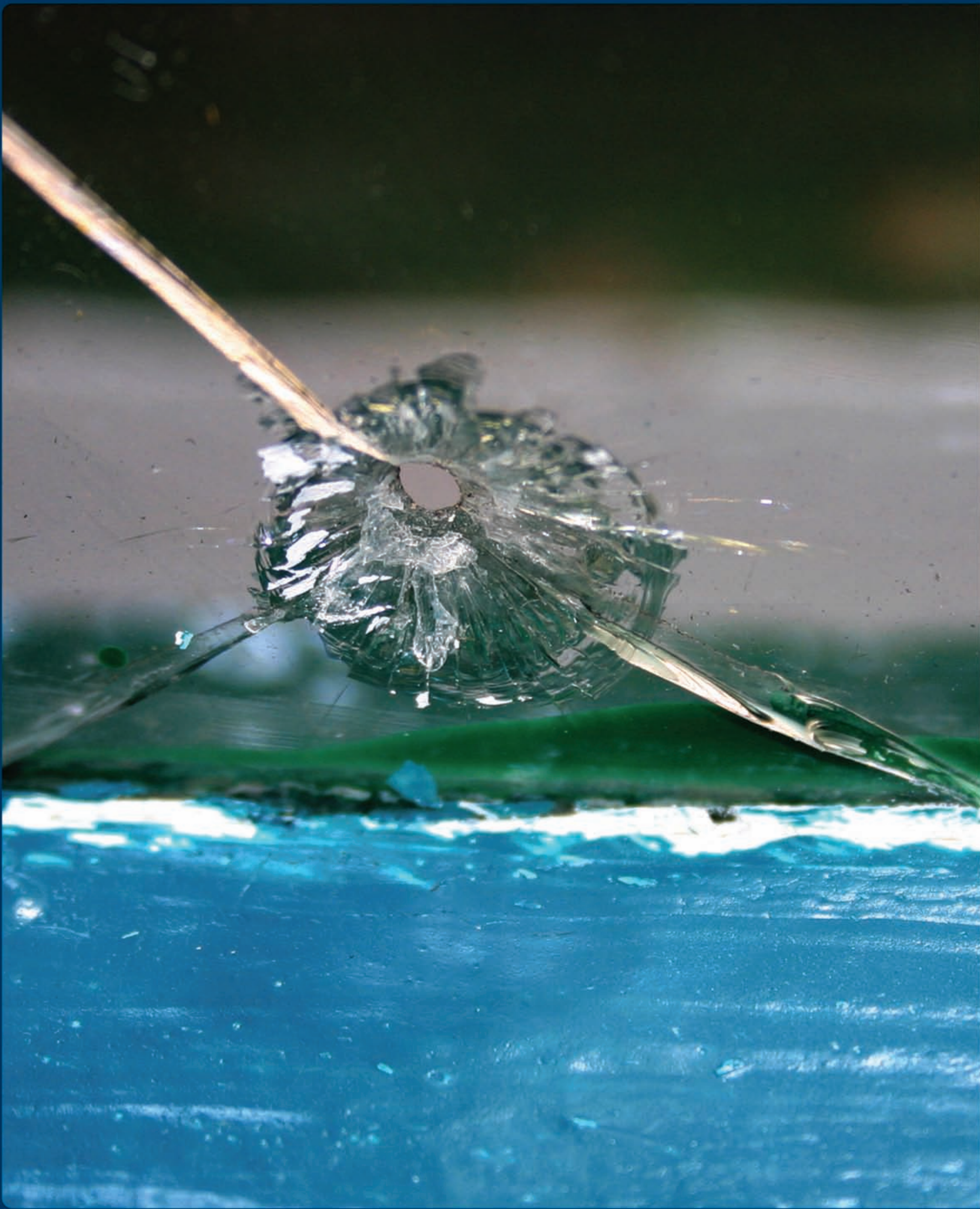
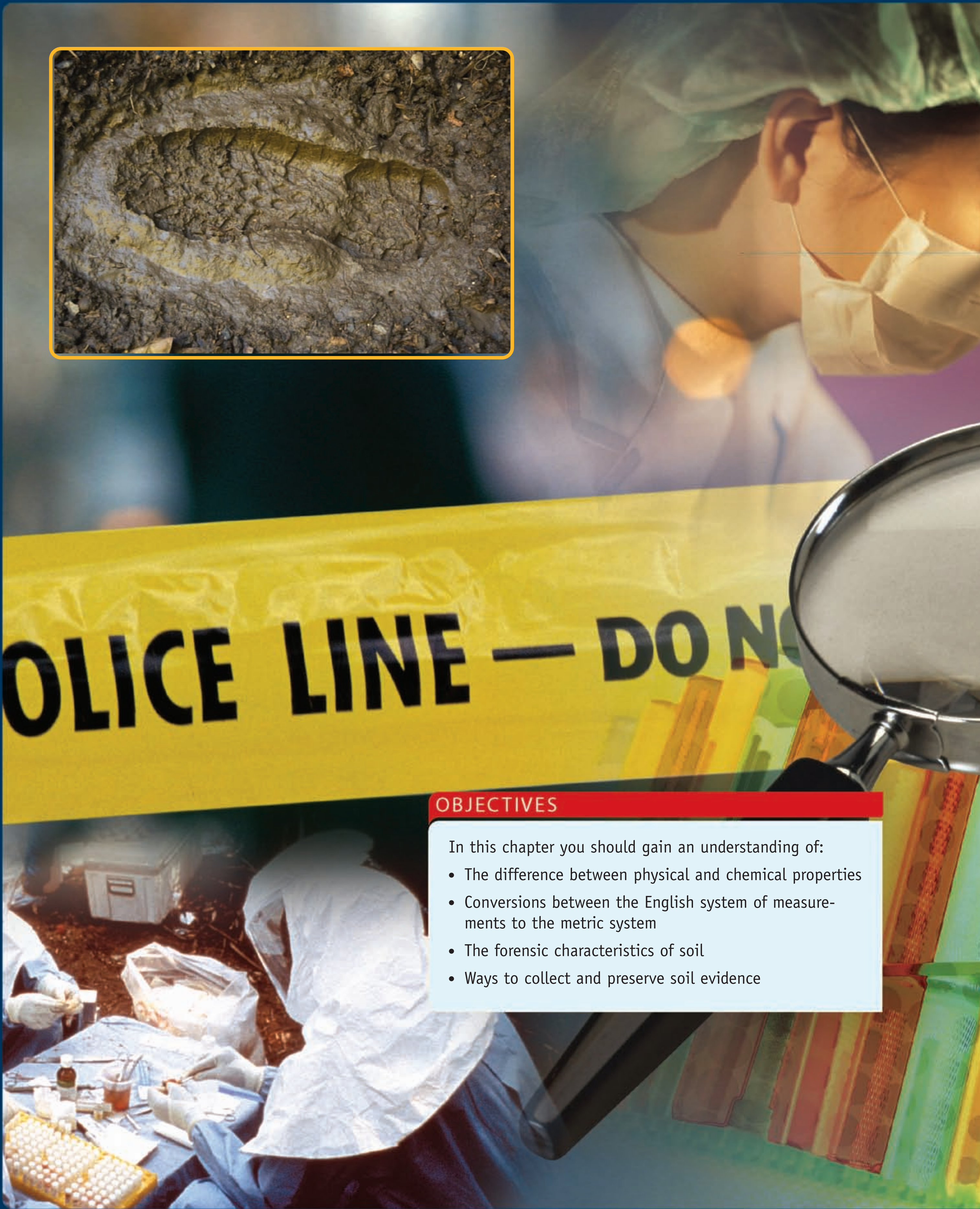


SECTION 2

Trace Evidence



OBJECTIVES

In this chapter you should gain an understanding of:

- The difference between physical and chemical properties
- Conversions between the English system of measurements to the metric system
- The forensic characteristics of soil
- Ways to collect and preserve soil evidence

CHAPTER

3

Physical Properties: Forensic Characterization of Soil

FEATURES

BACK AT THE CRIME LAB

CRIMINALIST'S NOTEBOOK

EXAMPLE

LET'S GET REAL

LINKS

ON THE CRIME SCENE

SEE YOU IN COURT

WORD TO THE WISE

YOU ARE THE FORENSIC SCIENTIST

WRAP UP

Chapter Spotlight

Key Terms

Putting It All Together

WWW.CRIMINALISTICS.JBPUB.COM

Chapter Pretests
Interactivities
Key Term Explorer

YOU ARE THE FORENSIC SCIENTIST

Soil provides useful evidence because it is either sticky or friable. A "friable" object is easily crushed and made into a powder. Whether sticky or friable, however, soil is easily transferred as trace evidence from the crime scene onto objects and people present at the scene. This trace evidence may then be transferred again by secondary transfer onto carpets or into vehicles.

