APPENDIX A: Minerals

Characteristic Properties of Minerals

Minerals are naturally occurring substances with defined physical and chemical properties. Physical properties are commonly used for identification, and chemical composition is the basis for mineral classification. Mineral properties can also have an aesthetic or utilitarian value. For example, native copper, when discovered in the Great Lakes region by Native Americans, was first valued for its metallic properties of luster and malleability and was used for jewelry and tools. Many ancient cultures, in addition to our own, have valued gemstones such as rubies and sapphires for their beauty. Historically, one of the most valued minerals has been halite (NaCl), or common table salt, because all animals, including people, need it to live. Halite has been mined and obtained from coastal evaporation ponds for thousands of years. Some clay minerals have been highly valued because they can be molded into useful pots and decorative statues and painted with black, red, and orange paint made from still other minerals. Today, specific physical properties of a wide variety of minerals are used for everything from ceramics to electronics, metallurgy, agriculture, water treatment, and personal jewelry. An understanding of the physical properties will help us identify common minerals.

Identifying Minerals

Identification of mineral specimens that are large enough to fit in the palm of your hand, referred to as hand specimens, is a combination of pattern recognition and testing for particular properties or characteristics. These

TABLE A.1 Mohs Hardness Scale

	Relative Hardness[1]	Mineral	Comment	Hardness of Common Materials
Softest	1	Talc	Softest mineral known; used to make powder	Graphite, "lead" in pencils (1–2)
	2	Gypsum	Used to make wall board	Fingernail (~2.2)
	3	Calcite	Main mineral in marble and limestone	Copper penny[2] (~3.2)
	4	Fluorite	Mined for fluorine, used in glass and enamel	
	5	Apatite	Enamel of your teeth	Pocketknife (~5.1), Glass (~5.5)
	6	Orthoclase	Common rock-forming mineral	Hard steel file or needle (~6.5)
	7	Quartz	When purple is gemstone amethyst, birthstone for February	
	8	Topaz	When transparent is gemstone, birthstone for November	
	9	Corundum	When red is ruby, gemstone, birthstone for July; when blue is sapphire, gemstone, birthstone for September	
Hardest	10	Diamond	Hardest known mineral; gemstones are extremely brilliant	

[1] Note: The scale is relative, and unit increases in hardness do not represent an equal increase in true hardness.

[2] U.S. penny minted before 1982 or Canadian penny minted before 1997.

properties include hardness, specific gravity, fracture, cleavage, crystal form, color, luster, as well as other properties that are diagnostic of a particular mineral or group of minerals.

HARDNESS

Most physical properties of minerals reflect characteristics of their internal atomic structure. For example, a mineral's *hardness*, that is, its resistance to scratching, is related to the size, spacing, and strength of bonding of the atoms within the mineral. Absolute hardness is not easy to measure, so in 1822 Austrian mineralogist Friedrich Mohs came up with an ingenious 1–10 scale of *relative hardness* (H) that is still widely used. On the Mohs scale the softest mineral is talc (H = 1) and the hardest mineral is diamond (H = 10) (Table A.1). The change in absolute hardness from one number to the next is not the same; any mineral or substance will scratch a mineral with a lower hardness on the Mohs scale. You can use common objects, such as a fingernail (H about 2.2), a copper penny (a U.S. penny minted before 1982, or a Canadian penny minted before 1997, H about 3.2), and a glass plate (H = 5.5) to approximate the relative hardness of minerals.

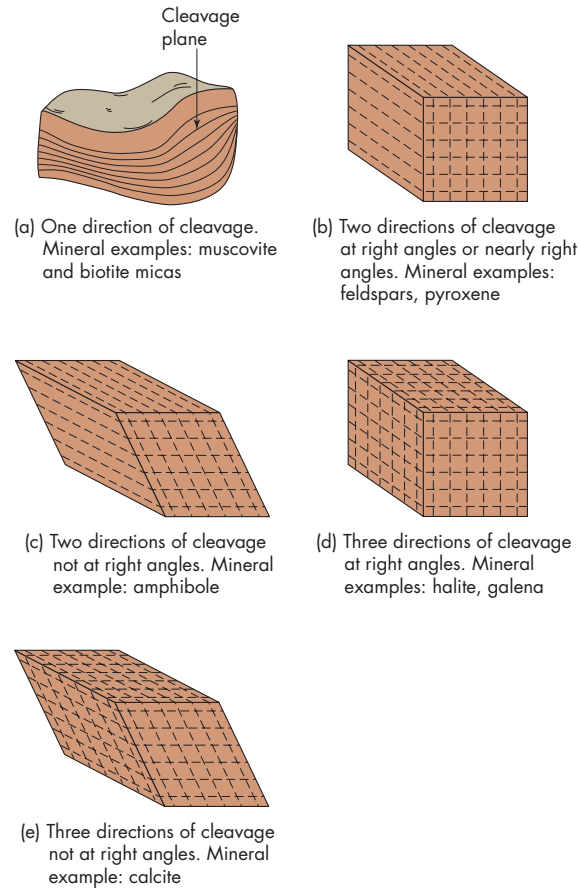
For example, you can determine if a mineral is harder or softer than 5.5 by taking a fresh, unweathered surface of the mineral and attempting to scratch a glass plate. You must be certain that the mineral is actually making a scratch and not just leaving a line of powdered mineral on the surface. Do not attempt to use a glass test plate if it becomes fractured or broken; be sure to follow proper procedures in disposing of broken or damaged glass. If the mineral is softer than glass, then you can determine if it is harder than a copper penny. By this process you can bracket the relative hardness (e.g., 73.2 and 65.5) of the unknown mineral sample. Hardness tests can sometimes be misleading, so never rely on hardness alone to identify a mineral.

SPECIFIC GRAVITY

Some minerals have unusually light or heavy specific gravity. The *specific gravity* of a mineral is the density of a mineral compared with the density of water. Water has a specific gravity of 1. The specific gravity of minerals varies from about 2.2 for halite to 19.3 for gold. Most minerals have specific gravities of about 2.5 to 4.5. In practice, we take a sample of a mineral in hand, heft it, and estimate if it has a light, medium, or heavy specific gravity.

CLEAVAGE

Many minerals have a distinctive way in which they break (Table A.2). Those that break along smooth, even planar surfaces are said to have cleavage. *Cleavage* develops because the forces that bond atoms together in a crystalline structure are rarely equal in all directions. Most cleavage will appear as a series of small, reflective steps with each parallel step breaking along the same direction of weak bonding within the mineral. One technique for recognizing cleavage is to rotate the specimen in front of you with a light source, such as the Sun or a ceiling light, over your shoulders. Each time you encounter a direction of cleavage, the small, parallel cleavage steps will reflect light all at once.



▲ FIGURE A.1 Common Types of Cleavage
Except for mica, where cleavage is indicated with solid lines, cleavage directions in this diagram are shown with dashed lines. (a) Mica has one cleavage direction and breaks into sheets. (b) Feldspar and pyroxene have two cleavage directions at nearly right angles. (c) Amphibole has two directions of cleavage that do not meet at right angles. (d) Halite and galena have three cleavage directions that meet at right angles. This relationship causes both minerals to break into cube-shaped fragments. (e) Calcite also has three cleavage directions, but they do not meet at right angles. This relationship causes calcite to break into rhombohedrons.

TABLE A.2 Properties and Environmental Significance of Selected Common Minerals

Mineral Class	Mineral	Chemical Formula	Color	Hardness	Other Characteristics	Comment
Silicates	Plagioclase feldspar	(Na, Ca)Al(Si, Al)Si_2O_8	Usually white or gray, but may be others	6	Two good cleavages at approximately 90°; and may have fine striations on one of the cleavage surfaces	One of the most common of the rock-forming minerals; is a group of feldspars ranging from sodium to calcium rich; important industrial minerals
	Alkali feldspar	(Na, K)$AlSi_3O_8$	Gray, white to pink or salmon color	6	Two good cleavages at 90°; may be translucent to opaque with glassy luster	One of the most common of the rock-forming minerals; used in porcelain and a wide variety of industrial processes
	Quartz	SiO_2	Varies from colorless to white, gray, pink, purple, and several others, depending on impurities	7	Often has good crystal shape with six sides; conchoidal fracture; coarse crystalline varieties have glassy luster, and microcrystalline varieties have dull to waxy luster	Very common rock-forming mineral; resistant to most chemical weathering; basic constituent of glasses and fluxes; commonly used as an abrasive; colored varieties, such as amethyst and agate, are semiprecious gemstones
	Pyroxene	(Ca, Mg, Fe)$_2Si_2O_6$	Usually greenish to black	5–6	Crystals are commonly short and stout; two cleavages at about 90°	Important group of rock-forming minerals; particularly common in igneous rocks; weathers rather quickly
	Amphibole	(Na, Ca)$_2$(Mg, Al, Fe)$_5Si_8O_{22}(OH)_2$	Generally black to green	5–6	Distinguished from pyroxene by the cleavage angle being 120° rather than 90°; generally has better cleavage with higher luster than pyroxene	Important group of rock-forming minerals particularly for igneous and metamorphic rocks; relatively nonresistant to weathering
	Olivine	(Mg, Fe)$_2SiO_4$	Generally green, but also may be yellowish	6.5–7	Conchoidal fracture; commonly occurs in aggregates of small glassy grains	Important rock-forming mineral, particularly for igneous and metamorphic rocks; relatively nonresistant to chemical weathering
	Clay	Various hydrous aluminum silicates with elements such as Ca, Na, Fe, Mg, and K	Generally white, but may vary due to impurities	1–2	Generally found as soft, earthy masses composed of very fine grains; may have an earthy odor when moist; often difficult to identify the particular clay mineral from hand specimen	Clay minerals are very important from an environmental viewpoint; many uses in society today; clay-rich soils often have many engineering geology problems

	Chlorite	Hydrous Mg, Fe, Al silicate	Green to dark green	2–2.5	Commonly in layered or scaly masses with one direction of cleavage; thin sheets are flexible and nonelastic; glassy to pearly luster	Important group of rock-forming minerals in metamorphic rocks
	Talc	$Mg_3Si_4O_{10}(OH)_2$	Pale green to white or gray	1	In layered or compact masses with one direction of cleavage; thin sheets flexible and nonelastic; soapy feel with pearly to greasy luster	Used to make ceramics, paint, paper roofing, cosmetics, and ornamental stone
	Biotite (black mica)	$K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$	Black to dark brown or dark green	2.5–3	Breaks apart in parallel sheets as a result of excellent cleavage in one direction	Important rock-forming mineral common in igneous and metamorphic rocks
	Muscovite (white mica)	$KAl_2(AlSi_3O_{10})(OH)_2$	White, light yellow, brown, pink, or green; colorless in cleavage sheets	2–3	Breaks apart into thin sheets due to excellent cleavage in one direction	Important rock-forming mineral, particularly for igneous and metamorphic rocks; used for several purposes, including industrial roofing materials, paint, and rubber
Carbonates	Calcite	$CaCO_3$	Colorless to white, but may have a variety of colors resulting from impurities	3	Effervesces strongly in dilute hydrochloric acid; often breaks apart to characteristic rhombohedral pieces as a result of two good cleavages at 78°; transparent varieties display double refraction, where a single dot on white paper looks like two dots if viewed through the mineral	Main constituent of the important sedimentary rock limestone and the metamorphic rock marble; associated with a variety of environmental problems with these rocks, including the development of sinkholes; chemically weathers rapidly; used in a variety of industrial processes including asphalts, fertilizers, insecticides, cement, and plastics
	Dolomite	$Ca, Mg (CO_3)_2$	Generally white, but may be a variety of other colors, including light brown and pink	3.5–4	When powdered, will slowly effervesce in dilute hydrochloric acid; two cleavages at 78°; may be transparent to translucent and have a vitreous to pearly luster	Common mineral in the sedimentary rock dolostone and dolomitic limestone
	Malachite	$Cu_2CO_3(OH)_2$	Bright to emerald green, may be dark green	3.5–4	Effervesces slightly in dilute hydrochloric acid and turns the acid solution green; often displays a swirling structure of light and darker green bands	Valued as a decorative stone; used in jewelry and as a copper ore

(Continued)

TABLE A.2 (*Continued*)

Mineral Class	Mineral	Chemical Formula	Color	Hardness	Other Characteristics	Comment
Oxides and Hydroxides	Hematite	Fe_2O_3	Usually various shades of reddish brown to red to dark gray	1–6.5	Streak is dark red	A common mineral found in small amounts in many igneous rocks, particularly basaltic rocks
	Magnetite	Fe_3O_4	Black	6	Magnetic	The most important ore of iron
	Goethite	FeO(OH)	Generally yellow to yellow-brown or black	1–5.5	Often present as earthy masses or in the form of a crust; streak is yellow-brown	Formerly referred to as limonite, which is now known to be relatively rare; often forms from the chemical weathering of iron minerals and is present as "rust"
Sulfides	Pyrite	FeS_2	Generally a pale brassy yellow tarnishing to brown	6–6.5	Often present as well-formed cubic crystals with striations on crystal faces	Has been used in the production of sulfuric acid, but mostly known for adding sulfur content to coal and contributing to the formation of acid-rich waters that result from the weathering of the mineral
	Chalcopyrite	$CuFeS_2$	Dark brassy to golden yellow, tarnishing to iridescent films that are reddish to blue-purple	3.5–4	Easily disintegrates; greenish black streak lacks cleavage	An important ore of copper; often associated with gold and silver ores
	Galena	PbS	Silver gray	2.5	Gray to black streak; high specific gravity; general metallic luster; cubic cleavage	Primary ore of lead
Sulfates	Gypsum	$CaSO_4 \cdot 2H_2O$	Generally colorless to white, but may have a variety of colors due to impurities	2	Often is transparent to opaque with one perfect cleavage; may form fibrous crystals, but often is an earthy mass	Several industrial uses in making of plaster of Paris for construction material, fertilizer, and flux for pottery
	Anhydrite	$CaSO_4$	Commonly white or gray, but may be colorless	3–3.5	Commonly observed as massive fine aggregates; may be translucent to transparent	Used for the production of sulfuric acid, as a filler material in paper, and occasionally as an ornamental stone

