.

Samples of oily material were collected from the concrete floor of a garage where the suspect, Sarbjit Kaur Minhas, parked her Honda automobile (Figure 3). Analysis of these samples showed that the particles from the victim's shirt and the parking garage were similar. In addition, samples were collected from ten other garages in the area. The oily materials from the victim's shirt and the suspect's parking place were significantly different from these other samples. Particles in samples taken from the victim's clothing and the suspect's parking spot provided considerable information. For analysis, the sand was sieved and subsamples were produced of the various size grades for the two samples. When compared, the color of each pair of subsamples was identical after the oil had been removed. The heavy minerals in both samples were similar when identified under the petrographic microscope.

Three different and distinct types of glass were found in both samples: amber glass, tempered glass and light bulb glass. The refractive index of each glass specimen was identical in samples from both the oily spot on the garage floor and the victim's shirt. Small particles of yellow paint with attached glass beads were also found in both samples. This type of paint is often found on center stripes of highways and is used to reflect light. Based on the evidence, Graves concluded that there was a high probability that the body of Gupta Rajesh had been in contact with the oily spot on the concrete garage floor at the place where the suspect parked her car. Minhas was tried in the Superior Court of the Province of Ontario in November 1983 and convicted of murder.

Similar to the 1856 case in Prussia, rock material was substituted for valuable computer equipment being shipped from Texas to Argentina via Miami. When the crate was opened in Buenos Aires, it contained only concrete blocks. Skip Palenik, a forensic scientist and the president of Microtrace LLC, was asked to examine the material. Using gentle acids to dissolve the cement, Palenik removed the sand from the concrete. Under the petrographic microscope, the sand appeared fine, with a very narrow distribution of grain sizes that is characteristic of beach sand. Furthermore, it had a composition of heavy minerals that suggested a location in Florida.

Palenik compared the sample with Florida sand from his extensive collection of sands and found them to be similar. He suggested to investigators that the people who substituted the concrete blocks probably did not move them far and recommended that they check the Miami airport, where investigators found identical blocks at an airport construction site. This led to the identification and conviction of those who substituted the computer equipment with the concrete blocks.

UNEARTHING MINE FRAUD

Forensic examiners of mineral material often find themselves involved in cases of mine fraud, gem fraud and art fraud. In these cases, the methods are the same as those used in other soil cases, because the goal is to identify and characterize the mineral particles.

The most massive and disastrous mine fraud in recent times involved the Bre-X mining company. This scandal began with a near-worthless gold mining property along Busang Creek on the island of Borneo and grew to become the biggest mining fraud case in Canadian history. John Felderhof and Michael de Guzman were geologists with excellent professional reputations, and both were desperate for work. Felderhof sent de Guzman to Busang in 1992 to see if the gold mine could be sold. De Guzman's report was very optimistic.

Previously in 1989, Canadian mining entrepreneur David Walsh had formed a company called Bre-X after his oldest son, Brett. It was listed on the Alberta Stock Exchange and traded between 14 and 30 cents for four years. The company was not doing very well until 1993, when it bought Busang for $80,000 on the basis of de Guzman's report. Drilling began a few months later, producing little gold from the first two holes. The third hole produced significant amounts of gold as did most of the subsequent holes that were drilled. Bre-X stock rocketed to $270.

In 1997, the American mining corporation Freeport-McMoRan acquired partial ownership of the property. Freeport geologists took a careful look at the deposit and discovered that the third drill hole had been salted, or adulterated, with a man-made gold and copper alloy. The other drill samples contained placer gold purchased from local miners. These were easily identified with the stereo binocular microscope. The core samples had all been thrown away, and a fire in one of the buildings had destroyed all records. On the night of March 10, 1997, the day David Walsh and John Felderhof were to be honored as "Canadian Prospectors of the Year" by the Prospectors Association, the two men received calls from Freeport-McMoRan telling them that the drilling had shown insignificant amounts of gold, and Freeport wanted an explanation. Nine days later in the Borneo jungle, de Guzman fell to his death from a helicopter under mysterious circumstances. Billions of dollars had been lost, and Busang was once again a worthless mining property.

There are many occasions for deception in the gem trade. Fortunately, the gemologist or forensic examiner has the instruments to detect gem fraud. In 1900, J.P. Morgan purchased the famous Bement collection of amber for $100,000 and presented it to the American Museum of Natural History. Specimen AMNH 13704 was labeled and noted in the catalogue as "small tree toad in amber."