Soil also has properties similar to those of soft, plastic objects such as Play-Dough; in particular, it can retain an impression that has been pressed into it. This property is especially useful in providing evidence of association. For example, a worn boot might leave an impression at the crime scene, and the footwear later be found to be owned by the suspect.

1. A suspect in a burglary is found to be wearing brand-new size 12 Wolverine boots. Outside the broken window, in the garden of the home that was robbed, is a boot impression that matches that made by a size 12 Wolverine boot. Does the evidence prove that this suspect was the burglar?
2. The burglar knocked over a flowerpot in the home, which fell to the ground and broke. A soil sample found in the suspect's car contains the same vermiculite material (a common component of potting soil) that was found in the soil of the flowerpot. Is this class or individual evidence?

Introduction

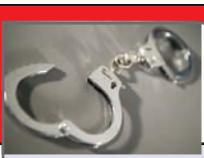
When common objects are found at crime scenes, forensic laboratories first examine those items in an attempt to identify properties that may serve to place the object within a particular class. The search for distinguishing properties then continues, as the forensic scientist tries to discover additional characteristics that will allow the object to be individualized. This chapter describes the properties that are most useful for characterizing soil, glass, fibers, and other physical evidence. It also discusses how to collect evidence and measure its distinguishing properties.

Physical and Chemical Properties

The distinguishing characteristics that are used to identify different objects are called properties. A person can easily recognize his or her own car among hundreds of other cars in a parking lot by characteristics such as make, model, color, dents in the body, and belongings left on the back seat. In much the same way, we can recognize different substances by their characteristics or properties. Properties of substances can be grouped into two main categories: physical and chemical.

The physical properties of a substance are those properties that can be observed and recorded without referring to any other substance. Color, odor, taste, hardness, density, solubility, melting point (the temperature at which a substance melts), and boiling point (the temperature at which a substance boils or vaporizes) are all physical properties. For example, if you were to describe the physical properties of pure copper, you might report that it is a bright, shiny metal; is malleable (can be beaten into thin sheets) and ductile (can be drawn into fine wire); and melts at 1083 °C (1981 °F) and boils at 2567 °C (4653 °F). No matter what its source, pure copper always has the same properties. These intensive physical properties are independent of amount of substance measured and depend only on the identity of the substance. For example, when a substance melts (e.g., when ice turns into water), heat is applied to change it from a solid to a liquid, but this change in state does not change the composition of the substance. Thus the appearance of the substance may change but there is no change in composition. By contrast, extensive physical properties—such as mass, volume, and length—depend on the amount of substance present.

The chemical properties of a substance are those properties that can be observed when the substance reacts or combines with another substance to change its chemical composition. For example, when gasoline burns, it undergoes a chemical change: It combines with oxygen in the air to form carbon dioxide and water. Likewise, copper turns



on the CRIME SCENE

The Enrique Camarena Case: Soil Evidence Reveals Location of Murder

In 1985, the bodies of Enrique "Kiki" Camarena Salazar, a U.S. Drug Enforcement Agency (DEA) agent, and Alfredo Zavala Aguilar, the Mexican reconnaissance pilot with whom Salazar worked, were found in the Mexican state of Michoacan. Camarena was an undercover agent assigned to clandestine surveillance of Mexican drug lords. The Mexican Judicial Police reported that both men died in a shootout between police and the drug dealers at El Mareno ranch in Michoacan. Close examination of the bodies, however, revealed that they had been tortured and that Camarena's head had been crushed. Furthermore, the Mexican police showed little or no interest in finding the perpetrators of this crime—unusual behavior for a crime in which a law enforcement agent had died.

DEA officials sent evidence taken from Camarena's body to the Federal Bureau of Investigation (FBI) Crime Laboratories for further testing to determine conclusively what had happened to the two men. FBI Special Agent Ron Rawalt, a forensic geologist, requested soil samples from both Camarena's body and the location the body was found. Soil had mixed with body fluids at wound sites throughout the slain agent's body, a process that takes some time. This rocky soil contained tan and brown volcanic ash and fragments of rhyolite, a fine-grained igneous rock that is rich in silica. By contrast, soil samples taken from the ranch in Michoacan contained a coarse, greenish-black basaltic glass but no rhyolite.

Further analysis of the material found in the body's wounds led FBI geologists, with the help of Smithsonian Institute scientists, to determine that the material was consistent with that found in the El Tequilla ash flow in the Guadalajara Basin, nearly 100 km north of the site in Michoacan. Investigators now knew that the agent was not murdered in Michoacan—but they needed still more information to solve the case.

Extensive field studies narrowed the location of the original grave site in the Guadalajara Basin. The investigators also knew that grass had burned nearby, because charred material was present in Camarena's body. Furthermore, they needed to find an area where the ash flow carrying the rhyolite was at least 6 to 8 ft deep. Using these criteria, a location was determined and cadaver dogs were used to find the exact grave site.

The evidence showing that the body was originally buried in Guadalajara allowed the investigators to solve the mystery. The Mexican police, facing mounting pressure from the U.S. government to find Camarena, had conspired with the drug lords to move the FBI agent's body from Guadalajara (where the crime occurred) to Michoacan. The Mexican police subsequently raided the farm in Michoacan, where they killed the occupants, placed the dead agent's remains in a prominent position, and declared that they had found Camarena's body.

green when it is exposed to the atmosphere for a long time; the surface reacts with moisture, oxygen, and pollutants in the atmosphere to form a new substance. If a substance does not react with another substance, its lack of reactivity also qualifies as a chemical property. For example, one chemical property of gold is that, unlike copper, it does not tarnish or change when exposed to the atmosphere.

Whether a forensic scientist measures a physical property or a chemical property of an object that is evidence, that measurement must conform to a standard system of measurements that is accepted throughout the world.

WORD TO THE WISE

Mineral: A naturally occurring crystalline solid.
Rock: An aggregate of minerals.
Soil: A complex mixture of minerals, rocks, and organic materials, such as plants.

The Metric System

In forensics and all other scientific fields, it is very important to take accurate measurements. For example, medical treatment relies on accurate measurements of factors such as temperature, blood pressure, and blood sugar concentration, just as baking requires careful measurement of flour, water, and sugar combined with the regulation of baking time and temperature.

All measurements are made relative to some reference standard. For example, if you measure your height using a ruler marked in meters, you are comparing your height to an internationally recognized reference standard of length called the meter.

Most people in the United States use the English system of measurement and think in terms of English units (i.e., feet and inches, pounds and ounces, gallons and quarts). If a man is described as being 6 ft 4 in tall and weighing 300 lb, we immediately think of a large man. Similarly, we know how much to expect if we buy a half-gallon of milk at the grocery store. Most Americans, however, have a far less clear idea of the meaning or size of a meter, liter, or kilogram. These common metric units of measurement are used by the scientific community and in most countries other than the United States. Although the United States is committed to changing to the metric system, the pace of change, so far, has been extremely slow.

The International System of Units

The International System of Units (SI) was adopted by the International Bureau of Weights and Measures in 1960. The SI is an updated version of the metric system that was developed in France in the 1790s, following the French Revolution.

The standard unit of length in the SI is the meter. Originally, the meter was defined as one ten-millionth of the distance from the North Pole to the equator measured along a meridian. Not surprisingly, this distance proved difficult to measure accurately. Thus, for many years, the meter was defined as the distance between two lines etched on a platinum iridium bar that was kept at the International Bureau of Weights and Measures in Sevres, France. Today, the meter is defined even more precisely, as being equal to 1,650,763.73 times the wavelength of the orange-red spectrograph line of the krypton isotope, ${}^{86}_{36}Kr$.

