Case closed. Scientists traced soil on this shovel to the burial site of two murder victims.

FORENSIC SCIENCE

Dirty Science: Soil Forensics Digs Into New Techniques

Geologists, chemists, and other scientists are developing better ways of matching soil samples to help catch and convict criminals

A woman and her mother are reported missing from a township east of Adelaide in South Australia. The next day, the woman's car is found 160 kilometers away with a dirty, bloody shovel in the trunk. When her son shows up in a nearby town and tries to get assistance for the broken-down car, police arrest him. But the suspect refuses to talk, and with no bodies to provide evidence or even prove someone is dead, the desperate police seek help.

They call in a team of forensic soil scientists to analyze the shovel. The minerals, acidity, and moisture level of the soil on the shovel lead the team to suggest that the police search a gravel quarry in the Adelaide Hills, where days later a fox uncovers a body. The next day, the second body is found near the first. The son confesses to killing his mother and grandmother and is sentenced to 18 years in prison.

Although it could be a television episode of *CSI*, the case was real—and so were the soil scientists, who now work at the Centre for Australian Forensic Soil Science (CAFSS) in Adelaide, created in 2003 following the team's successful intervention in this 2000 double homicide. CAFSS analyzes soil for investigations from murder to environmental pollution, helps train new forensic scientists, and conducts research on new soil-analysis techniques. It has become well known among Australian detectives. "Ten years ago, police wouldn't have wanted to talk to us," says Rob Fitzpatrick, the center's director. "Now we can't cope with the number of cases."

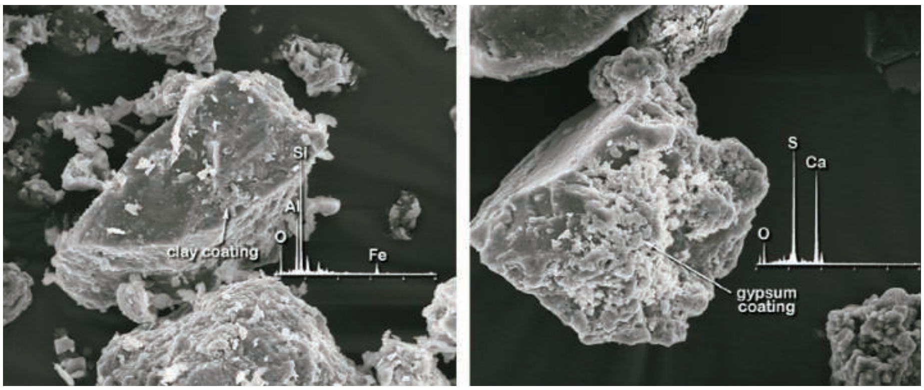
Soil evidence has been used to link criminals to crime scenes for more than a century. But in Australia and elsewhere, the recent automation of techniques and the ability to get information from smaller samples have made soil forensics an increasingly popular tool in criminal investigations. Scientists are now also exploring new ways of applying microscopy to dirt and of analyzing the plant waxes and microbial DNA within it.

Traditionally, soil forensics has been vulnerable to legal attack by defense lawyers because expert witnesses can testify only to whether samples are similar, versus the more absolute nature of a DNA or fingerprint match. Although some protocols are well-established—a soil sample is always sealed and locked, for example, and at least two people must be present while it's being analyzed—the field has yet to settle on the best means to analyze each soil type, explains Lorna Dawson of the Macaulay Institute in Aberdeen, U.K. One project aimed at standardizing old methods and validating new ones is the SoilFit project, led by Dawson and her colleagues. The effort also aims to provide a systematic database of soil fingerprints across the United Kingdom.

Reflecting the growing interest in applying new scientific techniques to soil, forensics researchers in Perth, Australia, last year hosted the first international conference on the topic, drawing several dozen attendees. This month, a second meeting in Edinburgh, U.K., is expected to bring together between 100 and 200 researchers, crime investigators, and forensic experts. "There's a lot of information in soil," says Dawson.

Fertile ground

Analyzing soil samples has a distinguished history in literature and real life. Sherlock Holmes uses soil to deduce Dr. Watson's peregrinations based on the dirt of his shoes in the 1890 work *The Sign of the Four*. A decade later, in the first known instance of soil evidence being used in a criminal investigation, German chemist Georg Popp helped authorities obtain a



Grounds for conviction? Scanning electron microscopy images of soil found on a suspect (*right*) and from a control (*left*) sample reveal differences on the microscale.

CREDITS (TOP TO BOTTOM): MICHAEL HEATH 2004 CSIRO; PHOTOS COURTESY OF EVELYNE DELBOS/MACAULAY INSTITUTE confession in a murder case near Freiberg, Germany. Popp connected dirt from the trouser cuffs and fingernails of the main suspect to the crime scene.