Even after re-examination by experts in 1993, the specimen appeared to be 40-million-year-old Baltic amber. The frog was complete with the middle of the head and right eye somewhat collapsed. The skin showed some pigmentation and bones could be seen. Air bubbles, common in most forgeries between the specimen and the resin, were absent. Experts originally judged a thin crack across one end of the specimen to be natural. However, laboratory study of the Bement frog with a stereo binocular microscope and fiber optic lighting revealed a very small sea scallop shell adjacent to the frog. The forger either made a mistake or had a sense of humor when he or she introduced the seashell, which apparently climbed up the tree into the sap. Analysis concluded that someone had drilled a hole in the amber, inserted the frog (and seashell), then carefully cemented the removed side back along a natural fracture.

ART EXPOSED AS FAKE

Scientific detection of art fraud often depends on identifying a mineral pigment that was not available at the time the painting was supposed to have been made (2). A notorious example was the discovery in 1985 of 1,500 Larionov pastels and drawings (3). Mikhail Larionov, a modern painter who left Russia in 1915, has become very fashionable in recent years and his work commands high prices. Experts assumed Larionov left the discovered works in Russia when he moved to Paris. The collection was widely distributed and exhibited in Germany and Switzerland.

Eventually, doubts began surfacing as to whether the 1,500 works were genuine. Using the polarizing microscope, Dr. Walter C. McCrone examined two of the pastels and found titanium white, with the titanium in the mineral rutile form (Figures 4 and 5). He confirmed the identification with X-ray diffraction. Artists did not begin using this material until the 1940s. In addition, the absence of barium sulfate dated the art to the 1950s. Based on this evidence, the alleged Larionovs were found to be fakes. The microscope, combined with a brilliant examiner, discovered the truth.

CHARACTERIZING SOIL SAMPLES

Forensic soil analysis begins with collection of samples. Questioned, or associated, samples are normally taken by accident, with no attempt to provide a good representative sample. For example, a rapist

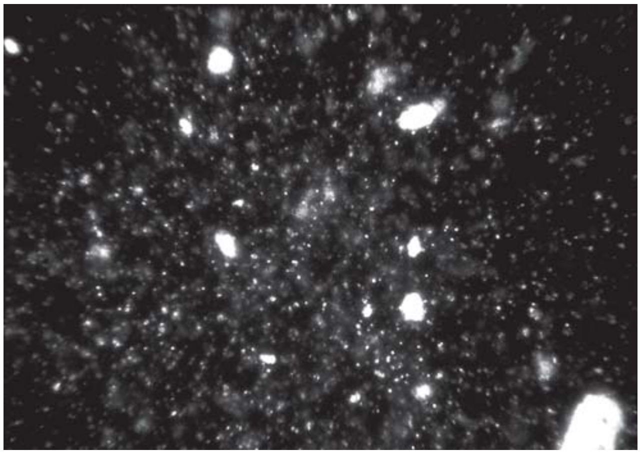

Figure 4 McCrone Research Institute

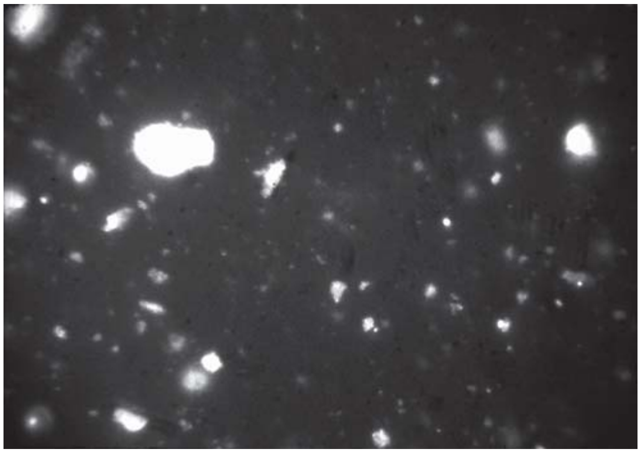

Figure 5 McCrone Research Institute

Figures 4 and 5. Dr. Walter C. McCrone determined that 1,500 paintings once credited to Russian artist Mikhail Larionov were actually fakes. McCrone found the white titanium oxide (TiO_2) mineral substances of rutile (Figure 4) and anatase (Figure 5) in the pigment samples of two pastel paintings that he examined. Artists began using these pigments in the 1940s, long after the original date of the alleged Larionov works.

rarely chooses the best sample of soil for his trouser cuffs, a sample that is the most representative of the soil at the scene of the crime. However, the particles that land in the trouser cuffs may lack some of the larger particles present at the scene. Such a sample can never be expected to be exactly the same as a known control sample, which includes all the available sizes. In such cases, the examiner can only study the particles in the control sample that are the same size as those in the questioned sample.

Known, or control, geologic samples are of two types: those collected from a crime scene or alibi location and those that exist in museums or collections as part of the scientist's professional resources. Investigators or evidence collectors collect samples from the suspect, crime scene and alibi locations as part of the investigation and submit them with other items of physical evidence to the forensic laboratory. The responsibility for recognizing the potential of soil evidence, and for proper sampling, lies with the evidence collector. Evidence collectors generally use the prescribed collecting and transporting procedures of the forensic laboratory.