LINK Learn more about spectrographic lines in Chapter 9.

The standard unit of mass in the SI is the kilogram. It is defined as the mass of a platinum iridium alloy bar that, like the original meter standard, is kept at the International Bureau of Weights and Measures.

SI Base Units

There are seven base units of measurement in the SI system (TABLE 3-1). Because these base units are often inconveniently large (or small) for many measurements, smaller (or larger) units—as defined by the use of prefixes—are often used instead. TABLE 3-2 lists the prefixes used in the SI, with the measurements that are most commonly used in forensic science being shaded.

In addition to the seven SI base units, many other units are needed to describe other physical quantities. All of these units are derived from the seven base SI units. For example, volume is measured in cubic meters (m^3), and area is measured in square meters (m^2). TABLE 3-3 lists commonly used SI derived units.

Because the SI is based on the decimal system, conversions within it are much easier than conversions within the English system. Units within the SI always differ by factors of 10, so conversions from one SI unit to another are made by moving the decimal point the appropriate number of places.

TABLE 3-1

SI Base Units

Quantity Measured	Name of Unit	SI Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

TABLE 3-2

SI Prefixes

Prefix	Symbol	Exponential Form	Decimal Form
mega	m	10^6	1,000,000
kilo	k	10^3	1,000
hecto	h	10^2	100
deka	da	10^1	10
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001

TABLE 3-3

SI Derived Units

Physical Quantity	Unit	SI Symbol
Area	square meter	m^2
Volume	cubic meter	m^3
Density	kilogram per cubic meter	kg/m^3
Force	newton	N
Pressure	pascal	Pa
Energy or quantity of heat	joule	J
Quantity of electricity	coulomb	C
Power	watt	W
Electric potential difference	volt	V

EXAMPLE

A search of a crime scene turns up 0.0583 kg of cocaine. How many grams of cocaine have been found?

Solution

1. Use Table 3-2 to find the relationship between kilograms and grams: 1 kg = 1000 g.
2. From this relationship, determine the conversion factor by which the given quantity (0.0583 kg) must be multiplied to obtain the answer in the required unit (g).

$$\text{conversion factor} = \frac{1000\ \text{g}}{1\ \text{kg}}$$

3. Multiply 0.0583 kg by the conversion factor to obtain the answer.

$$0.0583\ \text{kg}\left(\frac{1000\ \text{g}}{1\ \text{kg}}\right) = 58.3\ \text{g of cocaine}$$

When the multiplication is complete, the kilograms cancel out of the equation.

EXAMPLE

A bullet hole is found in a wall 4236 mm from the floor. How many centimeters is the bullet hole from the floor?

Solution

1. 1 cm = 10 mm

$$\text{conversion factor} = \frac{1\ \text{cm}}{10\ \text{min}}$$

2. Multiply 4236 mm by the conversion factor to obtain the answer.

$$4236\ \text{mm}\left(\frac{1\ \text{cm}}{10\ \text{mm}}\right) = 423.6\ \text{cm}$$

Conversion from the SI to the English System (and Vice Versa)

TABLE 3-4 lists units commonly used in the English system for length, mass, and volume. TABLE 3-5 gives the relationships that must be used to convert from SI units to English units, and vice versa.

EXAMPLE

A bloodstain is found 25 in. from the victim's body. How many centimeters is the body from the bloodstain?

Solution

1. Use Table 3-5 to find the relationship between inches (in.) and centimeters (cm).

$$1\ \text{in.} = 2.54\ \text{cm}$$

2. The answer needs to be expressed in centimeters. Therefore the conversion factor is

$$\frac{2.54\ \text{cm}}{1\ \text{in.}} = \text{conversion factor}$$

3. Calculate the answer.

$$25\ \text{in.}\left(\frac{2.54\ \text{cm}}{1\ \text{in.}}\right) = 63.5\ \text{cm}$$

EXAMPLE

The Border Patrol finds 60 lb of marijuana in the trunk of a car. How many kilograms of marijuana have been found?

Solution

1. Use Table 3-5 to find the relationship between pounds and kilograms.

$$1\ \text{lb} = 0.454\ \text{kg}$$

2. The answer needs to be expressed in kilograms. Therefore the conversion factor is

$$\frac{0.454\ \text{kg}}{1\ \text{lb}} = \text{conversion factor}$$

3. Calculate the answer.

$$60\ \text{lb}\left(\frac{0.454\ \text{kg}}{1\ \text{lb}}\right) = 27.24\ \text{kg of marijuana}$$

WORD TO THE WISE

To make rough estimates of English units and to get a feel for the meaning of SI units, you will find it useful to memorize the following approximations:

$1\ \text{kg} \cong 2\ \text{lb}$
$1\ \text{m} \cong 1\ \text{yd}$
$1\ \text{L} \cong 1\ \text{qt}$
$1\ \text{km} \cong 2/3\ \text{mi}$

Mass and Weight

Matter is the stuff that makes up all things. Matter occupies space and has mass. Iron, sand, air, water, and people, for example, all have mass and occupy space. Mass is a measure of the quantity of matter that an object contains. The mass of an object does not vary with location. Thus a person has the same

TABLE 3-4

Units of Measurement in the English System

Length	Mass	Volume
12 inches (in.) = 1 foot (ft)	16 ounces (oz) = 1 pound (lb)	16 fluid ounces = 1 pint (pt)
3 feet = 1 yard (yd)	2,000 pounds = 1 ton	2 pints = 1 quart (qt)
1760 yards = 1 mile (mi)		4 quarts = 1 gallon (gal)

mass on Earth and on the Moon. Weight, by contrast, measures the force exerted on an object by the pull of gravity. On Earth, it measures the force of attraction between our planet and the object being weighed. On the Moon, which has one-sixth the gravity of Earth, an astronaut weighs only one-sixth as much as he or she does on Earth. Thus weight varies with location.

The mass of an object is determined by weighing it on a balance. In the older two-pan balance, a balance beam is suspended across a knife edge and identical pans are hung from each side (FIGURE 3-1a). The object to be weighed is placed on the left pan, and a series of standard weights is placed on the right pan. When the mass of the standard weights in the right pan is identical to the mass of the object in the left pan (i.e., they balance), the indicator (located between the two pans) points to the center mark.

A modern electronic balance has only one pan and does not routinely use reference weights (FIGURE 3-1b). A typical electronic analytical balance has a capacity to weigh a 100- to 200-g object with a sensitivity of 0.01 mg. When an object is placed on the pan, it pushes the pan down with a force equal to its mass times the acceleration of gravity ($m \times g$). The electronic balance then uses an electromagnet to return the pan to its original position. The electric current required to generate this amount of force is proportional to the mass, which is displayed on a digital readout.

Temperature

For certain measurements, including those involving temperature and energy, forensic scientists continue to use units that are not SI units. The SI unit for temperature is the kelvin (K), but forensic scientists use the Celsius scale for many temperature measurements. On this scale, the unit of temperature is the degree Celsius (°C); this scale was devised so as to set the freezing point of water as 0 °C and its boiling point at 100 °C, both at atmospheric pressure. The 100 degrees between these two reference points are of equal size.

In the United States, most temperatures, including those given in weather reports and cooking recipes, are measured in Fahrenheit. On this scale, water's freezing point is 32 °F and its boiling point is 212 °F. Thus there are 180 degrees between the freezing and boiling points. Given that the Celsius temperature scale has only 100 degrees between these same two points, 5 degrees on the Celsius scale is equivalent to 9 degrees on the Fahrenheit scale.