Halides	Fluorite	CaF_2	Variable colors, often purple, yellow, white, or green	4	Often observed as cubic crystals but may also be massive; four perfect cleavages	A number of industrial uses, including a flux in the metal industry, optical lenses, and in the production of hydrofluoric acid
	Halite	NaCl	Generally colorless to white, but may be a variety of colors due to impurities	2.5	Salty taste; often has a cubic form due to three perfect cleavages	Common table salt; makes up rock salt, which is used for ice removal and as a host for buried nuclear waste
Native Elements	Gold	Au	Gold yellow	2.5–3	Crystals are rare; extremely high specific gravity; very ductile and malleable	Primary use as a monetary standard; used in jewelry and in the manufacture of computer chips and other electronics
	Diamond	C	Generally colorless, but also occurs in various shades of yellow, brown, blue, pink, green, and orange	10	Commonly cut to display brilliant luster	Used in industrial abrasives and, of course, jewelry
	Graphite	C	Black to gray	1–2	Often occurs as foliated masses; black streak and marks paper as well; greasy feel	A variety of industrial uses including lubricants, dyes, and in pencils as the "lead"
	Native Sulfur	S	Usually yellow when pure, but may be brown to black from impurities	1.5–2.5	Characteristic sulfurous smell, similar to the smell of fireworks or gunpowder	Often a by-product of the oil industry; may be used to manufacture sulfuric acid

Modified after Davidson, J. P., Reed, W. E., and Davis, P. M. 1997. *Exploring Earth*. Upper Saddle River, NJ: Prentice Hall; and Birchfield, B. C., Foster, R. J., Keller, E. A., Melhom, W. N., Brookins, D. G., Mintt, L. W., and Thurman, H. V. 1982. *Physical geology*. Columbus, OH: Charles E. Merrill.

Two characteristics of cleavage are important in identifying minerals: the number of cleavage directions and the angle between the cleavage directions. Minerals may have one, two, three, four, or six cleavage directions (Figure A.1). When you count the number of cleavage directions, be sure not to count the same direction twice because cleavage surfaces commonly repeat themselves on opposite sides of a specimen. In determining the angle between two cleavages, it is generally sufficient to decide whether or not the angle is close to 90°. In some specimens there is the potential to confuse a cleavage surface with a crystal face that developed as the crystal grew. Unlike cleavage surfaces, crystal faces are generally not repetitive, nor do they form imperfect steps.

CRYSTAL FORM

Crystal faces are important, however, in recognizing *crystal form*, which is the geometric shape taken on by the mineral as it crystallized. Unfortunately, most mineral specimens do not show crystal form; however, when it is present, crystal form can be a useful diagnostic property for identifying some minerals. For example, the pointed and elongate hexagonal crystal form of quartz is diagnostic, as are the cube-shaped crystals of pyrite.

FRACTURE

Broken surfaces of a mineral that do not show cleavage are described as *fracture*. The type of fracture that is present is generally important only if the specimen has no cleavage. Although most fracture is uneven or irregular, there are two types of fracture that are distinctive: *conchoidal fracture* and *fibrous fracture*. In conchoidal fracture, the broken surface is curved and can be at least partially smooth. A broken glass bottle will exhibit conchoidal fracture. In many cases a conchoidal fracture surface will reflect light continually as a specimen is rotated.

COLOR

The *color* of a mineral can be misleading because a given mineral may have several different colors, or several different minerals may have the same color. For example, depending on the impurities present, normally clear quartz may be white, pink, purple, red, brown, yellow, green, or black.

A more reliable way of using color to identify some minerals is to powder part of a specimen on an unglazed porcelain plate. The resulting *streak* made by the powder is especially useful in identifying metallic minerals. For example, the hand specimen of the mineral hematite (Fe_2O_3) may be dull black or a shiny, dark metallic silver color, but its streak is always red. Streak tests can be done only for minerals that are softer than the porcelain "streak plate," which typically has a hardness of about 6.5.

LUSTER

Luster refers to the way light is reflected from a mineral. Most minerals can be described as having either a metallic or nonmetallic luster. Minerals with metallic luster appear silver, brass, or shiny, but not an enamel-like black, and are opaque, even on thin edges. Nonmetallic luster can be quite variable with descriptive terms for luster such as glassy, pearly, greasy, earthy, and resinous (like pine sap or dried turpentine). Light will also pass through thin edges of a nonmetallic mineral.

Some minerals have more than one luster. For example, some specimens of graphite have metallic luster and others are nonmetallic.

STEPS IN IDENTIFYING A MINERAL

1. Decide if the mineral has a metallic or a nonmetallic luster and refer to Table A.3. If the mineral is metallic, determine the color of its streak.
2. Determine the relative hardness of the specimen by first testing to see if it will scratch glass or alternatively, if it can be scratched by a knife (Table A.1). Note that if the mineral has a hardness close to that of glass (H about 5.5) or a pocket knife (H about 5.1), determining hardness may be difficult and the mineral may appear in Table A.3 in either the "harder than glass" or "softer than glass" sections.
3. Decide whether the mineral has cleavage. If cleavage is present, determine the number of directions and whether the angle between the directions is close to 90°. If cleavage is not present, determine the type of fracture.
4. Once you think you have identified the mineral, test for other physical or chemical properties (e.g., taste, smell, reaction with dilute hydrochloric acid) listed for that mineral in Tables A.2 and A.3 to confirm your identification.

The identification of minerals in the field or in the laboratory from small specimens, using simple tests and perhaps a hand lens to determine cleavage and other properties, is basically a pattern recognition exercise. After you have looked at a number of minerals over a period of time and have learned how particular minerals vary, you will become more proficient at mineral identification. When positive identification is necessary, mineralogists use a variety of sophisticated analytical equipment to determine the chemical composition and internal structure of a sample.

TABLE A.3 Key to Assist Mineral Identification

To use this table; (1) decide whether the luster of the mineral to be identified is nonmetallic or metallic. If it is nonmetallic, decide whether it is a light-colored or a dark-colored mineral; (2) use a glass plate to determine if the mineral specimen is harder or softer than the glass plate; (3) look for evidence of cleavage; (4) compare your samples with the other properties shown here and use Table A.2 for final identification.

Light-colored nonmetallic luster	Harder than glass	Shows cleavage	White, pink or salmon-colored; 2 cleavage planes at nearly right angles; hardness, 6.	Orthoclase (Alkali feldspar)
			White, gray, or green-gray; 2 cleavage planes at nearly right angles; hardness, 6; striations on one cleavage.	Plagioclase
		No cleavage	White, clear, or any color; glassy luster; transparent to translucent; hexagonal (six-sided) crystals; hardness, 7; conchoidal fracture.	Quartz
			Various shades of green and yellowish green; glassy luster; granular masses and crystals in rocks; Olivine hardness, 6.5–7 (apparent hardness may be much less in granular masses).	Olivine
	Softer than glass	Shows cleavage	Colorless to white; salty taste; 3 perfect cleavages forming cubic fragments; hardness, 2.5.	Halite
			White, yellow to colorless; 3 perfect cleavages forming rhombohedral fragments; hardness, 3; effervesces with dilute hydrochloric acid.	Calcite
			Pink, colorless, white, or brown; rhombohedral cleavage; hardness, 3.5–4; effervesces with dilute hydrochloric acid only if powdered.	Dolomite
			White to transparent; 1 perfect cleavage; hardness, 2.	Gypsum
			Pale green to white; feels soapy; 1 cleavage; hardness, 1.	Talc
			Colorless to light yellow, brown, or green; transparent in thin elastic sheets; 1 perfect cleavage; hardness, 2–3.	Muscovite
			Colorless to yellow to light blue, green, or purple; 4 cleavages not at 90°; hardness, 4.	Fluorite
		No cleavage	Pale green to white; feels soapy; hardness, 1.	Talc
			White to transparent; hardness, 2.	Gypsum
			Yellow; resinous luster; smells like fireworks; hardness, 1.5–2.5.	Sulfur
Dark-colored nonmetallic luster	Harder than glass	Shows cleavage	Black to dark green; 2 cleavage planes at nearly 90°; hardness, 5–6.	Pyroxene
			Black to dark green; 2 cleavage planes about 120°; hardness, 5–6.	Amphibole
		No cleavage	Various shades of green and yellow; glassy to dull or waxy luster; granular masses and crystals in rocks; hardness, 6.5–7 (apparent hardness may be much less).	Olivine
			White, clear, or any color; glassy luster; transparent to opaque; hexagonal (six-sided) crystals; hardness, 7; conchoidal fracture.	Quartz
			Steel gray to black; reddish brown streak; earthy appearance; hardness, 5.5–6.5.	Hematite
	Softer than glass	Shows cleavage	Black to brownish or greenish black; cleavage, 1 direction; hardness, 2.5–3.	Biotite
			Violet, yellow, green, pink, white, and colorless; 4 cleavages other than 90°; hardness, 4.	Fluorite
			Various shades of green; cleavage, 1 direction; in layered or scaly masses; hardness, 2–2.5.	Chlorite
		No cleavage	Dull to bright red; reddish brown streak; earthy appearance; hardness, 1–6.5.	Hematite
			Lead-pencil black; smudges fingers; hardness, 1–2; 1 cleavage that is apparent only in large crystals.	Graphite
			Yellow-brown to dark brown; may be almost black; streak yellow-brown; earthy; hardness (usually soft), 1–5.5.	Goethite
Metallic luster			Black; strongly magnetic; hardness, 6.	Magnetite
			Lead-pencil black; smudges Angers; hardness, 1–2; 1 cleavage that is apparent only in large crystals.	Graphite
			Light brass yellow; black streak; cubic crystals, commonly with striations; hardness, 6–6.5.	Pyrite
			Dark brass yellow; may be tarnished; greenish black streak; hardness, 3.5–4; massive.	Chalcopyrite
			Shiny gray; black streak; very heavy; cubic cleavage; hardness, 2.5.	Galena

Modified after Birchfield, B. C., Foster, R. J., Keller, E. A., Melhom, W. N., Brookins, D. G., Mintt, K. W., and Thurman, H. V. 1982. *Physical geology*. Columbus, OH: Charles E. Merrill; and Hamblin, W. K. and Howard, J. D. 2005. *Exercises in physical geology*, 12th ed. Upper Saddle River, NJ: Pearson Prentice Hall.

APPENDIX B: Rocks

In Chapter 1 we stated that a *rock* is an aggregate of one or more minerals. In traditional geologic investigations, this is the most commonly used definition. Another definition is used by geologists and geological engineers who are concerned with the properties of earth materials that affect engineering design and environmental problems associated with natural hazards. In environmental and engineering geology, the term *rock* is reserved for earth materials that cannot be removed without blasting using explosives, such as dynamite; earth materials that can be excavated with normal earth-moving equipment, for example a shovel or a bulldozer, are called *soil*. Thus, loosely compacted, poorly cemented sandstone may be considered a soil, whereas well-compacted clay may be called a rock.

This pragmatic definition of rock described above also applies to the use of the term *soil* in engineering and environmental geologic reports. To an engineer, soil is earth material that can be excavated without blasting, regardless of whether it is on land or under water. In traditional geologic investigations the term *soil* is restricted to surficial earth material that has developed on land by in-place weathering. Other loose earth material not formed by in-place weathering is generally considered *sediment*, distinguished from sedimentary rock, which requires a hammer to break it apart. These differences in definitions are more than academic; they can affect communication between engineers, scientists, architects, planners, and emergency responders.

Identifying Rocks

Rocks are composed of minerals, and in some cases other substances such as natural glass and pieces of organisms. Whereas a few rocks contain essentially only one mineral, most contain several. As with minerals, the identification of hand specimens of rocks is primarily through the recognition of patterns. However, there are some useful hints that will assist you. The first task is to decide if the rock is igneous, sedimentary, or metamorphic. Sometimes this decision is not as easy as you might think. It is particularly difficult to identify rocks that are fine grained. A specimen is considered fine grained if you cannot see individual mineral grains with your naked eye. Even if a specimen is not fine grained, it is advisable to use a magnifying glass or hand lens to examine a mineral or a rock.