Matching soils is no small task. Soil is dynamic and part alive: A teaspoonful holds more than a million organisms, and soil microbes are constantly dying out or exploding in number. Water also leaches away compounds and introduces others as it trickles through. And soil is sensitive. Disturbing dirt—even by scooping a sample—changes it: Drying it alters its chemistry, exposing it to wind rounds out sharp edges on grains, and sealing it, such as in an evidence bag, can prompt a flurry of fungal growth. Such delicacy means that soil can only be pronounced in court as similar to or dissimilar from a possible source. Still, combining a few dirt characteristics can offer a compelling case for, say, linking a sample on a shoe to one in the back garden.

For the past few decades, soil scientists have used a variety of tools in criminal investigations. Ground-penetrating radar is able to pinpoint burial sites for individual bodies as well as mass graves. X-ray diffraction can uncover the minerals of the soil, infrared spectrometry determines the chemical pedigree, and analysis of diatoms and pollen provides biological clues to dirt's provenance.

Not all of those techniques can be applied to a given soil source, however. And others often require a greater sample size than the crime scene investigators can produce—hence the push for new, robust ways that require less dirt with which to work. As a visiting research fellow at CAFSS a few years ago, geologist Duncan Pirrie of the University of Exeter, U.K., saw how an automated scanning electron microscope could boost the availability and effectiveness of soil forensics. About 20 minerals occur in most soils, he explains, but what makes each sample identifiably distinct is the relative abundance of each mineral.

The CAFSS microscope, called QEMSCAN, finds both the mineral composition and its relative abundance from just 10 mg of dirt—50 times less than previously required. A similar instrument was originally developed for mining applications by Australian scientists, and the design was then adapted for use in forensic applications. QEMSCAN will analyze in 1 hour what would take a mortal days, and the scope's objective analysis triumphs over simple visual analysis of soils by people.

For a murder case in 2003, Pirrie hauled soil evidence from the United Kingdom to Australia for analysis, then promptly set up a QEMSCAN at his own university. Pirrie, who also conducts research on climate change in cretaceous Antarctica and on the effects of mining on coastal zones, says his lab is the only one in Europe with such a forensic scope. Today, the lab is called on about once a month to analyze traces of soil for murder and assault cases.

Tiny clue. New methods can link a soil sample to its source using a small fraction of a gram.

CREDIT: DAVID RILEY/MACAULAY INSTITUTE

Several new soil-analysis techniques remain a topic of lab research rather than court cases—at least for now. Organic substances among a soil's minerals can also offer an opportunity to match samples. One of Dawson's projects funded under the SoilFit umbrella looks at profiling soils by the mementos plants leave behind. Plants have a waxy covering to keep them waterproof. The mix of organic compounds—alkanes, acids, sterols, and other alcohols—is unique to each species and persists in the soil, sometimes for thousands of years. Dawson and colleagues are now refining a means of extracting the waxes to identify plants.

Jacqui Horswell, a soil microbiologist at the Institute of Environmental Science and Research in Porirua, New Zealand, is pursuing another means of matching soil samples: DNA. Millions of species of fungi and bacteria form complex communities in dirt, yet most remain unknown to scientists. Fewer than 1% of bacterial species can be cultured in the lab, she explains. But by applying a technique that chops DNA at specific target sequences and analyzes the length of the segments, Horswell can profile most of the bacteria in 200 mg of soil. The method doesn't identify individual species. Instead, without the need to culture any microbes, it produces a DNA signature for the organisms within the soil. Horswell and her research team published their first DNA soil profiles in 2001, and they hope that in another 5 years their database of soil DNA signatures will be large enough to be useful in court.

From science to law

Indeed, getting a new forensic technique established well enough for courts to recognize it can be a challenge. The SoilFit project, started in 2005 with funding from the U.K.'s Engineering and Physical Sciences Research Council (EPSRC), is one effort to give soil-matching more reliability as evidence. For prosecutors to better survive legal challenges in court, "we need a comprehensive survey of soil types in the United Kingdom" to substantiate the conclusions of an expert witness, says Derek Auchie, director of undergraduate law programs at Aberdeen Business School. To that end, EPSRC gave Dawson's team a £350,000 grant to analyze all feasible combinations of soil types—such as loams, peat, and alluvial soils—and vegetation such as grassland, heather, and forest. To date, they have tested an array of analysis techniques on all 120 combinations and are now comparing each technique's accuracy to work out which ones work better for which soil combinations.

EPSRC funded SoilFit under its Crime Initiative, which seeks to bridge crime-fighting services and academic research to benefit U.K. citizens. The project is "developing a community of researchers active in [fighting] crime," says Peter Hedges, head of EPSRC's Economy, Environment and Crime Team. Dawson predicts that the SoilFit database will be ready for detectives and prosecutors in 2008. Sherlock Holmes would be pleased.

–KRISTA ZALA

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