To convert from Fahrenheit to Celsius, use the following equation:

$$°F = \frac{9}{5}(°C) + 32 \text{ or } °F = 1.8(°C) + 32$$

To convert from Celsius to Fahrenheit, use the following equation:

$$°C = \frac{5}{9}(°F - 32) \text{ or } °C = 0.56(°F - 32)$$

TABLE 3-5

Conversion Factors for Common SI and English Units

Length	Mass	Volume
1 inch (in.) = 2.54 centimeters (cm)	1 ounce = 28.4 grams (g)	1 fluid ounce (fl oz) = 29.6 milliliters (mL)
1 yard (yd) = 0.914 meter (m)	1 pound (lb) = 454 grams (g)	1 U.S. pint (pt) = 0.473 liter (L)
1 mile (mi) = 1.61 kilometers (km)	1 pound (lb) = 0.454 kilogram (kg)	1 U.S. quart (qt) = 0.946 liter (L)
		1 gallon (gal) = 3.78 liters (L)


(a)

(b)

FIGURE 3-1 (a) A traditional two-pan balance. The object to be weighed is placed on the left pan, and standard weights are placed on the right pan until the two pans balance. (b) A modern electronic laboratory balance has only one pan and a direct digital readout.

The measurement of temperature is one of the physical properties commonly recorded at crime scenes and in forensic labs. Indeed, one simple way to determine the identity of an unknown liquid is to measure its boiling point. In the past, temperature was measured with a glass thermometer that contained either mercury or alcohol colored with a red dye. When the thermometer came into contact with a hotter object, heat was transferred to the thermometer and the mercury (or alcohol) expanded and moved up the glass column. If the object was cooler, the mercury (or alcohol) contracted and moved down the glass column. Because mercury is poisonous and glass breaks easily, this type of thermometer is rarely used today.

Currently, temperature is measured with either electronic or optical thermometers. The electronic thermometer uses a thermocouple to measure temperature. Inside the probe, two different metals are joined together. Electrons have a lower free energy in one of the metals than the other, so they flow from one metal to the other. The flow of electrons depends on temperature and is measured by a small circuit that converts the electrical signal into temperature. A switch on these thermometers changes the output from Fahrenheit to Celsius.

Optical thermometers (pyrometers) measure temperature without making contact with the object. They are available as hand-held point-and-shoot guns (FIGURE 3-2). All objects release infrared radiation (IR), and the wavelength of the IR emitted is directly proportional to the temperature of the object. After using an infrared detector to convert the IR energy to an electrical signal, the optical thermometer reports temperature in either Fahrenheit or Celsius. It is important to remember

FIGURE 3-2 An optical thermometer measures the temperature without contacting the object being measured.

that this device records the temperature of the surface of the object. An optical thermometer should not be used to measure the temperature of an object that may be warmer in the interior than on the surface, such as a dead body.

Algor mortis is the natural drop in body temperature that occurs after death. Normal body temperature is 98.6 °F. If the temperature of the area surrounding the body is in the range of 18 °C (64 °F) to 20 °C (68 °F), then the temperature of a naked body will drop 1.5 °C per hour for the first 8 hours after death. To identify the time of death, the rectal temperature of the body is measured with a thermometer and the postmortem interval determined.

EXAMPLE

1. Normal body temperature is 98.6 °F. What is this temperature in degrees Celsius?

Solution

$$°C = \frac{5}{9}(°F - 32) = \frac{5}{9}(98.6 - 32) = 37\ °C$$

2. The medical examiner determines that a body found at a crime scene wearing only underwear has a rectal temperature of 87.8 °F. Estimate the postmortem interval.

Solution

1. Convert the temperature of the dead body from Fahrenheit to Celsius:

$$°C = \frac{5}{9}(°F - 32) = \frac{5}{9}(87.8 - 32) = 31\ °C$$

2. Determine how many degrees the body cooled. The living body was at 37 °C and it dropped to 31 °C:

$$37\ °C - 31\ °C = 6\ °C \text{ drop}$$

3. Given that body temperature decreases 1.5 °C per hour after death, then

$$6\ °C = (1.5\ °C/\text{hr})\ (x \text{ hours})$$

$$x \text{ hours} = \frac{6\ °C}{1.5\ °C/\text{hr}} = 4 \text{ hr}$$

The victim has been dead for 4 hours (postmortem interval).

Density

When examining an object of evidence, density may be useful to help establish its composition. Density is often confused with weight, as in the following inaccurate examples: "Mercury is heavier than water" and "iron is heavier than aluminum." What is actually being compared is the densities of these materials, not their weights. The density (d) of a substance is defined as the mass (m) of the substance per unit volume (V):

$$d = \text{sample mass/sample volume} = m/V$$

Density is an intensive property of matter. An intensive property does not depend on how much matter you have; thus the density of a material is the same regardless of how big a sample of that material you are investigating. Gases are less dense than liquids, and liquids are less dense than solids. The common units of density for solids and liquids are g/cm^3 or g/mL and for gases, g/L. A good fact to memorize is that the density of water is 1 g/mL. Knowing this density allows you to estimate the weight of any volume of water. The densities of some common substances are listed in TABLE 3-6.

The procedure for determining the density of a solid object is simple. First, the object is weighed on an electronic balance and its mass determined. Next, a graduated cylinder is partially filled with water and the volume recorded (V_1). The solid object is then carefully lowered into the graduated cylinder. Once the object is completely submerged, the total volume of the object and the water in the graduated cylinder (V_2) is measured (FIGURE 3-3). The difference between the original volume and the final volume ($V_2 - V_1$) is the volume of the object.

TABLE 3-6

Densities of Some Common Substances at 20 °C

Substance	Density (g/mL)
Gases	
Air	0.00124
Carbon dioxide	0.00198
Hydrogen	0.00009
Liquids	
Mercury	13.6
Ethyl alcohol	0.79
Gasoline	0.69
Water	0.998
Solids	
Gold	19.3
Lead	11.5
Iron	7.8
Aluminum	2.7
Glass	2.5
Ice	0.92

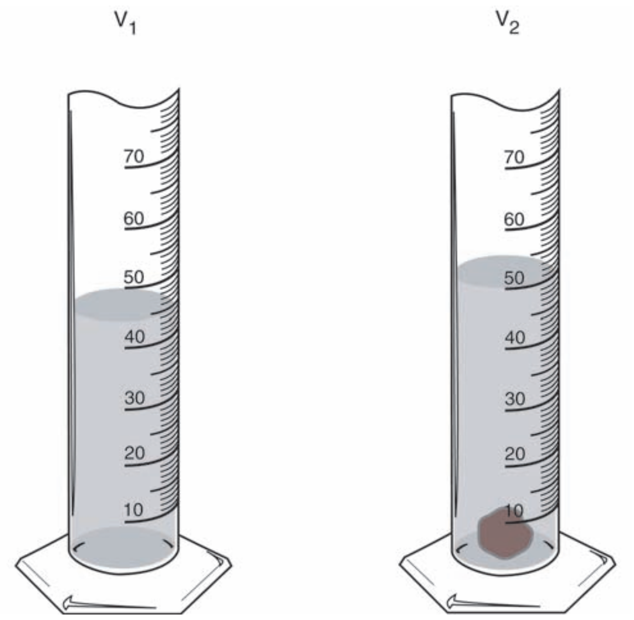


FIGURE 3-3 The volume of the object can be determined by measuring the volume of water it displaces ($V_2 - V_1$).

EXAMPLE

The district attorney wants to know if a metal object recovered from a crime scene is iron or aluminum. When you weigh the object, you find that it weighs 39 g. You take a graduated cylinder and fill it with water until it reads 45 mL. Next, you carefully submerge the metal object into the graduated cylinder; the level of water raises to 50 mL. What is the density of the object? Is it iron or aluminum?

Solution

1. To determine the volume of the object:

$$V_{object} = V_2 - V_1$$

$$V_{object} = 50 \text{ mL} - 45 \text{ mL} = 5 \text{ mL}$$

2. To determine the density:

$$m = 39 \text{ g}$$
$$V = 5 \text{ mL}$$

$$d = m/V = 39 \text{ g}/5 \text{ mL} = 7.8 \text{ g/mL}$$

3. Compare the density of the metal object to the densities in Table 3-6. From Table 3.6 we learn that the density of iron is 7.8 g/mL. Thus this object is iron.

Density exhibits an inverse relationship with temperature. In general, the density of a substance decreases as temperature increases. The amount of change is greatest for gases: Their density decreases on average by 0.33% per 1 °C increase. The density decrease for liquids and solids with increases in temperature depends on the specific substance. The density of water decreases by 0.025% per 1 °C increase, the density of alcohol decreases by 0.011% per 1 °C increase, and the density of mercury decreases by 0.018% per 1 °C increase. It is important to make sure the temperature of an object is constant (not changing) before making density measurements. Ideally, these measurements will be made in a constant-temperature chamber.