Some general rules of thumb will assist you in getting started: (1) If the sample is composed of bits and pieces of other rocks, it is most likely sedimentary, especially if the pieces have rounded corners; (2) if the rock specimen has minerals that are all oriented in the same direction, such as parallel sheets of mica, then it is most likely metamorphic; (3) if individual mineral crystals are relatively coarse grained, meaning you can see them with the naked eye or easily with a hand lens, and the crystals are interlocking and composed of minerals such as quartz and feldspar, it is probably an igneous rock that cooled underground, such as granite; (4) if the rock is mostly fine grained but contains some larger crystals, it is probably an igneous rock that cooled on or just below Earth's surface; (5) if the rock is relatively soft and effervesces (fizzes) when dilute hydrochloric acid is applied, it is probably a carbonate sedimentary rock, such as limestone, or a metamorphic rock, such as marble; (6) if it is a really grungy, soft, highly weathered, or altered rock, as many in nature seem to be, you are going to have some problems identifying it!

Physical Properties of Rocks

Physical properties of rocks include color, specific gravity, relative hardness, porosity, permeability, texture, and strength.

COLOR

The color of a rock varies depending upon the minerals present and the amount of weathering that has occurred. Rocks encountered in their natural environment are various shades of light gray to brown to black.

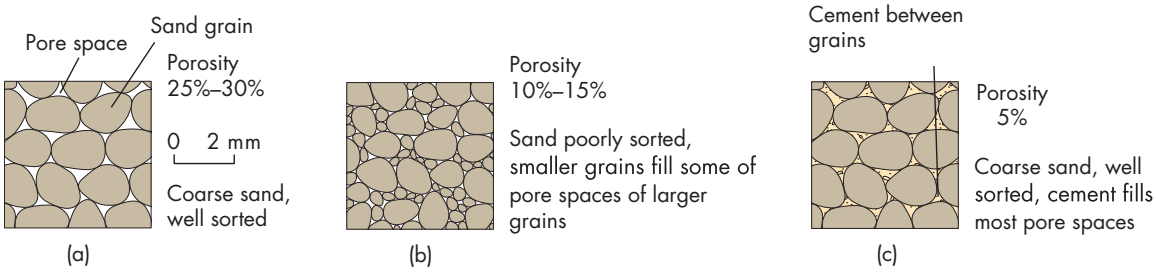


FIGURE B.1 Sorting and Cementation Affect Porosity
(a) Porosity of a well-sorted coarse sand. (b) Porosity of a poorly sorted sand. (c) Porosity of a cemented, well-sorted coarse sand; examples include calcium carbonate ($CaCO_3$) and silica (SiO_2).

Chemical weathering can produce surface stains of black iron or manganese oxides, and brown to orange stains of iron oxides and hydroxides.

SPECIFIC GRAVITY AND RELATIVE HARDNESS

The same definition of specific gravity we gave for minerals applies to rocks and refers to the weight of the rock relative to the weight of water. Some rocks are lighter than water and will float. For example, pumice, a light-colored volcanic rock with many holes produced by gas bubbles, is lighter than water. Rocks become heavier as iron- and magnesium-bearing minerals become more abundant. There is no scale for relative rock hardness similar to the Mohs scale for minerals. Soft rocks can be broken with your fingers, and hard rocks require a sledgehammer to break apart.

POROSITY AND PERMEABILITY

Porosity is the percentage of a rock's volume that is empty space, that is void space between grains, or open space in fractures. *Permeability* is the capacity of a porous rock to transmit a fluid, such as oil or water. The properties of porosity and permeability are important in understanding many geologic hazards, such as landsliding and earthquakes.

TEXTURE

The *texture* of a rock refers to the size, shape, and arrangement of the crystals or grains within it. Crystal or grain size can be measured directly or described qualitatively as fine or coarse grained. A rock with crystals or grains that are visible with the naked eye or easily with a magnifying hand lens is considered coarse grained; one that is not is fine grained. The degree to which grains in a rock are similar in size is referred to as *sorting*. For example, a sandstone in which most sand grains are similar in size is described as well sorted (Figure B.1a, c), whereas one that contains a variety of grain sizes is poorly sorted (Figure B.1b). Crystal or grain shape can vary from spherical with rounded corners to irregular with sharp, angular corners. Likewise, the arrangement of crystals or grains can be variable. Crystals can be interlocking, such as in granite or marble; aligned, such as mica grains in schist; or small grains may occupy spaces between large grains, such as in poorly sorted sandstone (Figure B.1b). Other rock textures are characterized by vesicles, or cavities, formed by gas expansion during their formation. For example, vesicular rocks commonly occur near the surface of a lava flow where gas is escaping. The texture of a rock can also influence its porosity. Rocks that are poorly sorted or well cemented generally will have lower porosity than those that are well sorted and only partially cemented. For example, in sandstone, porosity decreases from about 30 percent to 5 percent as pore spaces are filled with smaller grains or cementing material such as calcite ($CaCO_3$) or quartz (SiO_2) (Figure B.1).

STRENGTH

The *strength* of a rock is commonly reported in terms of its compressive strength, which is the mechanical compression necessary to break or fracture the specimen. As measured in the laboratory, the strength of a rock is given as a force per unit area, such as Newtons per meter squared (N/m^2). Ranges of compressive strength for some of the common rock types are shown in Table B.1.

TABLE B.1 Strength of Common Rock Types

	Rock Type	Range of Compressive Strength (10^6 N/m^2)	Comments
Igneous	Granite	100 to 280	Finer-grained granites with few fractures are the strongest; generally suitable for most engineering purposes.
	Basalt	50 to greater than 280	Zones of broken rock holes or fractures reduce the strength.
Metamorphic	Marble	100 to 125	Solution openings and fractures weaken the rock.
	Gneiss	160 to 190	Generally suitable for most engineering purposes.
	Quartzite	150 to 600	Very strong rock.
Sedimentary	Shale	Less than 2 to 215	May be a very weak rock for engineering purposes; careful evaluation is necessary.
	Limestone	50 to 60	May have clay layers, solution openings, or fractures that weaken the rock.
	Sandstone	40 to 110	Strength varies with nature and extent of fractures, composition of grains, degree and type of mineral cement.

Data primarily from Bolz, R. E., and Tuve, G. L. eds. 1973. *Handbook of tables for applied engineering science*. Cleveland, OH: CRC Press.

APPENDIX C: Maps and Related Topics

Topographic Maps

A *topographic map* depicts the shape and elevation of the land surface as well as the location of human-made features, such as roads, schools, and political boundaries. Elevations and some other natural features are shown by *contour lines*, which on topographic maps are lines of equal elevation above sea level. Individual contour lines on a topographic map are a fixed vertical distance apart, known as the *contour interval* (CI). Common contour intervals are 5, 10, 20, 40, 80, or 100 meters or feet. The contour interval selected for a particular map depends upon the topography being represented as well as the scale of the map. If there is relatively little difference in elevation, or relief, between the highest and lowest points on a map, then the contour interval selected may be relatively small; however, if there is higher relief, the map maker will choose a larger contour interval so that the reader can resolve individual contour lines on steep slopes. This brings up an important point: Where contour lines are close together, the inclination or slope of the land is relatively steep, compared to flatter areas where contour lines are farther apart.

The *scale* of a topographic map, or of any other map, may be communicated in several ways. First, a scale may be given as a ratio, such as 1 to 24,000 (1:24,000), which means that 1 inch on a map is equal to 24,000 inches (2000 ft.) on the ground. Second, a topographic map may have several graphic or bar scales that are subdivided in feet, kilometers (kilometres), and miles. These scales are generally found in the lower margin of the map and are useful for measuring distances. Finally, the scale of some maps is stated in terms of specific units of length on the map, such as 1 inch equals 200 feet. This means that 1 inch on the map is equivalent to 200 feet (2400 in.) on the ground. In this example we could also state that the scale is 1 to 2400. The most common scale for U.S. Geological Survey topographic maps is 1:24,000 and for Natural Resources Canada maps is 1:50,000, but scales of 1:125,000 or smaller are also used. Remember, 1 ÷ 24,000 is a larger number than 1 ÷ 125,000, so 1:125,000 is the smaller scale. Generally, the smaller the map scale, the more area is shown. In addition to contour lines, topographic maps also show a number of cultural features, such as roads, houses, and other buildings. Features such as streams and rivers are often shown in blue. In fact, a whole series of symbols are commonly used on topographic maps. These symbols are shown in Figure C.1 for United States maps, and similar symbols are printed on the back of most Canadian maps.

READING TOPOGRAPHIC MAPS

Reading or interpreting topographic maps is as much an art as it is a science. After you have looked at many topographic maps that represent the variety of landforms and features found at the surface of Earth, you begin to recognize these forms by the shapes of the contours. This is a process that takes a fair amount of time and experience in looking at a variety of maps. However, there are some general rules for reading topographic maps:

- Valleys containing streams of any size have contours that form Vs, in which the apex of the V points in the upstream direction. This is sometimes known as the *rule of Vs*. Thus, if you are trying to draw the drainage pattern that shows all the streams, you should continue the stream in the upstream direction as long as the contours are still forming a V-pattern. The Vs will no longer be noticeable near the drainage divide, that is, the high point between two drainage basins.
- Where contour lines are spaced close together, the slope or inclination of the land surface is relatively steep, and where contour lines are spaced relatively far apart, the slope is relatively low and the land is flatter. As you travel up an incline or slope, you may notice that the contour lines are spaced relatively far apart and that at some point the angle of inclination or slope changes and the contour lines become closer together; this point is known as "break in slope." A break in slope is commonly observed at the foot of a mountain or where a valley side meets the surface of a floodplain.
- Contours near the upper parts of hills or mountains may show closure; that is, the contour line meets itself rather than extending to the edge of the map. These closed contours may be relatively oval or round for a conical peak, or longer and

Control data and monuments

Vertical control

- Third order or better, with tablet — BM ×16.3
- Third order or better, recoverable mark — ×120.0
- Bench mark at found section corner — BM 18.3
- Spot elevation — × 5.3

Contours

Topographic

- Intermediate
- Index
- Supplementary
- Depression
- Cut; fill

Bathymetric

- Intermediate
- Index
- Primary
- Index primary
- Supplementary

Boundaries

- National
- State or territorial
- County or equivalent
- Civil township or equivalent
- Incorporated city or equivalent
- Park, reservation, or monument

Surface features

- Levee — Levee
- Sand or mud area, dunes, or shifting sand — Sand
- Intricate surface area — Strip mine
- Gravel beach or glacial moraine — Gravel
- Tailings pond — Tailings pond

Mines and caves

- Quarry or open pit mine
- Gravel, sand, clay, or borrow pit
- Mine dump — Mine dump
- Tailings — Tailings

Vegetation

- Woods
- Scrub
- Orchard
- Vineyard
- Mangrove — Mangrove

Glaciers and permanent snowfields

- Contours and limits
- Form lines

Marine shoreline

Topographic maps

- Approximate mean high water
- Indefinite or unsurveyed

Topographic-bathymetric maps

- Mean high water
- Apparent (edge of vegetation)

Coastal features

- Foreshore flat — Foreshore flat
- Rock or coral reef — Rock or coral reef
- Rock bare or awash
- Group of rocks bare or awash
- Exposed wreck
- Depth curve; sounding — 3
- Breakwater, pier, jetty, or wharf
- Seawall

Rivers, lakes, and canals

- Intermittent stream
- Intermittent river
- Disappearing stream
- Perennial stream
- Perennial river
- Small falls; small rapids
- Large falls; large rapids
- Masonry dam
- Dam with lock
- Dam carrying road
- Perennial lake; Intermittent lake or pond
- Dry lake — Dry lake
- Narrow wash
- Wide wash — Wide wash
- Canal, flume, or aquaduct with lock
- Well or spring; spring or seep

Submerged areas and bogs

- Marsh or swamp
- Submerged marsh or swamp
- Wooded marsh or swamp
- Submerged wooded marsh or swamp
- Rice field — Rice
- Land subject to inundation — Max pool 431

Buildings and related features

- Building
- School; church
- Built-up area
- Racetrack
- Airport
- Landing strip
- Well (other than water); windmill
- Tanks
- Covered reservoir
- Gaging station
- Landmark object (feature as labeled)
- Campground; picnic area
- Cemetery: small; large — Cem

Roads and related features

Roads on Provisional edition maps are not classified as primary, secondary, or light duty. They are all symbolized as light duty roads.

- Primary highway
- Secondary highway
- Light duty road
- Unimproved road
- Trail
- Dual highway
- Dual highway with median strip

Railroads and related features

- Standard gauge single track; station
- Standard gauge multiple track
- Abandoned

Transmission lines and pipelines

- Power transmission line; pole; tower
- Telephone line — Telephone
- Aboveground oil or gas pipeline
- Underground oil or gas pipeline — Pipeline

▲ FIGURE C.1 Topographic Map Symbols

This chart shows some of the common symbols that the U.S. Geological Survey uses on its topographic maps. Older maps may have slightly different symbols. Symbols on Canadian topographic maps are printed on the reverse side of the map. *(From U.S. Geological Survey)*

narrower for a ridge. Remember, the elevation of the top of a mountain or hill is higher than the last contour shown and may be estimated by taking half the contour interval and adding that value to the elevation of the highest contour line. That is, if the highest contour on a peak were 1000 m with a contour interval of 50 m, then the approximate elevation of the mountain top is 1025 m.

- Most topographic depressions are also shown with closed contours; the difference is that a depression contour has small *hachure* or tic marks on the contour lines that point toward the center of the depression.
- Sometimes the topography on a slope is unusually *hummocky*, that is, undulatory or uneven, when compared with the general topography of the area. Such hummocky topography may indicate mass wasting processes and landslide deposits.