Because soil types change rapidly over very short distances, both horizontally and vertically, it is important to collect control samples as close as possible to the site where the questioned material originated. Because soil color is commonly the first test used to determine whether or not two samples once had a common source, it is useful to collect control samples that have the same color as the questioned samples.

Examination methods vary depending on the questions being asked and the nature of the samples. In studies where the question is asked, "Do these samples have a common source?" most examiners begin with color. Color is one of the most important identifying characteristics of minerals and soils. In the 1970s, investigators in Great Britain studied the use of color as an examination method (4). Their work helped establish the study of color as an important first step of examination. More recently, Y. Marumo and R. Sugita of the National Research Institute of Police Science in Tokyo have increased the knowledge base of this important tool (5). The color of two samples may be compared by the healthy human eye or by using instrumentation such as a photospectrometer.

Determining the distribution of particle sizes in a sample can lead to significant evidence. The most common method is allowing the sample to fall through a nest of sieves of decreasing pore size. Examiners establish the particle size distribution in samples for a variety of reasons. Sometimes they produce samples for comparison studies that are similar. For example, the control sample may contain some larger or smaller particles that are not present in the questioned or associated sample. In such a case, those particles are removed.

To perform mineral or color studies, forensic geologists sometimes break samples down into subsamples in which all particles are in the same size range. Sometimes particle size distribution itself is a factor in comparison. In a court setting, a diagram of the distribution of grain sizes can have evidential value.

Microscopic examination of soil samples is a critical step in the process. Samples are usually examined using a stereo binocular microscope, which allows examiners to view objects as small as approximately 10 microns in diameter. The upper size limit is dependent on how large a sample can fit under the instrument so that the surfaces of pebbles and cobbles are easily viewed. Various inserts available for these microscopes permit the measurement of object size or provide grids for counting particles.

In examining a soil sample or similar material, the scientist first examines the whole sample as it is received, observes the types of grains and particles, and records a general impression of the material. Particles such as metals, hair, fibers, paint and plastic (which could be extremely valuable evidence), are removed for further examination by specialists. Plant particles can also be of great value. The amount of plant material in a sample is usually less important for forensic purposes than identification of individual grasses, seeds, or leaves.

Using a stereo binocular microscope, the experienced geologist can identify the rocks and minerals in a clean sample on sight or through simple tests. It is possible to observe the texture and coatings on the surface of the grains, and such properties as shape, rounding, weathering, inclusions, color and polish. The counting of different kinds of grains is especially important.

The petrographic microscope, which is important in many aspects of forensic work, is the best tool for studying the properties of rocks and minerals. The study of individual mineral grains or thin sections of rocks and related material is easily accomplished by anyone trained to use this instrument. For a thin section of rock, the rock is cut with a diamond saw and the surface of the slice is polished. This polished surface is cemented to a glass microscope slide with an adhesive. The scientist then makes a saw cut parallel to the glass, leaving a wafer of rock cemented on the slide. Grinding of the wafer proceeds to a thinness of approximately 30 microns. A thin glass cover is then glued to the polished rock surface to protect the rock and improve viewing. Most rocks are transparent at this thickness and can be viewed in transmitted light.

Similarly, loose mineral grains of the same general size are commonly mounted in appropriate media on a microscope slide and covered with glass for microscopical study. This is the method used when heavy minerals (minerals with a high specific gravity, such as rutile, garnet, zircon and tourmaline) are separated from common lighter minerals, such as quartz and feldspar. The process is carried out based on settling in heavy liquids. Heavier, dense minerals will sink to the bottom, while lighter minerals float. The heavy minerals, when identified, can often be very important in characterizing the sample. X-ray diffraction is the principal tool in the modern identification of clay minerals. The chemical composition of clays generally tells us very little about their nature, but the possibilities of identifying clays by X-ray diffraction are almost unlimited. X-ray diffraction methods provide a definitive identification of minerals and other crystalline substances.

The scanning electron microscope (SEM) can be useful in observing and identifying very small particles and observing the surface of a particle at high magnification. Some laboratories, especially those in Great Britain, use a technology called QEMSCAN. This is an SEM with three energy dispersive x-ray spectrometers with software designed to provide quantitative mineral identification data. Although it can be quite useful, it does not discriminate polymorphic mineral species. These and other analytical methods provide information that helps characterize a soil sample. Armed with the information that the methods provide, the examiner must make the interpretation: whether or not two samples have a common source, or else determine a sample's original location.

When we see what the microscope is capable of in solving crimes, it is no wonder that a German newspaper headline reporting on a late 19th century crime proclaimed, "The Microscope as Detective."

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