To make a rough estimate of the density of an object, simply immerse it in water. If the object sinks, it has a density greater than 1 g/mL. If it floats, it has a density less than 1 g/mL. This flotation technique can be used to characterize soils.

Soils

Soil is a complex mixture of inorganic and organic materials. The inorganic part comprises remnants of rock fragments that were formed over thousands of years by the weathering of bedrock. The organic part is derived from the decayed remains of plants. The mineral (inorganic) particles of soil are composed primarily of silicates; depending on the location, however, soil may also contain phosphates and limestone. The size of the particles in a soil determines its texture. Relatively coarse particles (diameter of 0.10 to 2.0 mm) form sand, slightly finer particles form silt, and the finest particles (0.002 mm or less) form clays. Typical soil contains all three types of particles.

A typical soil is made up of several main layers, or horizons (FIGURE 3-4). The uppermost, or O

Criminalist's Notebook

- ❑ Soil evidence can provide essential information connecting the suspect to the victim and/or crime scene.
- ❑ Double transfer is convincing evidence that links the suspect to the victim. The probability of a single exchange of soil may be 1 in 800, but double transfer occurs with a probability of 1 in 64,000.

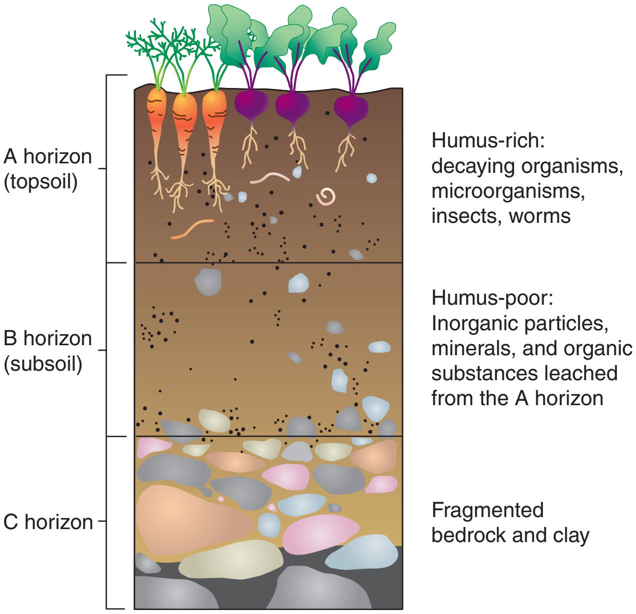


FIGURE 3-4 Soil contains three major layers, or horizons, in which the thickness varies considerably depending on the type of soil.

horizon, contains heavily decomposed organic matter. The A horizon, which includes the **topsoil**, is dark in color. It contains most of the humus—decayed plant and animal materials—in the soil. The A horizon is rich in microorganisms and other creatures, including earthworms, insects, and small burrowing animals that keep the soil aerated. Below the topsoil is the lighter-colored, humus-poor, and more compacted B horizon, also known as the **subsoil**. This layer, which may be several feet thick, consists of inorganic particles of the parent rock and contains minerals and organic materials leached from the A horizon. The C horizon consists of a layer of fragmented bedrock mixed with clay that rests on solid bedrock.

Because they are mixtures of materials, soils have highly individual characteristics. The diversity of materials and the rapid rate at which they change both horizontally and vertically provide a forensic scientist with a powerful tool with which to distinguish one soil from another. The kinds of igneous rock that could be present in soils are almost unlimited, and they are both identifiable and recognizable because they differ in color, mineralogy, and texture. It is this diversity in earth materials, combined with our ability to measure and observe the different kinds of materials, that gives forensic scientists the power to discriminate among various soil samples.

WORD TO THE WISE

Soils are not just surface phenomena; they have three-dimensional characteristics based on their height, length, and width. Typically, horizons (or layers) of soils are established with depth, and each horizon is distinctive in terms of its color, texture, mineralogy, and chemical properties. For this reason, investigators must consider the soil location as well as the depth from which the soil came.

Forensic Characteristics of Soils

Most forensic soil examinations involve comparison of many soil samples taken from different locations. Matching a crime scene sample to a reference establishes a high probability that two samples have a common source. In comparison studies of soils, not only are the natural components of the soils observed, but any artifacts in the soil—such as human-made objects like paint, fiber fragments, or chemicals—are considered as well.

Soil evidence is often found at a crime scene and transferred at the scene of the crime onto the criminal. Mud or soil in the treads of an athletic shoe or tire, for example, may link a suspect to the crime scene. As is the case with most physical evidence, forensic soil analysis is a comparative technique. That is, if soil is found on the shoes of the suspect, it must be carefully collected and compared to soil samples from the crime scene. Soil evidence that is not from the crime scene is also often very helpful to investigators. Careful examination of soil found on a victim's shoes by an expert in forensic geology, for instance, may allow investigators to determine specific sites where the victim might have been before the crime took place.

Most examiners begin by making a visual comparison of the color of the soil sample with reference materials. Forensic experts estimate there are more than 1000 different soil colors that can be distinguished from one another. Side-by-side comparison of the color and texture of soil samples is a simple test that eliminates a large percentage of samples as not being matches (FIGURE 3-5a,b). Because the color of soil becomes darker when it is wet, it is important that all specimens be dried in an oven before their comparison.

Soil color has been standardized according to the Munsell soil color notation. The Munsell soil color book is used to help describe the color of the

FIGURE 3-5 (a) Samples found on the suspect's shoes are compared with soil samples collected from all possible locations where the soil could have originated. (b) Samples are also needed from areas where the suspect claimed the soil originated (alibi samples).

soil in question (FIGURE 3-6). The color of each soil sample in question is compared to a color chart, where each color is given a Munsell code.

Examination of the soil under a low-power microscope may reveal small soil components, such as roots of plants or human-made fibers or plastic fragments. Soils are often passed through sieves to separate soil components by size. After the larger components are removed, examination with a high-power microscope (higher magnification) will help in identifying small rock or mineral fragments in the soil. The size distribution of particles can also be determined if the sample is passed through a nest of sieves (FIGURE 3-7). In such a setup, the sieve on the top has a screen with the largest openings, and each lower screen has smaller holes than the screen above it. After the soil is added through the top, the entire nest of sieves is shaken to agitate the soil and cause components to drop through the screens. As the components fall through the sieves, each subsequent screen catches smaller and smaller components. When the separation is complete, the

FIGURE 3-6 Soil sample color is described with a Munsell soil color code. The soil is matched to color chips in the manual.

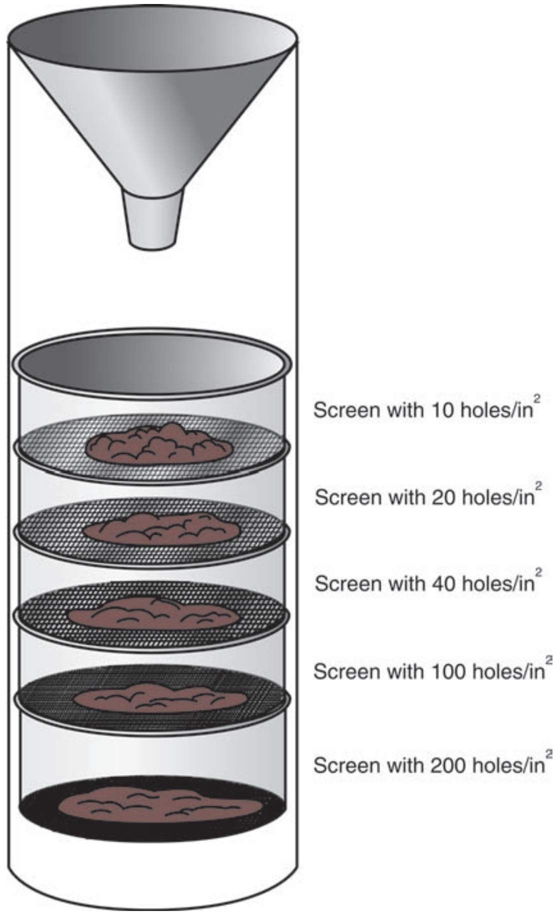


FIGURE 3-7 In a nest of sieves, the top sieve has the coarsest screen. Each subsequent screen has an increasingly finer screen that traps ever-smaller particles.

fractional weight of each screen is determined. The results of the sieve nest can then be used to compare soil samples.