In summary, after observing a variety of topographic maps and working with them for some time, you will begin to see the pattern of contours as an actual landscape consisting of hills, valleys, and other features.

LOCATING YOURSELF ON A MAP

The first time you take a topographic map outdoors you may have some difficulty locating where you are. Determining where you are is crucial to mapping floodplains, landslides, or other features. One way to locate yourself on a map is to identify two or three distinctive features that you can see—such as a mountain peak, road intersection, or a prominent bend in a road or river—that are also shown on the map. You can then use a compass to determine your location. This is done by taking a compass direction, that is, a bearing, to each of the prominent features and drawing these bearings on the map; your location is where they intersect.

Today we can also use orbiting *global positioning system (GPS)* satellites for locating ourselves and working with maps. Hand-held GPS satellite receivers are readily available at a very modest price and can generally locate your position on the ground with an accuracy of 5 to 10 m (16 to 33 ft.). GPS receivers work by receiving signals from at least four satellites and by calculating the distance from each satellite to your location. This is done with extremely accurate clocks that determine the time delay in receiving an expected radio signal from each satellite; the longer the delay, the further the satellite is from the receiver. With signals from at least four satellites, the computer in your GPS receiver can calculate a three-dimensional position on Earth's surface. Using correction signals transmitted from the Federal Aviation Administration *Wide Area Augmentation System* (WAAS), the accuracy of defining your position can be reduced to less than 3 m (10 ft.) (Figure C.2). Another way to increase positional accuracy is to average multiple measurements taken at the same location over a period of 10 minutes or more.

Your GPS receiver can be linked directly to *geographic information system (GIS)* computer software, so when a position is known, it may be plotted directly on a map viewed on a computer display in the receiver, your vehicle, or a laptop computer. GPS and GIS technology have revolutionized the way we do mapping in the field. A note here concerning the expression "*in the field*"; this expression means "outside on the surface on Earth," not the "field of geology." For example, a geologist about to go out and study landslides triggered by heavy rains in the Appalachians would say to her colleagues, "I am going into the field."

AN EXAMPLE FROM A COASTAL LANDSCAPE

In this example we will look at topographic and cultural features in a coastal landscape (Figure C.3). If we were flying along the coast in a plane, we would have a sideways or oblique view of this landscape consisting of two hills with an intervening valley (Figure C.3a). The coast along the eastern hill to the right is a sea cliff, and in the center is a peninsula that was formed as a sand spit by longshore coastal processes. A hook on the end of the peninsula suggests that the direction of littoral sand transport in the surf zone and beach is from the east (right) to the west (left).

The topographic map for the area has a contour interval (CI) of 20 ft. (Figure C.3b). This map indicates that the elevation of the highest hill on the east side of the map is approximately 290 ft. above sea level; the estimated elevation is half way between 280 ft., the highest contour on the hill, and 300 ft., which would be the next contour if the hill were higher. Three streams drain the hill, two into the ocean and one into a river; notice that in all three streams the topographic contours create a V in the upstream direction toward the top of the hill.

Other information that may be "read" from the topographic map includes the following:

- The landform on the western portion of the map (left side) is a hill with elevation of about 275 ft., a gentle slope to the west, and a steep slope to the east (right) toward the ocean and the river valley. The eastern slope is particularly steep near the top of the mountain where the contours are very close together.
- A river in the center part of the map is flowing into a bay protected by a hooked sand bar. The relatively flat land next to the river is a narrow floodplain. Along the west side of the river is a light-duty road

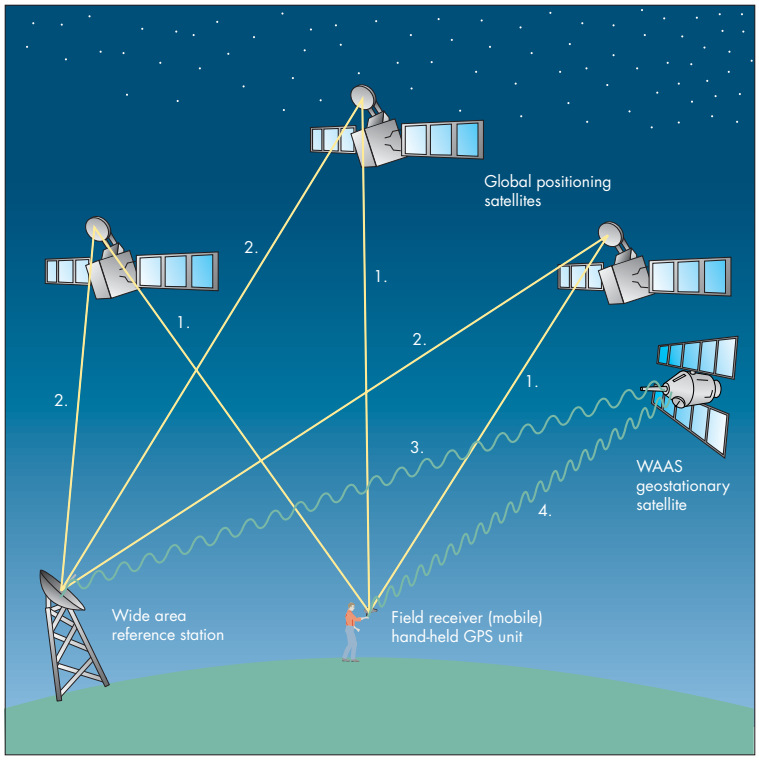


FIGURE C.2 Using the Global Positioning System

U.S. Air Force NAVSTAR Global Positioning System (GPS) satellites orbit approximately 22,200 km (13,800 mi.) above Earth. Each satellite has its own distinct signal, shown with #1 yellow lines, which can be recognized by a hand-held GPS receiver. Using extremely accurate timekeeping, the receiver calculates the distance to a satellite by determining how long its signal took to arrive. A receiver must process signals from at least four satellites to calculate a three-dimensional position on Earth's surface. As long as the satellite signal is not altered, most GPS receivers will achieve a positional accuracy of within 5 to 10 m (16 to 33 ft.) of their true position on Earth's surface. Increased accuracy can be obtained with a correction signal obtained from a Wide Area Reference Station that is part of the Federal Aviation Administration's Wide Area Augmentation System (WAAS). The WAAS reference station receives signals from the same GPS satellites, shown as #2 yellow lines, at the same time as the mobile GPS receiver. The WAAS then compares the position calculated from the GPS satellites with its true position to establish a correction factor. The correction factor is then transmitted to a WAAS geostationary satellite, shown as the #3 wavy line, and then broadcast back to the mobile GPS receiver, shown as the #4 wavy line. A GPS receiver with WAAS correction typically has a positional accuracy of within 3 m (10 ft.) or less of the true position.

that parallels the river and then extends along the coastline. A second, unimproved road crosses the river and extends out to the head of the sand spit, providing access to a church and two other buildings. The floodplain is delineated on both sides of the river by the 20-ft. contour, above which to the 40-ft. contour is a break in slope at the edge of the valley.

- The eastern and southern slopes of the 275-foot hill on the west (left) side of the map have a number of small streams flowing mostly southward into the ocean. These streams appear to be relatively steep gullies that are eroding into the hillslope. In particular, the stream directly south of the 275-foot elevation mark appears to be cutting headward into the steep hillside.

To continue a study of this area, we might construct an east–west *topographic profile* across the area along line A–A′. In constructing a profile we must decide how much to exaggerate the vertical scale of the view (Figure C.3c). The resulting *vertical exaggeration (VE)* is determined by comparing the same unit on both the vertical and the horizontal scale; for example, the number of feet represented by 1 inch on both scales. After constructing topographic profiles, your next task might be to obtain aerial photographs and geologic maps to draw more conclusions concerning the topography and geology.

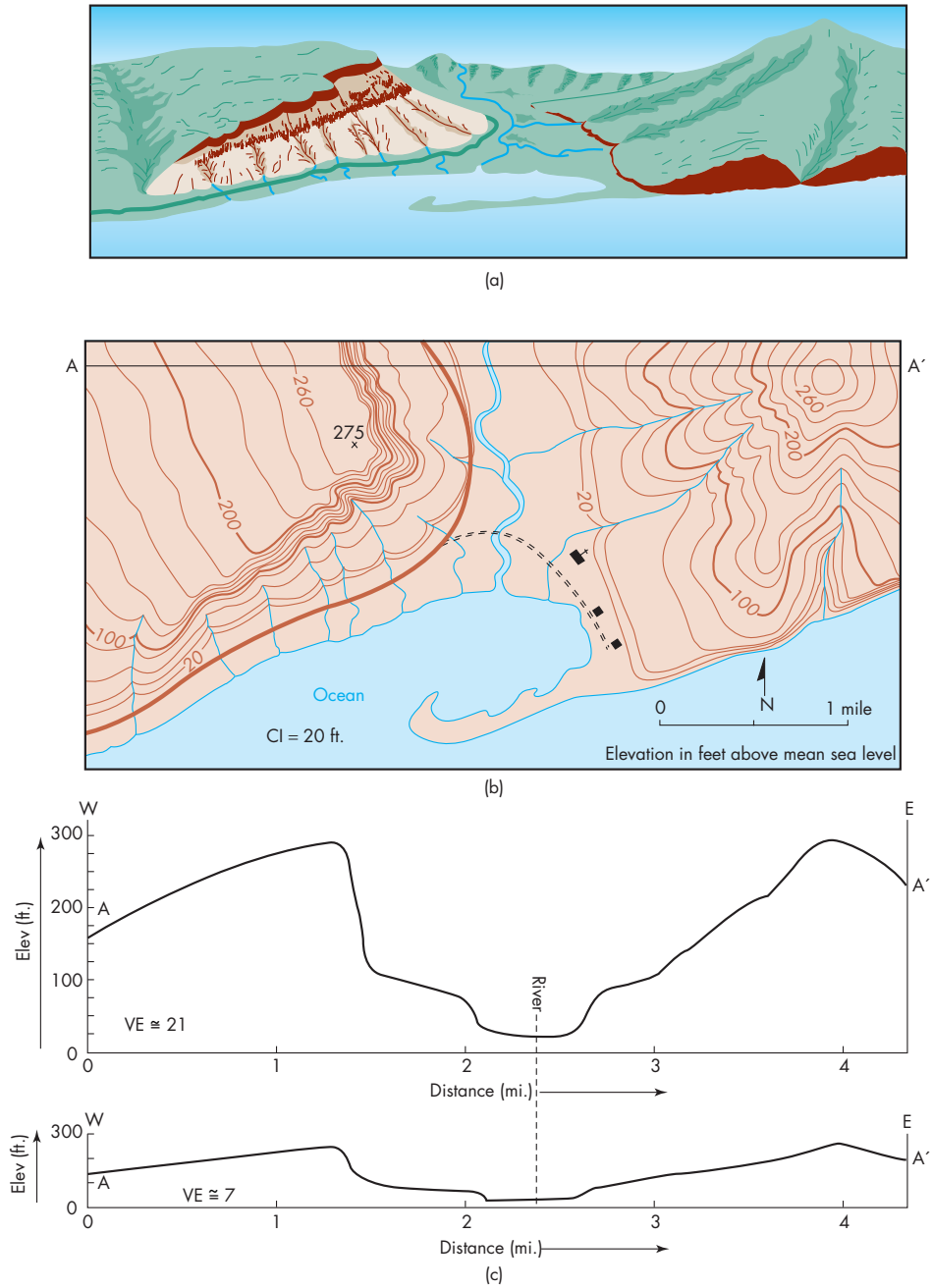


FIGURE C.3 Topography of a Coastal Landscape

(a) An oblique view of the coastline mapped in part (b) of this figure. (b) Topographic map for the same area with a contour interval of 20 ft. (c) Topographic profiles along line A–A′ of the topographic map shown with vertical exaggeration of approximately 21 times and 7 times. Vertical exaggeration is the ratio of the vertical to horizontal scale for the topographic profile. The ratio for the upper profile is approximately 21, so it has a vertical exaggeration of approximately 21 times. For the lower profile, the vertical exaggeration is about 7 times. In the real world, of course, there is no vertical exaggeration (the vertical and horizontal scales are the same). As an experiment, you might try to make a topographic profile along line A–A′ with no vertical exaggeration. What do you conclude? *(From U.S. Geological Survey)*

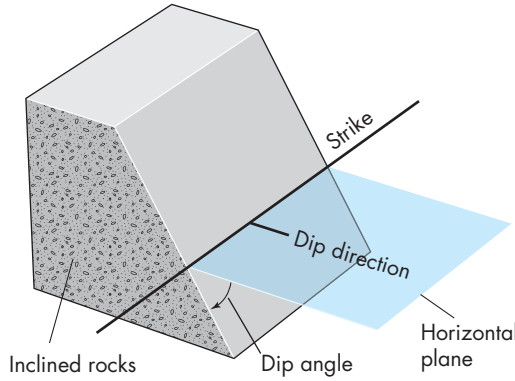
GEOLOGIC MAPS

Geologists are interested in the types of earth materials found in a particular location and in their spatial distribution. Producing a geologic map is a very basic step in understanding the geology of an area. In constructing a *geologic map* a geologist must make interpretations that are consistent with the Earth history of the mapped area and the geologic processes that have been at work. Like any other scientific endeavor, each new observation becomes a test of the geologist's interpretations, sometimes referred to as a working hypothesis.