Soils are extremely heterogeneous, and their composition can vary greatly over even short distances, both horizontally and vertically. A surface sample offers little possibility for comparison with soil from a grave that has a depth of 5 ft. Soil sampling in many cases is the search for the one sample that is a match. Surrounding samples may merely serve to demonstrate the range of local differences. Screening techniques during sampling that eliminate samples that do not match (i.e., elimination samples) are, therefore, extremely important.

Forensic soil examiners must have training in numerous aspects of geology, such as recognition of minerals and rocks. A **mineral** is a solid inorganic substance that occurs naturally. Most are crystals and have physical properties that are unique to their crystal structure. In particular, they have characteristic colors, densities, geometric shapes, and refractive indexes that can be measured to identify the mineral's presence in a sample.

LINK Refractive index and other physical properties of crystals are discussed in Chapter 5.

More than 2000 minerals naturally occur on Earth, but many are very rare. A forensic geologist usually encounters only about 50 minerals on a routine basis. In addition to being present in soil, minerals are also used in the manufacture of many human-made products.

Rocks are composed of a combination of minerals. As the natural environmental process of weathering takes place, fragments of large rocks are reduced in size and become components of nearby soil.

The combination of minerals and human-made components in soil creates a unique "signature" that the forensic geologist can use to compare soil samples. If two samples share enough similarities, the examiner may be able to determine that they share a common origin.

How can soil analysis benefit law enforcement? Consider the following case: A police officer in a Midwestern city who was arresting a man on a minor crime noticed what looked like a bad case of dandruff on the suspect's shoulders. Later examination showed it was not dandruff but rather diatomaceous earth, a white powder composed of fossilized skeletons of one-celled organisms called diatoms, whose coral-like skeletons are porous and have unique, specific shapes (FIGURE 3-8a,b). The diatomaceous earth on the suspect matched the diatomaceous earth insulating material that was in a safe that had been burglarized the previous day.

Gradient Tube Separation of Soil: Separation by Density

In the past, forensic laboratories used a **density gradient column** to compare soil samples. To find the density distribution of particles, a density gradient column is used to separate known weight samples that have been previously sieved.

The density gradient column consists of two glass tubes, each of which is filled with layers of two liquids, where every layer has a different density (FIGURE 3-9). Often, the liquid at the bottom of the tube is pure tetrabromoethane (density = 2.96 g/mL). The liquid at the top of the tube is typically pure ethanol (density = 0.789 g/mL). In between are layers consisting of various mixtures of these chemicals, which have densities ranging between the two extremes of the pure substances.

To compare two soil samples on the basis of density, each sample is carefully placed on the top of the liquid in one of the tubes in the density gradient column. The various components fall

BACK AT THE CRIME LAB

Many types of tests can be performed on standard soils and soil evidence in the forensic crime laboratory:

- Visual comparison of soil color
- Low-power microscopy
- High-power microscopy
- Sieves
- Density-gradient tube
- Chemical tests

on the CRIME SCENE

On the Crime Scene

On May 9, 1991, the body of nine-year-old Rebecca O'Connell was discovered in a secluded area in Sioux Falls, South Dakota. O'Connell had gone missing the day before after visiting a local store. She had been raped, both vaginally and anally, and stabbed in the neck, shoulder, chest, hip, and hands. The forensic pathologist determined that her death was the result of a cut to her jugular vein.

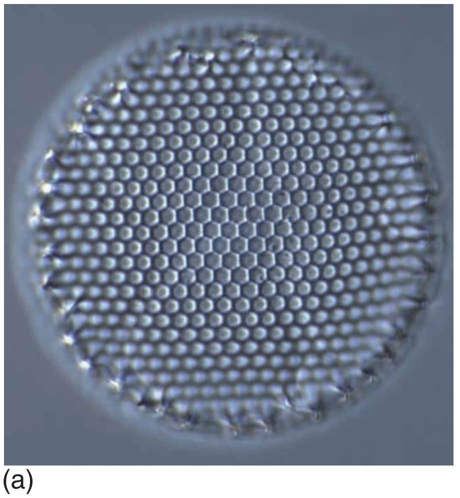
Witnesses noticed a light blue pickup truck leaving the area where O'Connell's body was found, and they gave a description of the driver to police. Three days later, a police detective spoke to Donald Moeller, who owned a blue pickup truck, matched the general description of the driver, and was at a local store at the same time as the victim. Moeller denied any involvement and gave blood and hair samples for analysis. The next day, Moeller fled the state, leaving behind his light blue pickup truck. The police obtained a search warrant for his vehicle and his home.

Soil samples were taken from the wheel wells of the truck, the crime scene, and several unpaved roads near Sioux Falls. Retired forensic geologist Dr. Wehrenberg found numerous consistencies between the soils at the crime scene and the truck, including an unusual blue mineral called gahnite found in the left wheel well of the truck and at the crime scene. Based on the characteristics of the samples, Dr. Wehrenberg was able to rule out the locations where Donald Moeller said he drove his truck.

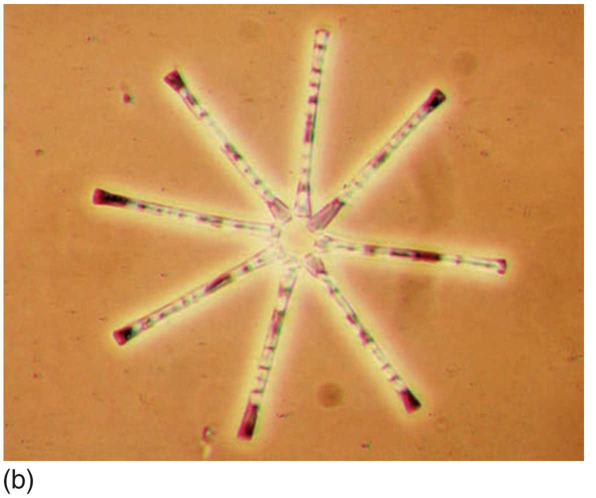
The soil evidence strengthened the case against Donald Moeller. He was convicted and sentenced to death for the rape and murder of Rebecca O'Connell in 1992. In 1996, his conviction was overturned on procedural grounds. Donald Moeller was retried, reconvicted, and resentenced to death in 1997. This time, the conviction was upheld. Donald Moeller has continued his appeals.

through the layers, with each component being held up—that is, floating—at the point where its density is less than the density of the layer beneath it. The distributions of particles within the tubes can then be compared, revealing whether the two samples have a common origin.

To see the value of this type of soil assessment, consider the following example: A murder was committed on a college campus. The victim was found to have soil adhering to the cleats on his athletic shoes. Soil samples were collected at several locations on campus and compared by the density gradient column method. As shown in FIGURE 3-10, the crime scene sample was most similar to the garden sample and strongly indicated the victim was in the garden before his death.



(a)



(b)

FIGURE 3-8 (a) *Coscinodiscus*, a salt water species. (b) *Asterionella*, a colony of freshwater pennate diatoms.

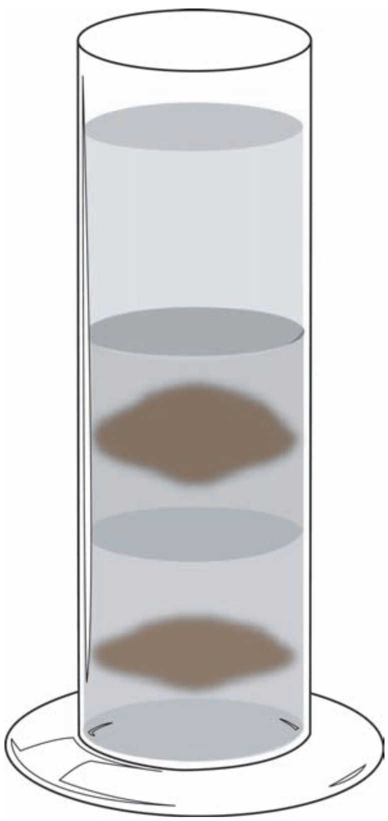


FIGURE 3-9 In a gradient tube separation, the distribution of the components is based on density.

The gradient tube separation method is not considered a definitive test because soils collected from different locations can give similar density distribution patterns. Instead, the density gradient column is most useful when forensic geologists are comparing soils. More sophisticated testing of soil specimens, such as atomic absorption spectroscopy and X-ray fluorescence spectroscopy, should be used to confirm the results of these tests.

LINK X-ray fluorescence spectroscopy is discussed in Chapter 9.

Collection and Preservation of Soil Evidence

Crime scene investigators who collect soil samples must be certain to sample the exact, original location of the crime. Soil samples should be collected as soon as possible because the soil at the crime scene can change dramatically over time. To establish the variation in the soil at the crime scene, the crime scene investigator should collect specimens at the scene of the crime and reference specimens with a 100-yard radius of the crime scene. But the investigator should not stop there: He or she should

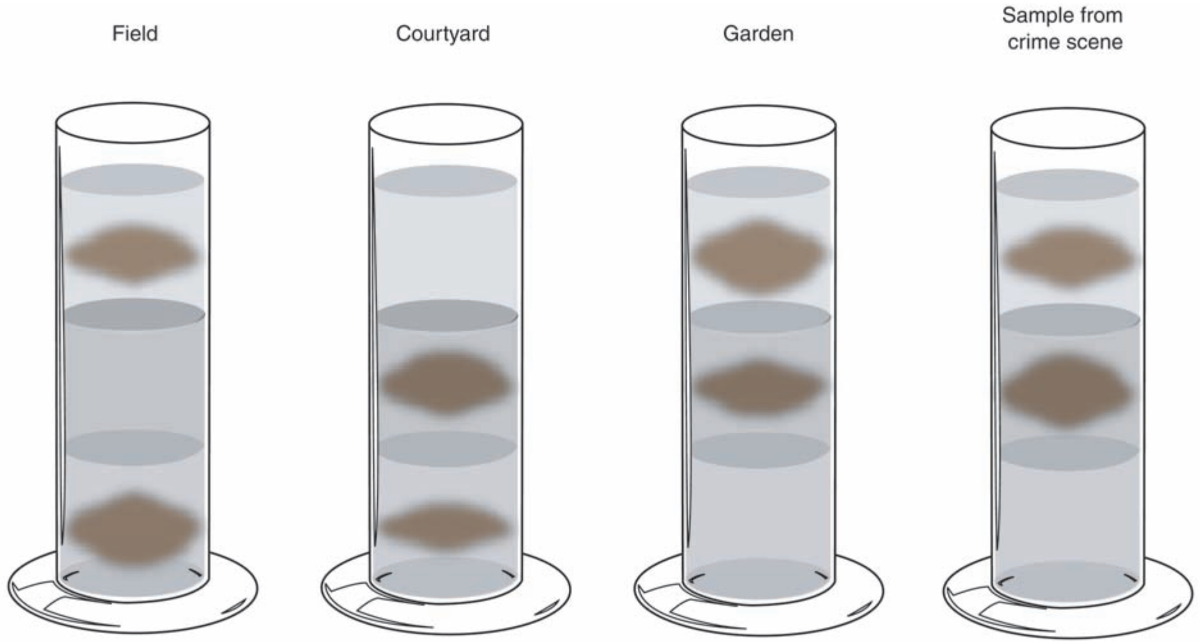


FIGURE 3-10 Comparison of reference samples from the courtyard, college gardens, and baseball field to the sample taken from the shoes of the victim (crime scene). The crime scene sample matches the soil from the garden.

SEE YOU IN COURT

Soils are often considered to be physical evidence. The high diversity of minerals, rocks, fossils, organic material, and other items in soils allows forensic geologists to discriminate between samples. A forensic geologist will characterize and compare soil samples in the lab, and many samples can be excluded based on these comparisons. Specimens are considered to come from a single source only if there are a sufficient number of correlations between soil samples.

also take soil samples from all paths into and out of the site. If the suspect claims to have been elsewhere at the time of the crime, the investigator should take soil samples at that location as well, so as to prove (or disprove) the alibi. Sometimes the investigator may notice discrepancies in soils' color, texture, and composition at the site, suggesting that a soil might have been dug up from a greater depth or transferred from a different location.

When collecting samples, the investigator should make sure that the depths (i.e., the soil horizon) from which he or she takes the suspect soil sample and a reference sample are the same. Given that only a small sample (less than a tablespoon) is needed for testing, taking a specimen of the top surface is all that is needed. Investigators should also draw a map identifying soil sample locations and correlating them to sample identification numbers.

All samples collected should be packaged in individual containers. Specimens should be submitted in leak-proof containers such as film canisters or plastic pill bottles. Paper envelopes or glass containers should not be used. It is very important to ship known and questioned debris separately to avoid contamination of evidence by the reference materials.

When a lump of soil is found, it is important that it be packed and subsequently preserved intact, because such a sample may have substantial evidentiary value. To see why, consider that an automobile collects and builds up layers of debris on its undercarriage. These layers represent a composite sample that is unique to that car. During the normal use of a car, it will pick up soil from almost all of the locations it visits. If the car is involved in a hit-and-run accident and the impact jars a lump of soil loose, this evidence can be used to prove that this specific car was involved in the crime. That is, soil from the undercarriage of the suspect's car may be compared with soil left at the scene to prove (or disprove) that the car was present at the hit-and-run incident. Soil adhering to vehicles should be carefully removed, air-dried, and packaged separately in paper bags.

Soil found on a suspect or victim must also be handled very carefully. Do not remove soil adhering to shoes, clothing, and tools. Tools with soil adhering should not be processed for latent prints until processed first by the forensic geologist. The soil and the clothing (tools, shoes) should be air-dried and packaged separately in paper bags and then shipped to the laboratory.

Usually, the forensic geologist looks for the unusual in a soil sample, such as an uncommon mineral, a microfossil, or human-made materials. Sometimes, however, simply matching soil, rocks, minerals, or fossils found on a suspect to a particular location will provide all the evidence that is needed. Hans Gross, one of the earliest forensic scientists, noted in his 1893 handbook that, "Dirt on shoes can often tell us more about where the wearer of those shoes had last been than toilsome inquiries."

WRAP UP

YOU ARE THE FORENSIC SCIENTIST SUMMARY

1. The plastic properties of soil allowed the impression of the boots to be captured. Unfortunately, the suspect is wearing new boots. The impression left by these boots will fall into the category of class evidence (all size 12 Wolverine boots). The new boots will carry no individualizing wear marks that might allow investigators to conclude that the boot prints were unique. The boot print evidence is class evidence and does not individualize the evidence to this one suspect.
2. Because the soil in the pot is friable, when the pot hit the floor, the solid clump of soil was broken apart and the components dispersed as a powder. This powder could have stuck to the suspect's shoes. When the suspect drove his car, the soil components dropped onto the carpet of the car. Because soil in our yards does not usually contain vermiculite, the soil in the car did not come from there. The vermiculite present does narrow the soil to a smaller class of soil samples, although it does not individualize the sample.

Chapter Spotlight

- Soil can be identified by physical and chemical properties.
- Physical properties are properties that can be observed directly, including color, odor, taste, hardness, density, and melting and boiling points.
- Chemical properties are properties that can be observed when the sample reacts with another substance. For instance, if the sample neutralizes a basic solution, then the original sample is acidic in nature.
- Scientists should be comfortable using the metric system and the SI.
- Mass measures how much of a material is present.
- Weight measures how much force is exerted on a mass by gravity.
- Density measures mass per volume. It is affected by temperature, so that warmer objects are often slightly less dense than colder objects.
- Temperature can be measured in Fahrenheit or Celsius. The conversion from one to the other can be calculated using the following equations: $°F = (9/5)\ °C + 32$ or $°C = 5/9(°F - 32)$.
- Algor mortis is the drop in body temperature that occurs after death. It generally follows the pattern of a -1.5 °C per hour if the surrounding temperature is between 18 and 20 °C.
- Soil has four major horizons:
  - The O horizon is the organic layer made of decomposing litter with very little to no base soil.
  - The A horizon is located below the O horizon and is a mixture of organics and soil.
  - The B horizon includes primarily mineral soils and is heavily influenced by the leachate from the upper layers. It is often quite thick in comparison to the other horizons.
  - The C horizon comprises mostly fragmented bedrock and clay materials.
- Soil analysis includes visual identification, including determination of the soil's color and identification of specific components such as roots and minerals.
- Sieve analysis is used to separate components of a soil sample according to size.
- Gradient tube separation is used to separate components of a sample according to density.
- Soils are characterized by significant horizontal and vertical variability.
- Elimination samples are very important to limit the number of noncomparable samples.