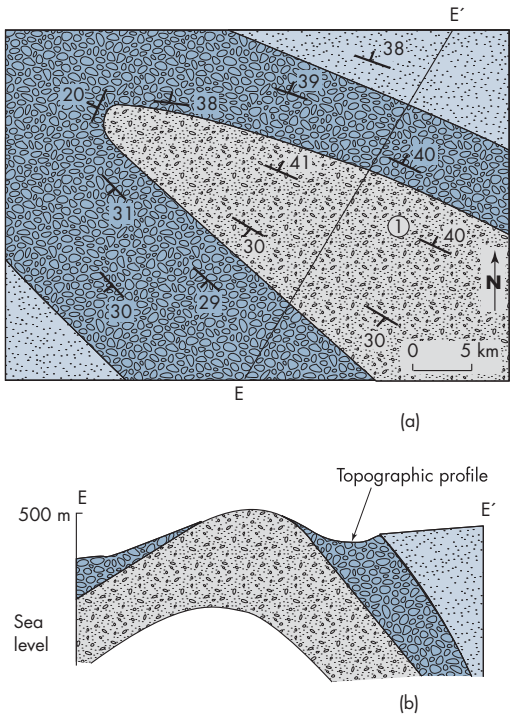
The first step in preparing a geologic map is to obtain a good base map (usually topographic) or aerial photograph on which the geologic information may be transferred. A geologist then goes into the field and makes observations of earth materials where they are exposed at or near the surface. From these exposures, called outcrops, the geologist groups distinctive rock or sediment types into separate units called *formations*. Each formation must be thick enough to be depicted on the scale that is being mapped. On the geologic map, each formation is separated from adjacent formations by boundaries known as *contacts*, which appear on the map as thin lines between swaths of different colors.

As the geologist maps formations, he or she also takes measurements of the three-dimensional orientation, or attitude, of the mapped units. These measurements, referred to as *strike and dip*, are generally made with a compass and a device for measuring vertical angles known as a clinometer. Each strike and dip measurement is commonly recorded directly on the map with a T-shaped strike and dip symbol. Strike is the compass direction of the line formed by the intersection of layering in the earth material with a horizontal plane, and dip is the maximum angle that the layering makes with the horizontal (Figure C.4).

For example, a simple geologic map of an area of approximately 1350 km^2 (520 mi.^{2}) might show three rock types—sandstone, conglomerate, and shale (Figure C.5a).



▲ FIGURE C.4 Strike and Dip
Idealized block diagram showing the strike and dip of inclined sedimentary rocks. Strike is the long direction of a T-shaped symbol, and the dip direction is shown with the short line perpendicular to strike.



◀ FIGURE C.5 Geologic Map
(a) A very simple, idealized geologic map showing three formations, each consisting of a different type of sedimentary rock. (b) Geologic cross-section and topographic profile along line E–E′. The cross-section shows that the pattern of the formations on the geologic map is one made by an arch-like geologic structure known as an anticline.



▲ FIGURE C.6 Digital Elevation Model
This digital elevation model (DEM) of the Los Angeles area is constructed as an oblique view from the southwest with a fair amount of vertical exaggeration. The flat, light blue area in the lower half of the image is the Los Angeles Basin. The smaller basin above the Los Angeles Basin is the San Fernando Valley, site of the epicenter of the 1994 Northridge earthquake. It is separated from the Los Angeles Basin by the Santa Monica Mountains. To the left of the Los Angeles Basin are the Palos Verdes Hills on the Palos Verdes Peninsula, the site of the Portuguese landslide discussed in Chapter 6. Finally, on the right side of the map is the San Andreas Fault, a strike-slip fault that is one of the major geologic hazards in southern California. *(Courtesy of Robert Crippin, NASA, Jet Propulsion Laboratory)*

On this map the arrangement of the strike and dip symbols suggests the presence of an arch-like underground geologic structure known as an anticline. The nature of this structure becomes apparent in a geologic cross-section and topographic profile constructed along the line E–E′ (Figure C.5b). Geologists often make a series of cross-sections of a geologic map to better understand the geology of the area. Geologic maps at a variety of scales from 1:250,000 to 1:24,000 are generally available from a number of sources, including the U.S. Geological Survey.

Digital Elevation Models

Topographic data for the United States and many other parts of the world are now available as digital files. These data sets contain arrays of elevation values at a specific spacing, for example, the surface ground elevations on a 30 m grid for a 900 m^2 (9700 $ft.^2$) area. Computer programs are then used to synthesize and view the data; color shading may be added to show the topography. The resulting graphic representation of Earth's surface is known as a *digital elevation model* (DEM). DEMs can be examined from a variety of angles using software such as Google Earth, and you may view the topography obliquely from any compass direction. The vertical dimension may also be exaggerated so that minor topographic differences may become more apparent. A DEM for the Los Angeles Basin clearly illustrates that Los Angeles is nearly surrounded by mountains and hills, which have been uplifted by recent tectonic activity (Figure C.6). DEMs are becoming important research tools in evaluating the topography of an area. They may be used to delineate and map features such as fault scarps, landslides, karst topography, floodplains, and volcanic and impact craters.

Summary

Several types of maps and images are useful in evaluating geology and Earth processes. Of particular importance are topographic maps and profiles, and geologic maps and cross-sections. Digital elevation models may be constructed from topographic data, and a variety of other special purpose maps are also available. Examples include maps of recent landslides, floodplain and coastal flood hazard maps, and engineering geology maps that show engineering properties of earth materials.

APPENDIX D: How Geologists Determine Geologic Time

In order to understand the history of Earth, we must determine the actual age of earth materials with the science of *geochronology*. In geochronology, scientists combine *relative and absolute dating* techniques to reconstruct Earth history. Relative dating establishes a chronological order of events using fossil evidence and geologic relationships, the use of which is governed by geologic principles and laws. The oldest of these laws, the law of superposition, was proposed by Nicholas Steno in 1668, and has been applied and tested by scientists for over 300 years. This law states that in any succession of sediment or sedimentary rock that has not been deformed, the oldest layer lies at the bottom, with successively younger layers above. Although a relative geochronology can be established based upon superposition and other laws and principles of relative dating, it is absolute dating that provides the information necessary to establish rates of geologic processes and the numeric ages of earth materials.

From a natural hazards perspective, it is important to establish rates of geologic processes and the timing of past geologic events such as volcanic eruptions, earthquakes, tsunamis, floods, and landslides. The chronology of these events is critical in estimating their return period or recurrence interval. Knowing how frequently an event takes place helps us better understand the hazard and predict when a similar event is likely to occur in the future.

Geologic time is much different, in a way, than our normal time framework. Although geologic time and "normal" time use the same units of measure—years—they differ vastly in duration and in the instruments we use to measure duration.[1] Normal time is counted in hours, days, seasons, or decades, and the instrument used to measure time is a clock. In contrast, geologic time—sometimes called "deep time"—is measured in tens of thousands to hundreds of millions to several billion years. To measure this vast amount of time, geologists take advantage of naturally occurring forms of uranium (U), potassium (K), carbon (C), and other chemical elements to date the earth materials in which they are found.

The natural forms of these chemical elements are called *isotopes* and are distinguished from each other by their weight. The weight of an isotope is the sum of the weight of smaller, subatomic particles called protons and neutrons that are found in the center of the atom, the nucleus. Each proton and neutron has a weight of 1, so the number of protons plus the number of neutrons determines the atomic weight of an isotope. All isotopes of a chemical element have the same number of protons, because it is the number of protons that defines a chemical element. Where isotopes vary is in their number of neutrons. For example, carbon has three common isotopes, carbon-12, carbon-13, and carbon-14. All three isotopes have 6 protons because they are carbon, but the number of neutrons varies from 6 to 7 to 8, respectively.

Isotopes also differ in their stability. Some isotopes, such as carbon-12 and carbon-13, have a stable number of neutrons and protons in their nucleus and do not split apart. Most isotopes, however, are unstable and will undergo spontaneous splitting, sometimes called decay, at some point in the future. Unstable isotopes are commonly called *radioactive isotopes* because radiation is released when they decay. Although it is impossible to predict when an individual unstable atom will decay, laboratory studies can determine the rate at which a large number of atoms of a radioactive isotope will decay. Each radioactive isotope has a constant rate of decay that is unaffected by physical forces.

Absolute dating is possible if a measurable quantity of a radioactive isotope is incorporated into a mineral or substance when it forms. The decay of the unstable radioactive isotope is irreversible and becomes a clock that is running at a constant rate. In absolute dating, the unstable radioactive isotope is known as the *parent* and the *stable isotope* that eventually forms from the decay of the parent is known as the *daughter product*. Radioactive isotopes, particularly those of very heavy elements, undergo a series of radioactive decay steps that finally ends when a stable, nonradioactive isotope is produced. For example, the isotope uranium-238 (U-238) undergoes 14 nuclear transformations in different steps to

TABLE D.1 Half-Lives of Radioactive Isotopes Commonly Used in Absolute Dating

Parent Radioactive Isotope	Daughter Stable Isotope	Half-Life
Uranium-238	Lead-206	4.5 billion yr
Uranium-235	Lead-207	700 million yr
Potassium-40	Argon-40	1.3 billion yr
Carbon-14	Nitrogen-14	5730 yr

finally decay to stable lead-206 (Pb-206), which is not radioactive.

An important characteristic of a radioactive isotope such as U-238 is its *half-life*, which is the time required for one-half of a given amount of the isotope to decay to another form. Every radioactive isotope has a unique and characteristic half-life (Table D.1). As decay proceeds over time, the amount of parent radioactive isotope in a substance decreases and the amount of the stable daughter isotope proportionally increases (Figure D.1). Without knowing the actual quantity of radioactive isotope that was initially present, it is often possible to obtain a numeric date by comparing the relative proportions of parent and daughter isotope in a substance. In most cases, two important conditions must be met to obtain an accurate numeric date. First, no new atoms of the parent isotope have been added to the substance since it formed; this is true for many minerals in igneous rocks where the radioactive isotope becomes part of the atomic structure when a mineral crystallizes from magma. Second, all atoms of the daughter isotope produced by decay remain trapped in the substance; again this occurs for minerals in igneous rocks where atoms are strongly bonded in the crystal structure. Should any daughter product "leak" from the sample, it would give a numeric date that was too young. Because radioactive isotopes such as U-238, U-235, and K-40 have relatively long half-lives (Table D.1), their decay is useful in dating rocks on the order of millions to billions of years. For example, the ratio of Pb-207/Pb-206, the daughter products of U-235 and U-238, has been used to date the oldest piece of continental crust, a crystal of the mineral zircon from sandstone in Western Australia, at 4.4 billion years before the present. The actual methods for measuring amounts of parent and daughter isotopes and calculating numeric dates are complex and tedious, although the concept is easy to grasp. These methods have been successfully used to assign numeric dates to the geologic time table and to delineate important Earth history events such as mountain building, ice ages, and the appearance of life forms.

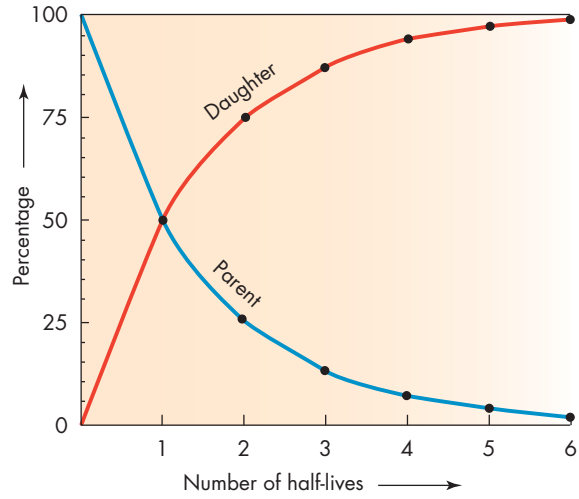


FIGURE D.1 Relative Proportion of Parent and Daughter Isotopes Over Time
This graph shows the reduction of a parent radioactive isotope to a daughter stable isotope with each additional half-life.

Physical anthropologists and archeologists concerned with human history are interested in developing a geochronology for the last 8 million years of Earth history; that is the period from which human and ancestral human fossils are found. From a natural hazards perspective, we are often interested in establishing the geochronology of the past few hundred to few hundred thousand years of Earth's history, and for this we have several potential methods. For example, the radioactive isotope U-234 undergoes decay to thorium (Th)-230 at a known rate, and the ratio of these two isotopes is useful in numerically dating a variety of materials, such as coral, back to several hundred thousand years.

For sediment younger than about 40,000 years, C-14 is used extensively for numeric dating. The most common form of carbon is stable C-12, but C-14, which is radioactive, occurs in small quantities and undergoes radioactive decay to the stable daughter isotope nitrogen-14 (N-14). The half-life of the decay of C-14 to N-14 is 5730 years. The C-14 method works because C-14 is only incorporated into organic matter while an organism is alive; when the organism dies, the C-14 in its tissue undergoes radioactive decay without being replaced with new C-14. Common materials dated with C-14 include wood, bone, charcoal, and other types of buried organic material. C-14 has a relatively short half-life; as a result, after about 40,000 years, the amount of C-14 remaining is very small and difficult to measure. Consequently, use of this technique is limited.

The field of geochronology is expanding rapidly, and new techniques are constantly being developed. For example, it is now possible to directly date the amount of time that a landform has been exposed at Earth's surface. This is known as *exposure dating*. The basic idea is that certain isotopes, such as beryllium-10, aluminum-26, and chlorine-36, are produced when cosmic rays interact with Earth's atmosphere and accumulate in measurable quantities in surface materials such as soil, alluvium, and exposed rock surfaces. Thus, the amount of these isotopes that has accumulated is a measure of the minimum time of exposure to the surface environment.

Another innovative technique, known as *lichenometry*, uses the slow, but constant growth of *lichens* on rock surfaces to determine a minimum time that a rock is exposed. Lichens are plant-like growths of photosynthetic algae or bacteria with a fungus. These organisms tend to grow in circular patches with a rate of growth that is known for a particular species. Careful measurements of the size of lichen patches, coupled with known growth rates, provide minimum numeric ages for exposure of the rocks on which they are found. This method has been successfully used in California and New Zealand to date regional occurrences of rockfalls generated by large earthquakes, thus dating past seismic activity.[2,3] Lichenometry can provide dates to about 1,000 years before present.

Sediment may also be accurately dated through the use of *dendrochronology*, which is the analysis of annual growth rings of wood. Because of variations in annual precipitation, the width of tree rings differs from year to year. This produces a distinctive sequence of wide and thin rings similar to a bar code on merchandise at a store. Once a regional chronology is developed using growth rings in both living and dead trees, it then becomes possible to determine the age of a growth ring pattern from a piece of buried wood. This method has been used extensively by archeologists to date prehistoric sites of human habitation and also by climatologists as a method of reconstructing prehistoric patterns of precipitation. Growth rings record climate because during dry years, tree rings are narrow relative to wet years.

Very accurate numeric geochronology may also be obtained from counting varves. A *varve* is a layer of sediment representing one year of deposition, usually in a lake or an ocean. Careful counting of varves may extend the chronology back several thousand years.

Although the most accurate chronology is the historical record, its length varies from only a few hundred years in the United States and Canada to several thousand years in China. Given the brevity of human history compared with the great length of geologic history, we resort to numeric dating methods to establish geochronology. There are more than 20 methods useful in establishing geochronology that yield numeric dates. These methods are crucial to understanding rates of geologic processes and the recurrence interval of natural hazards.

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Glossary

Aa A cooler or thicker lava flow that solidifies with a blocky surface texture.

Abrupt climate change Large-scale change in the global climate system that takes place over a few decades or less.

Absolute dating Determination of the geologic age at which time a fossil organism, earth material, or geologic feature formed; the age is usually expressed in years; commonly established by the analysis of radioactive isotopes and their decay products.

Acceptible risk Exposure to danger that an individual or society is willing to take.

Acid rain Water droplets falling from clouds that have been made artificially acidic by pollutants. In volcanoes, this acidity commonly comes from sulfate aerosols in eruption clouds, or sulfur dioxide fumes or from hydrogen chloride gas produced when lava vaporizes seawater. Rainwater normally has a slight acidity from dissolved carbon dioxide.

Active fault A fault along which future movement is thought possible. Two criteria are mappable displacement along a fracture or fractures in the past 10,000 years or several mappable displacements in the past 35,000 years.

Adaptive management Structured management with the use of science that promotes sustainable coasts, and allows for changing conditions during management.

Advance With respect to a glacier, an interval of time during which the area occupied by glacial ice increased.

Aerosol With respect to climate, a suspension of microscopic liquid and solid particles, such as mineral dust and soot, in the atmosphere.

Aftershock A subsequent, less intense earthquake that occurs a few minutes to a year or so after a main earthquake, and in the same general area. Usually one of many quakes of lesser magnitude than the main shock.

Airburst With respect to collision with extraterrestrial objects, the explosion of a meteoroid or comet in the atmosphere, generally at an altitude of 12 to 50 km (~7.5 to 30 mi.).

Air mass thunderstorm An ordinary storm with lightning and thunder that develops from local convection within an unstable air mass. Commonly forms in the afternoon and is generally not severe.

Albedo A measure of the reflectivity of a material or surface to electromagnetic radiation, especially sunlight. Commonly expressed as the percentage of radiation reflected versus absorbed.

Alberta Clipper An extratropical cyclone that forms east of the Rocky Mountains in the Canadian province of Alberta and moves rapidly to the southeast across Canada and the northern United States. Commonly associated with snowstorms, especially blizzards.

Alluvial fan Fan-shaped deposit composed of coarse sediment that is dropped by a stream as it emerges from a mountain front onto flatter terrain; typically made of a variable proportion of stream and debris-flow deposits. The fan takes the shape of a segment of a cone.

Alluvium Unconsolidated sediment, such as sand, gravel, and silt, deposited by a stream.

Andesite A type of lava that has a silica content intermediate between basalt and rhyolite. Commonly, but not exclusively, associated with composite volcanoes where it forms by the partial melting of oceanic crust in a subduction zone below the volcano.

Angle of repose Maximum angle that loose material will sustain.

Anthropogenic Produced by humans or originating in human activity.

Anticipate In respect to natural hazards and disasters, advance planning for the effects of the natural process.

Aquifer A useable accumulation of subsurface water in earth material that is saturated with water.

Artificial bypass Human action that moves sand or other sediment around an obstruction, such as dredging and pumping sand from updrift to downdrift sides of a jetty or harbor.

Artificial control of natural processes An action or structure made by humans to influence phenomena that are not caused or produced by humans.

Ash fall Fine airborne material that settles onto the land surface. The material is unconsolidated volcanic debris (ash), less than 4 mm in diameter, that has been blown out of a volcano during an eruption; it may travel a considerable distance from the volcano.

Ash flow See *Pyroclastic flow*.

Asteroid Rock or metallic particle in space with a diameter between 10 m (~30 ft.) and 1000 km (~620 mi.).

Asteroid belt Region between orbits of Mars and Jupiter that contains most of the large rock or metallic particles in our solar system.

Asthenosphere Upper zone of Earth's mantle, located directly below the lithosphere; a hot, slowly flowing layer of relatively weak rock upon which tectonic plates move.

Atmosphere Layer of gases surrounding a planet, such as Earth.

Atmospheric pressure The force per unit area exerted by the weight of gas molecules that surround a planet; also called barometric pressure, because it is commonly measured with a barometer.

Atmospheric stability A condition of equilibrium in which a rising or sinking parcel of air tends to return to its original position. This equilibrium develops when a relatively small difference in air temperature exists between the surface and the air aloft.

Atoll A ring or horseshoe-shaped group of coral reefs, low islands, and shoals generally surrounding a large island, submerged island, bank, or underwater plateau.

Attenuation With respect to earthquakes, the loss of energy as seismic waves pass through earth materials. For example, this process reduces the energy of seismic waves from deep subduction-zone earthquakes before they reach Earth's surface.

Avalanche A type of landslide involving a large mass of snow, ice, or entrained rock debris that slides, flows, or falls rapidly down a mountainside.

Avulsion The process by which all or part of a river or distributary channel is abandoned in favor of a new channel.

Bankfull discharge Flow condition in which water completely fills a stream channel. Many stream channels are formed and maintained by bankfull discharge.

Barometric pressure See *Atmospheric pressure*.

Barrier island An elongate, offshore accumulation of sand that is above water level and is separated from the mainland by a bay or lagoon; stops large waves from reaching the shore of the mainland.

Basalt A common volcanic rock consisting of feldspar and other silicate minerals rich in iron and magnesium; has a relatively low silica content of about 50 percent; forms shield volcanoes.

Base level The theoretical lowest elevation to which a river may erode, generally at or about sea level.

Beach Associated with an ocean or lake, an accumulation of loose material, most commonly sand, gravel, or bits of shell, on a shoreline as the result of wave action. As used by river rafters, a wide sand accumulation along a low bank of the channel.

Beach budget Inventory of sediment influx and loss along a particular stretch of coastline.

Beach drift Continual movement of sand grains along the shore by the runup and backwash of waves.

Beach face The part of the shore that is normally exposed to swash action, that is, the runup and backwash of the waves; the sloping surface between the ocean or lake and the berm.

Beach nourishment Mechanical addition of sediment, generally sand, to a shore for recreational and aesthetic purposes, as well as to buffer coastal erosion.

Bedding plane A surface separating layers of sedimentary rocks. In mass wasting, this is commonly a weakness along which weathering occurs and landslides develop.

Berm The relatively flat or landward sloping part of a beach profile produced by wave-deposited sediment; the part of the beach where most people sunbathe.

Bermuda-Azores High A persistent high-pressure region in the North Atlantic during the summer and fall months that lies approximately between the Island of Bermuda, east of North Carolina, and Azores Islands, west of Portugal.

Blind fault A fracture or zone of rupture along which displacement does not extend to the Earth's surface.

Blizzard A severe winter storm producing large amounts of falling or blowing snow that create low visibilities for extended periods of time. In the United States, for a storm to be classified as a blizzard winds must exceed 56 km (~35 mi.) per hour with visibilities of less than 0.4 km (~0.25 mi.) for at least 3 hours in Canada, for a storm to be classified as a blizzard winds must exceed 40 km (~25 mi.) per hour with visibilities of less than 1 km (~0.6 mi.) for at least 4 hours.

Block With respect to a fragment ejected from a volcano, an angular particle that is longer than 64 mm (~2.5 in.).

Bluff As a landform, a high steep bank or cliff along a lakeshore or river valley commonly made of weakly consolidated earth material.

Bomb With respect to a volcanic fragment, a smooth-surfaced particle that is longer than 64 mm (~2.5 in.); commonly forms from a blob of magma ejected from a lava fountain; the magma cools and forms a streamlined shape as it falls to the surface.

Braided With respect to a river or stream, a channel pattern with numerous islands and sand and gravel bars that continually divide and subdivide the flow of water. This pattern is most evident during low and moderate stream flow.

Braided river See *Braided stream*.

Braided stream A flowing channel of water with numerous islands and sand and gravel bars that continually divide and subdivide the flow.

Breaker zone With respect to a shoreline, that part of the beach and nearshore environment where incoming waves peak up, become unstable, and collapse toward the shore.

Breakwater A structure, such as a wall, that may be attached to a beach or located offshore, designed to protect a beach or harbor from the force of waves.

Breccia A rock or zone within a rock composed of angular fragments; may have a sedimentary, volcanic, tectonic, or impact origin.

C soil horizon Lowest soil horizon, sometimes known as the *zone of partially altered parent material*.

Caldera A semi-circular region of low topography that develops at the top of a volcano or in the continental crust due to collapse of the surface due to removal of magma from the subsurface during a volcanic eruption.

Calving The separation of large blocks of ice from the terminus of a glacier that flows into a large body of water; calved blocks may form icebergs.

Carbon-14 Radioactive isotope of carbon with a half-life of approximately 5730 years; used in absolute dating of organic materials back to approximately 40,000 years.

Carbon dioxide (CO_2) A colorless, odorless gas that is denser than air and is produced by plant and fossil fuel combustion, animal and microbe respiration, and volcanic eruptions. In the atmosphere, it is the primary cause of global warming because, as a greenhouse gas, it heats the air by absorbing infrared radiation.

Carbon monoxide (CO) A colorless, odorless gas that forms in low-oxygen conditions with incomplete combustion or is released from volcanoes; in low concentrations it is highly toxic to humans and animals.

Carbon sequestration The removal and isolation of carbon compounds, particularly carbon dioxide, from chemical reactions in the carbon biogeochemical cycle; a term commonly used to describe the removal of atmospheric carbon dioxide and its isolation underground or in the ocean.

Carrying capacity Maximum number of a population of a species that may be maintained within a particular environment without reducing the ability of that environment to maintain that population in the future.

Catastrophe An event or situation causing sufficient damage to people, property, or society that recovery or rehabilitation is long and complex; natural processes most likely to produce a catastrophe include floods, hurricanes, tornadoes, tsunamis, volcanoes, and large fires.

Cave A natural subterranean void commonly consisting of a series of chambers that are large enough for a person to enter; formed most often in limestone or marble.

Cave system See *Cave*.

Cavern A large cave.

Cenote On the Yucatán Peninsula of Mexico, a steep-walled collapse sinkhole

that extends below the water table. Some of these sinkholes are developed in fractured limestone on the perimeter of the Chicxulub impact crater.

Channel pattern The shape of a flowing stream as viewed from above ("bird's-eye view"); the three most common shapes or patterns are straight, meandering, and braided.

Channel restoration The process of returning a stream and adjacent areas to a more natural state.

Channelization Engineering technique to straighten, widen, deepen, or otherwise modify a natural stream channel.

Chute In mass wasting and landslides, a narrow path formed and maintained by the rapid downslope movement of avalanches, rockfalls, or debris flows.

Cinder cone A conical volcanic hill formed by an accumulation of coarse pyroclastic material erupted from the volcano; also known as a *scoria cone*.

Clay particles Very small particles less that 1/256 mm in diameter.

Clear-cutting Forestry practice of harvesting all trees from a tract of land.

Cleavage In a mineral, the smooth, easy fracture that takes place along parallel surfaces lying in one or more planes; these surfaces develop where bonds between atoms are weak or are especially long.