Key Terms

Celsius scale: A temperature scale on which water freezes at 0 °C and boils at 100 °C at sea level.

Chemical property: A characteristic of a substance that describes how it reacts with another substance.

Density: The mass of an object per unit volume.

Density gradient column: A glass tube filled (from bottom to top) with liquids of sequentially lighter densities.

Extensive physical property: A property that is dependent on the amount of material present.

Fahrenheit scale: A temperature scale on which water freezes at 32 °C and boils at 212 °C at sea level.

Friable: Easily broken into small particles or dust.

Intensive physical property: A property that is independent of the amount of material present.

Mass: A measure of the quantity of matter.

Mineral: A naturally occurring inorganic substance found in the Earth's crust as a solid.

Physical property: A property that can be measured without changing the composition of a substance.

Postmortem interval: Time elapsed since death.

Reference standard: Physical evidence whose origin is known and that can be compared to evidence collected at a crime scene.

Subsoil: Soil lying beneath the topsoil, which is compacted and contains little or no humus.

The International System of Units (SI): The metric units preferred by scientists.

Topsoil: The surface layer of soil, which is rich in humus.

Weight: A measure of the force of attraction of the Earth for an object.

Putting It All Together

Fill in the Blank

1. The ____________ properties of a substance are those properties that can be observed when the substance reacts or combines with another substance so as to change its chemical composition.
2. The _____________ properties of a substance are those properties that can be observed and recorded without referring to any other substance.
3. The international system of units is known as the ________ units.
4. The basic SI unit for length is the __________.
5. The basic SI unit for mass is the ___________.
6. The basic SI unit for volume is the _________.
7. Distance on a map expressed in __________ (kilometers or millimeters).
8. A kilogram is approximately __________ pounds.
9. A meter is approximately _____________ yards.
10. _________ is a measure of the quantity of matter in an object.
11. The Celsius temperature scale defines the freezing point of water to be __________ °C.
12. The Fahrenheit temperature scale defines the boiling point of water to be __________ °F.
13. A(n) __________ is immersed in a liquid to make a temperature measurement.
14. A(n) __________ measures temperature without touching the object.
15. The density of water is _______ g/mL.
16. The top layer of soil, the O horizon, is mostly __________ matter.
17. The B horizon, which is located below the topsoil, is mostly _________ matter.
18. The igneous rock found in soils differs in _______, _________, and ________.

19. When a nest of sieves is used to separate soil components by size, the bottom-most sieve will contain the _______ (smallest/largest) size particles.
20. More than _________ minerals naturally occur on Earth, but a forensic geologist routinely encounters only about _________ minerals.
21. A separation of soil components can be done by using a(n) _________ tube.
22. A density gradient column contains two liquids of different density that are added to give a gradient from _______ (most dense/least dense) on the bottom of the tube to _______ (most dense/least dense) on the top.
23. When a soil sample is placed in a density gradient column, the inorganic minerals in the soil should _______ (float near the top/sink to the bottom).
24. To establish the variation in soil at the crime scene, the investigator should collect reference soil samples within a(n) _________ radius of the scene.

True or False

1. When a substance melts, its composition changes.
2. An optical pyrometer should be used to measure the temperature of a dead body.
3. The density of an iron bar depends on the length of the bar.
4. The density of water increases as it is heated.
5. Soil samples should be collected from the crime scene as soon as possible.
6. Soil samples should be collected at all alibi locations claimed by the suspect.

Review Problems

1. Canadian police investigating an arson call to tell you they confiscated 825 mL of an accelerant. Express this amount in
   a. Liters.
   b. Quarts.
   c. Gallons.
2. Mexican police have confiscated 153,000 g of cocaine. Express this amount in
   a. Kilograms.
   b. Pounds.
3. A bag containing 3 lb 8 oz of cocaine is found in a suitcase by a customs inspector at Dulles Airport. How many kilograms have been found?
4. In the state of New York, the minimum prison time imposed for unlawful possession of cocaine depends on the amount of cocaine a person is found to possess. Penal law 220-21 states that possession of 4 oz or more is a Class A1 felony with a penalty of 15 years to life in prison. Joe Bradshaw has been arrested and found to have a package in his pocket containing 150 g of cocaine. How many ounces of cocaine are in the package? Has Joe committed a Class A1 felony?
5. In the state of New York, the minimum prison time imposed for unlawful possession of cocaine depends on the amount of cocaine a person is found to possess. Penal law 220-18 states that possession of 2 oz or more is a Class A2 felony with a penalty of 3 years to life in prison. Mary Gordon has been arrested and found to have a package in her purse containing 10 g of cocaine. How many ounces of cocaine are in the package? Has Mary committed a Class A2 felony?
6. In Illinois, unlawful possession of 900 g of heroin is a Class 1 felony with a penalty of 10 to 50 years in prison. Harvey Nelson was arrested and found to have 50 oz of heroin in his car. How many grams of heroin did he have? Is he guilty of a Class 1 felony?
7. In Illinois, unlawful possession of 500 g of marijuana is a Class 3 felony with a penalty of 1 to 5 years in prison. Judy Whitman was arrested and found to have 10 oz of marijuana in her car. How many grams of marijuana did she have? Is she guilty of a Class 3 felony?
8. The state of Alabama imposes a $0.52 tax on beer per gallon. If 5,250,000 liters of beer were

sold in Alabama in 2005, how much money was raised by this tax?

9. You are investigating a murder. The coroner measures the body of the cadaver to be 34 °C.
   a. What is the average temperature of a living person in degrees Fahrenheit and degrees Celsius?
   b. By how many degrees has the body temperature of the victim dropped since death?
   c. What is the postmortem interval?
10. You are working in a forensic lab. The microscope manufacturer recommends that your microscope be kept at a constant 75 °F temperature. The temperature of the lab is 15 °C. Should you turn on the heat or the air conditioning?
11. The district attorney wants to know if a metal object recovered from a crime scene is iron or aluminum. You weigh the object and find that it weighs 540 g. You take a 500-mL graduated cylinder and fill it with water until it reads 100 mL. When you carefully submerge the metal object into the graduated cylinder, the level of water rises to 300 mL. What is the density of the object? Is it iron or aluminum?
12. Thieves broke into a jewelry store and stole a large amount of gold that was later used to make expensive rings and other jewelry. The police arrest a suspect and impound a large amount of yellow metal. The suspect claims it is brass. You select a piece of the yellow metal and find it weighs 482 g. You take a 200-mL graduated cylinder and fill it with 50 mL of water. When you carefully submerge the metal object into the graduated cylinder, the level of water rises to 75 mL. What is the density of the yellow metal? Is it gold?

Further Reading

Girard, James E. *Principles of Environmental Chemistry*, Sudbury, MA: Jones and Bartlett, 2005.

Munsell Soil Color Charts. Baltimore, MD: MacBeth, a division of Kollmorgan Instruments Corporation, 1994.

Murray, R. C., and Solebello, L. P. Forensic examination of soil. In R. Saferstein (ed.), *Forensic Science Handbook*, vol. 1 (ed 2). Upper Saddle River, NJ: Prentice-Hall, 2002.

Murray, R. C., and Tedrow, J. C. F. *Forensic Geology*. Upper Saddle River, NJ: Prentice-Hall, 1992.

Petraco, N., and Kubic, T. *Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators*. Boca Raton, FL: CRC Press, 2004.