Climate Characteristic weather at a particular place or region during many seasons, years, or decades.

Climate forcing An imposed positive or negative change of Earth's energy balance measured in Watts per meter squared (W/m^2).

Coarse grained soils Type of soil where over half of the soil particles (by weight) is composed of particles greater than 0.074 mm in diameter.

Coastal Zone bioengineering Coastal defense that uses living or dead plants to assist in controlling coastal erosion.

Cold front An atmospheric boundary between two air masses of contrasting temperature along which the cooler air mass advances into the warmer air mass.

Collapse sinkhole Depression in sediment or bedrock caused by a subsurface cave-in.

Collapsible soils Some windblown dust deposits that are loosely bound with clay particles and water-soluble minerals that collapse when water percolates through them, often resulting in land surface subsidence.

Colluvium Mixture of weathered rock, soil, and other, usually angular, material on a slope; produced by creep, landsliding, and other surface processes.

Color In a mineral, the name associated with the particular wavelengths of light that are reflected from the entire specimen or from its powder.

Combustion Second phase of a wildfire that follows every ignition. Includes flaming, where fine fuel and volatile gases are rapidly oxidized at high temperature, and glowing or smoldering, which take place later at lower temperature. Both flaming and glowing liberate energy as heat and light.

Comet Particle in orbit in space composed of a spongelike rocky core surrounded by ice and covered by carbon-rich dust with a tail of gas and dust that glows, as its orbit approaches the sun; ranges from a few meters to a few hundred kilometers in diameter.

Community Internet Intensity Map Online depiction of how people and structures have experienced an earthquake on the basis of email reports.

Composite volcano Steep-sided volcanic cone produced by alternating layers of pyroclastic debris and lava flows; also known as a *stratovolcano*.

Conchoidal fracture In a rock or mineral, a broken surface that is smoothly curved, like the inside of a clamshell.

Conduction With respect to physics, the transfer of heat through a substance by molecular interactions.

Constructive interference In an ocean or a lake, combining two or more waves on the water surface to form a resultant higher wave.

Contact Interface or boundary between two geologic mapping units that is generally shown as a thin line on a geologic map.

Continental collision boundary The interface between two tectonic plates of similar density that are moving toward each other. Deformation and mountain formation occur along the interface because neither plate is able to slide below the other.

Continental Drift Hypothesis proposed by Alfred Wegener, in the early twentieth century, that states the continental landmasses of the world "drift" about the surface of the globe and were once united to form a single super-continent, which he called Pangea. The hypothesis was supported by geologic and paleontologic data.

Contour line On a topographic map, a series of connected points in which all points are the same elevation above sea level.

Contour interval (CI) On a topographic map, the vertical distance between each line of equal elevation; generally expressed in meters or feet.

Convection Transfer of heat by a mass of moving particles; for example, in boiling water, hot water rises to the surface and displaces cooler water that moves toward the bottom. Atmospheric heat may be transferred vertically. This is the primary process in which heat is transferred within the atmosphere and during wildfires.

Convection cell A self-contained circulation loop in a fluid in which hot, less dense fluid rises and cooler, denser fluid sinks; develops on a large scale in the atmosphere and within the Earth.

Convergence Coming together.

Convergent boundary Interface between two tectonic plates in which one plate generally descends below the other in a process known as *subduction*.

Core With respect to the interior of Earth, the central part of Earth below the mantle, divided into a solid inner core with a radius of approximately 1300 km and a molten outer core with a thickness of about 2000 km; the core is thought to be metallic and composed mostly of iron.

Coriolis effect An apparent deflection in the path of a moving object. This apparent deflection, to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, results from Earth's rotation. The magnitude of this effect increases with increasing latitude from the equator to the poles.

Crater A type of volcanic vent that forms a semicircular depression near the summit of most volcanoes, particularly cinder cones and stratovolcanoes. Volcanic craters form in response to the forceful ejection of volcanic debris and gasses.

Creep Slow downslope movement of soil and other weakly consolidated earth materials; characterized by slow flowing, sliding, or slipping.

Crevasse On a glacier, a large, deep fracture in the surface of the glacial ice caused by stretching of ice at and near the glacier surface.

Crown fire With respect to wildfires, flaming combustion that carries through canopies of trees; commonly driven by high wind and aided by a steep slope.

Crust The thin outermost rock layer of Earth that is differentiated from the underlying mantle by having a lower density.

Crustal assimilation A process where crustal rocks are melted by and incorporated into a body of magma that is rising toward the surface. Addition of felsic crustal melt to the original magma body causes progressive increase of the silica content of the magma as it rises.

Crystal form In a mineral, the characteristic geometric shape assumed by that mineral because of its orderly, internal atomic structure.

Crystallization Process by which atoms precipitate from solution such that they organize themselves into the orderly internal atomic arrangement of a mineral. The mineral may or may not possess crystal faces.

Cumulonimbus Thunderstorm cloud that grows vertically until it reaches a stable layer of air; generally with an anvil-shaped top.

Cumulus Any cloud that develops vertically; generally has a flat base with a cauliflower-like top; one of the three basic cloud types.

Cumulus stage First phase of thunderstorm development characterized by the growth of domes and towers on the top of a cumulus cloud as it becomes a cumulonimbus cloud.

Cutbank Steep or nearly vertical slope on the outside of a bend in a stream channel; typically forms by stream erosion.

Cyclone An area of low atmospheric pressure characterized by rotating winds that, in the Northern Hemisphere, circulate in a counterclockwise direction.

Cyrosphere The portion of a planet consisting of ice; on Earth this includes permafrost in soil and below the seafloor, glaciers, ice sheets, ice caps and fields, ice shelves, and icebergs.

Daughter product A stable isotope that forms by radioactive decay of an unstable parent isotope.

Debris flow Rapid downslope movement of unconsolidated, water-saturated earth material that became unstable because of torrential rain, rapid melting of snow and ice, or sudden drainage of a pond or lake; sometimes restricted to flows of this type that contain mainly coarse material.

Decadal cycles Cycles of storm tracks and thus climate and weather in North America and Western Europe that may last several decades; also known as *Decadal oscillations*.

Decompression melting The process by which solid rock melts due to a decrease in pressure that is caused by upwelling of hot rocks within the interior of the planet.

Delta Low, nearly flat area of land formed near the mouth of a stream where it enters a lake or the ocean; commonly triangular or fan-shaped and crossed by branching distributary channels of the stream that created it.

Delta plain Generally flat land surface that develops where a stream enters an ocean or lake; commonly covered with marsh or swamp and cut by distributary channels.

Dendroclimatology Study of tree rings, sets of which usually form each year, to establish the absolute age of a tree or piece of wood from a tree.

Deposition In geology, the laying down or accumulation of earth material by processes that include the mechanical settling of sediment, the chemical precipitation of mineral matter, or the in-place accumulation of organic matter.

Derecho A windstorm with straight-line winds exceeding 90 km (~56 mi.) per hour along a line that is at least 400 km (~250 mi.) in length; damage produced by this windstorm is often equivalent to that caused by a tornado.

Desert An arid or semiarid region typified by mean annual precipitation less than 250 mm (~10 in.); native animals and vegetation adapted to conserve limited water and soil that may be rich in salts.

Desertification Conversion of land from a more biotically productive state to one that more closely resembles a desert.

Desiccation crack A rupture in fine-grained sediment, typically mud, produced by complete or nearly complete drying.

Differentiated With respect to meteoroids and asteroids, rock that has undergone igneous and sometimes metamorphic processes.

Digital elevation model (DEM) Three-dimensional computer depiction of a land surface as viewed from an oblique angle. Constructed with a computer program that samples land-surface elevation data on a specific spacing grid, such as every 30 m (~100 ft.).

Direct effect A change that follows an event without any intervening factors. In a natural accident, disaster, or catastrophe, such effects could include people killed, injured, or dislocated and property damaged or destroyed; also referred to as a *primary effect*.

Directivity With respect to an earthquake, the increased intensity of shaking in the direction toward which a fault ruptures; observed in some moderate-to-large earthquakes.

Disappearing stream A brook, creek, or river that flows from a surface channel into the ground and continues flowing underground.

Disaster One possible effect of a hazard on society. Usually a sudden event that causes great damage or loss of life during a limited time and in a limited geographic area.

Disaster preparedness With respect to a natural hazard, actions of individuals, families, communities, states, provinces, or entire nations to minimize losses from a hazardous event before it occurs.

Discharge Quantity of water flowing past a particular point on a stream, usually measured in cubic feet per second (cfs) or cubic meters per second (cms).

Dissipative stage Final phase of a thunderstorm in which the supply of moist air is blocked by downdrafts in the lower levels of the cloud. Without a source of moisture, precipitation decreases and the storm cloud begins to disappear.

Distant tsunami A series of gravity waves in the ocean originating from a source typically thousands of kilometers away from the shoreline that is inundated. These waves are produced by the displacement of the entire water column of the ocean by an underwater earthquake, landslide, volcanic eruption, or extraterrestrial impact.

Distributary channel A waterway that branches from another waterway in a downstream direction. Typically found on stream deltas and some alluvial fans.

Divergence Spreading apart.

Divergent boundary Interface between tectonic plates characterized by production of new lithosphere; found along mid-ocean ridges and continental rift zones. Equivalent reference points on each plate will move away from each other with time.

Doppler effect Change in wave frequency that takes place when either the emitter or the detector is moving toward or away

from the other. This effect can be heard in the higher-pitched sound of an approaching ambulance and the lower-pitched sound of one that is moving away.

Doppler radar With respect to weather, an electronic system that emits electromagnetic waves to detect the velocity of precipitation that is falling either toward or away from the receiver. Used to detect rotation within a thunderstorm that often precedes formation of a tornado.

Downburst Localized area of very strong winds in a downdraft; commonly beneath a severe thunderstorm.

Downdrift Located in the direction toward which a current of water, such as a longshore current, is flowing.

Downstream flood Condition in which surface runoff from a relatively wide area has caused a stream to overflow its banks—more common in the lower part of a drainage basin where tributary streams have increased the discharge of the overflowing stream.

Drainage basin Area that contributes surface water to a particular stream network.

Driving force With respect to mass wasting, an influence that tends to make earth material move downslope.

Drought Extended period of unusually low precipitation that produces a temporary shortage of water for people, other animals, and plants.

Dryline An atmospheric boundary between two air masses of contrasting moisture content where the air mass with less moisture advances into the air mass with greater moisture. Common in the south-central United States in late spring and summer, it is a source of atmospheric instability for the development of severe weather.

Dry ravel After a fire, the gravity-driven process of moving a large volume of sand, gravel, and organic debris downslope. This debris was stored upslope of brush vegetation before a fire.

Dry slot A nearly cloud-free area behind a cold front in an extratropical cyclone or a wall cloud in a severe thunderstorm that is created by sinking dry air.

Duff A layer of compacted and partially decomposed leaves, twigs, and other organic matter in a forest soil that accumulates below leaf litter and above mineral soil; generally burns by glowing and smoldering combustion.

Dust storm A weather event in which visibility at eye level drops to less than 1 km (0.6 mi.) for hours or days because of fine airborne particles of silt and clay.

Dynamic equilibrium With respect to the behavior of streams and rivers, the overall balance between the work that a river does in transporting sediment and the amount of sediment that it carries.

E-line Long, narrow band inland from the shore that marks the distance to which coastal erosion is expected to have washed away dry land in a given number of years.

E soil horizon A light-colored horizon underlying the A horizon that is leached of iron-bearing compounds.

E-zone With respect to coastal erosion, a hazard area between sea level and an e-line that is expected to erode away within a particular time period.

Earth climate system Emphasizes the interactions among the atmospheric, cryospheric, and terrestrial, and marine biospheric processes that affect the climate of Earth.

Earth fissure A large, deep crack in loose sediment at the land surface; formed by the lowering of the water table and the consequent drying out of the earth material.

Earth's energy balance Condition in which incoming solar radiant energy generally equals outgoing radiant energy from our planet; this equality exists despite changes in the energy's form as it moves through the atmosphere, oceans, land, and living things before being radiated back into outer space.

Earth system science The study of Earth as a system.

Earthquake Sudden movement of a block of Earth's crust along a geologic fault; the movement releases accumulated strain in the rocks.

Earthquake cycle A hypothesis that explains the periodic nature of earthquakes on a given fault on the basis of a drop in elastic strain after an earthquake and reaccumulation of strain before the next event.

Easterly waves North–south oriented low-pressure troughs that migrate from east to west at equatorial latitudes causing local convergence and divergence of the trade winds giving rise to persistent thunderstorms, which can develop into tropical storms and hurricanes.

Eddy With respect to ocean currents, the circular movement of water that develops behind an obstruction, where two currents pass in opposite directions or along the edge of a permanent current; can have a central core of either warm or cold water. Can be large enough to be detectible with satellite sensors.

Eddy vortex A persistent, circular movement of warm water that develops on the edge of the Loop Current in the Gulf of Mexico that can affect the intensity of hurricanes that cross it.

EF scale A graduated range of values from EF0 to EF5 for describing tornado intensity based on the maximum three-second wind velocity inferred from damage to buildings, towers, poles, and trees. A modification of the F-scale developed by T. Theodore Fugita in 1971.

Effusive eruption A passive outpouring of magma onto Earth's surface generating a lava flow. Effusive eruptions are typical of low viscosity basaltic magmas, which readily allow volatiles to escape non-explosively. Low-volatile Andesitic and rhyolitic magmas may erupt effusively.

Ejecta blanket Layer of debris surrounding an impact crater; typically forms an irregular terrain of low mounds and shallow depressions.

El Niño An event in the atmosphere and ocean during which trade winds weaken or even reverse, the eastern equatorial Pacific Ocean becomes anomalously warm, and the westward moving equatorial ocean current weakens or reverses; this change in ocean temperature can cause anomalous weather in adjacent landmasses.

Elastic rebound A process where elastic strain is replaced by permanent fault offset during an earthquake.

Elastic strain Deformation that returns to its original shape when stress is released.

Electrical resistivity Degree to which earth materials are unable to conduct an electrical current. Measurements of this property are used in the exploration for energy, mineral, and water resources.

Electromagnetic energy Property of a system that enables it to do work through oscillations in an electric and magnetic field.

Electromagnetic spectrum The collection of all possible wavelengths or frequencies of electromagnetic radiation.

Electromagnetic wave An oscillation in an electric and magnetic field that transfers radiant energy.

Energy A quantifiable physical property describing the state of an object or a system. The part of energy pertinent to this text and natural hazard is the force. See *Force.*

Enhanced Fujita scale See *EF scale*.

Environmental unity A principle of environmental studies that states that everything is connected to everything else.

Epicenter Point on Earth's surface directly above the focus of an earthquake; the focus is the area that first ruptures on a geologic fault in an earthquake.

Eustatic sea level The worldwide average vertical position of the ocean surface.

Evacuation With respect to a natural hazard, the movement of people away from the location of a probable dangerous or destructive natural phenomenon.

Expansive soil In-place, weathered earth materials that, upon wetting and drying, will alternately expand and contract, causing damage to foundations of buildings and other structures.

Exponential growth A type of compound growth in which a total amount or number increases at a certain percentage each year, and each year's rate of growth is added to the total from the previous year; characteristically stated in terms of a particular doubling time, that is, the time in years it will take the original number to double; commonly used in reference to population growth.

Exposure dating Determining the amount of time that sediment or rock has been at Earth's surface by measuring quantities of isotopes in the material that are produced by cosmic rays.

Extinction With reference to a wildfire, the final phase in which all combustion, including smoldering, ceases because of insufficient heat, fuel, or oxygen. With reference to organisms, the complete disappearance of a biological species.

Extratropical cyclone An area of low atmospheric pressure, characterized by rotating winds, which generally develops along a weather front between 30° and 70° latitude; commonly associated with heavy precipitation, strong winds, and other severe weather; can produce a storm surge and coastal erosion when crossing a shoreline.

Eye With respect to hurricanes and related intense tropical cyclones, the central circular area of light winds and partly cloudy skies where subsiding dry air encounters rising moist air.

Eyewall The portion of a hurricane immediately adjacent to a central circular area of nearly clear sky and light winds; usually the region having the highest winds and most intense rainfall.

F-scale See *EF scale*.

Falling With respect to mass wasting and landslides, earth materials such as rocks dropping through the air from steep slopes.

Fault A fracture or fracture system in earth materials along which rocks on opposite sides of the fracture have moved relative to one another.

Fault creep Slow, essentially continuous movement of blocks of Earth's crust principally along one side of a fracture; also called *tectonic creep*.

Fault gouge A clay-rich zone of pulverized rock produced by movement along a fracture or fracture system in Earth's crust; can act as an underground barrier or dam to the flow of groundwater.

Fault scarp Steep slope or small cliff that was formed during an earthquake by rupture and displacement of a block of Earth's crust.

Faulting The process of creating a rupture in Earth's crust by the movement of one crustal block in relation to another.

Felsic Refers to an igneous rock or melt composition with more than about 65 percent silica rich in, which is characteristic of granitic rock and rhyolitic magma.

Fetch Distance that wind blows over a body of water; a principal factor that determines the height of windblown waves; in a cyclone, a contributing factor to the height of the storm surge.

Fibrous fracture A distinctive pattern for the breakage of minerals in which long slivers of the mineral break away from the specimen.

Fine grained soils Type of soil where over half of the soil particles (by weight) is composed of particles less than 0.074 mm in diameter.

Fire management With respect to wildfires, the control of combustion to minimize loss of human life and damage to property. Accomplished through understanding the fire regime, public education, remote sensing of vegetation to determine fire potential, and prescribed burns.

Fire regime An ecosystem's potential for wildfire as inferred from fuel types, terrain, and past fire behavior.

Fissure Large fracture or crack in rock along which the opposing side have separated; may become a volcanic vent if lava or pyroclastic material is extruded.

Flash flood Overbank flow that results from a rapid increase in stream discharge; commonly occurs in the upstream part of a drainage basin and in small tributaries downstream.

Flashy discharge Stream flow characterized by a short lag time or response time between rainfall and peak stream discharge.

Flood basalt A laterally extensive, basaltic lava flow that generally is part of a thick sequence of similar flows. These flows commonly build up a plateau; also referred to as a *plateau basalt*.

Flood discharge The stream flow volume per unit of time (represented by the units cms, cubic meters per second, or cfs, cubic feet per second) at which damage to personal property is likely to begin.

Flooding From a hazards perspective, high water levels in a stream, lake, or ocean that may damage human facilities. As a natural process, overbank flow that may construct a floodplain adjacent to a stream channel or a higher-than normal water level along a coast that extends inland beyond the beach.

Floodplain Flat topography adjacent to a stream produced by overbank flow and by lateral migration of the channel and associated sand or gravel bars.

Floodplain regulation Governmental restriction of land use in an area likely to be inundated by a stream's overbank flow that could damage buildings and infrastructure.

Flood-proofing With respect to urban flooding refers to practices such as raising buildings above potential floodwater, constructing flood doors on buildings, placing flood walls around buildings or other structures, or installing improved drains to remove floodwater accumulation.

Flood stage Water level of a stream at which damage to personal property is likely to begin.

Flow With respect to mass wasting, downslope movement of earth materials that deform as a fluid, such as the fluid movement of grains of sand, rock, snow or ice, debris, and mud.

Flowage See *Flow*.

Flowstone General term for a mineral deposit, most commonly of calcium car-

bonate, formed by flowing water on the wall or floor of a cave.

Flux In a natural system, the rate at which a substance moves from one part of the system to another.

Focus In an earthquake, the point or location in Earth of the initial break or rupture, and from which energy is first released; during an earthquake, seismic energy radiates out from this point or location. Also known as the *hypocenter*.

Foliation plane With respect to mass wasting, a surface or zone of weakness in metamorphic rocks produced by the alignment of minerals during metamorphism.

Footwall Block of Earth's crust that is below a slanted geologic fault.

Fog A cloud that is in contact with the ground.

Force With respect to physics, an influence that tends to produce or to change the motion of a body, or one that produces stress within a body.

Forcing With respect to climate, a variable, such as solar radiation, volcanic aerosols, or greenhouse gases, that influences the direction of climate change.

Forecast With respect to a natural hazard, an announcement that states that a particular event, such as a flood or storm, is likely to occur during a particular time interval, often with some statement of the degree of its probability.

Foreshock Small to moderate earthquake that occurs before and in the same general area as the main earthquake.

Formation A body of rock or sediment composed of one or more distinctive types that can be mapped at the surface or traced in the subsurface—commonly given a geographic place name (e.g., Potsdam Sandstone) and formally defined in a scientific publication.

Fracture With respect to minerals, the breakage of a mineral in an irregular, curving or fibrous manner.

Free face A steep cliff of bare rock.

Frequency The number of waves passing a point of reference per second; commonly expressed in cycles per second or hertz (Hz); the inverse of the wave period.

Front With respect to weather, a boundary between two air masses that are distinguished by differences in temperature and, commonly, moisture content. See *Cold front*, *Warm front*, *Stationary front*, and *Occluded front*.

Frostbite Injury to body tissues caused by exposure to extreme cold.

Frost heaving The upward and lateral movement of soil particles and the land surface as the result of ice formation in the soil.

Frost-susceptible soil Surficial earth material that is likely to move and expand when frozen as the result of the accumulation of ice between particles of the material; commonly unconsolidated material with a high content of silt.

Fugita scale See *EF-scale*.

Funnel cloud A narrow, rotating cloud extending downward from a thunderstorm. This cloud may become a tornado if it reaches the ground.

Gabion A metal wire basket, commonly made out of chain-link fencing that is filled with rocks. These baskets are stacked along stream banks to prevent erosion and are used as barriers to slow water flow in retention ponds.

Geochronology Science of dating earth materials, fossil organisms, and geologic features and events; and of determining the sequence of events in Earth history.

Geographic information system (GIS) Computer technology capable of storing, retrieving, transforming, and displaying spatial information about Earth and of making maps with these data.

Geologic cycle A group of interrelated sequences of Earth processes known as the hydrologic, rock, tectonic, and biogeochemical cycles.

Geologic map A two-dimensional representation of the age and composition of earth materials that are found beneath the soil within a given geographic area.

Geyser A particular type of hot spring that ejects hot water and steam above Earth's surface; perhaps the most famous is Old Faithful in Yellowstone National Park.

Glacial interval A portion of Earth history during which a cooler, wetter climate supported widespread continental glaciers.

Glacier A large mass of flowing ice that moves downslope under its own weight and persists from year to year; formed, at least in part, on land by the compaction and recrystallization of snow.

Global climate model (GCM) Linked computer programs that use environmental data in mathematical equations to predict global change, such as increases in mean temperature, changes in precipitation, or some other atmospheric variable.

Global positioning system (GPS) Interacting ground control, satellites, and radio receivers that obtain extremely accurate locations and elevations on Earth's surface. Especially useful for detecting land surface changes related to a volcanic eruption, earthquake, tectonic creep, the slow movement of a landslide, or land subsidence.

Global warming The increase in the mean annual temperature of the lower atmosphere and oceans in the past 150 years, primarily as a consequence of burning fossil fuels that emit greenhouse gases into the atmosphere.

Gradient Slope of the land over which a stream flows. Determined by calculating the vertical drop in elevation through some horizontal distance; commonly expressed as m per kilometer or ft. per mile.

Granular structure A soil structure consisting of individual grains or clumps of grains that form generally small semiround soil peds.

Great earthquake A sudden rupture along a geologic fault in which the release of energy has a moment magnitude of 8 or greater.

Greenhouse effect Trapping of heat in the lower atmosphere by the absorption of infrared energy by water vapor, carbon dioxide, methane, nitrous oxides, halocarbons, and other gases.

Greenhouse gas A substance such as carbon dioxide, methane, nitrous oxides, or halocarbons (e.g., Freon) that absorb infrared radiation, and contributes to global warming of the lower atmosphere.

Groin A long, narrow structure of rock, concrete, wood, or other material generally constructed perpendicular to the shore to protect the coastline and trap sediment in the zone of littoral drift.

Groin field With respect to coastal processes, a group of long, narrow structures of rock, concrete, wood, or other material generally constructed perpendicular to the shore to protect the coastline and trap sediment in the zone of littoral drift.

Ground acceleration With respect to an earthquake, the amount that the speed or

velocity of the shaking of the Earth's surface changes in a unit of time, such as a second. Ground acceleration is commonly given as a fraction or percentage of gravitational acceleration, which is 980 cm (~380 in.) per second. The greatest (or peak) ground acceleration during an earthquake is a principal control on the amount of damage to structures.

Ground fire With respect to wildfires, combustion that takes place below the surface; characterized by more smoldering and little flaming; fuels typically are roots and partially decayed organic matter, such as peat.

Ground penetrating radar An electronic system that uses 10 to 1000 MHz electromagnetic waves to image Earth's shallow subsurface to locate features such as natural cavities and fissures, permafrost, contaminated groundwater, and buried pipes and tanks.

Groundwater Subsurface accumulation of water that entirely fills all voids in earth materials.

Groundwater mining The pumping of subsurface water at a faster rate than it is being replenished.

Gust front Leading edge of strong and variable surface winds from a thunderstorm downdraft.

Habitat A particular set of environmental conditions in which adapted plants and animals thrive.

Hachure With respect to topographic contours, a small mark drawn perpendicular to a contour line to indicate the downward sloping of the land into a closed depression; also referred to as a *tic mark*.

Hail Large rounded or irregular piece of ice that has grown while moving up and down numerous times within the clouds of a severe thunderstorm.

Half-life The amount of time necessary for one-half of the atoms of a particular radioactive element to decay.

Halocarbon A chemical compound (e.g., Freon) containing a halogen element, such as chlorine, fluorine, or bromine, that is bonded to carbon; generally synthetic in origin and in the atmosphere contributes to global warming in troposphere and ozone depletion in stratosphere.

Hanging wall A block of Earth's crust that is above a slanted geologic fault.

Hardness With respect to minerals, the resistance of a mineral to scratching; see *Relative hardness*.

Hardpan A soil layer of hard material such as clay or silica oxide or calcium carbonate.

Hawaiian-type eruption An effusive to mildly explosive volcanic eruption that ranks between 0 and 1 on the volcanic explosivity index. This eruption type is characterized by fire fountains and lava flows and is typical of shield volcano eruptions. A central caldera, in contrast to an Icelandic-type eruption where lavas erupt from a fissure, typifies the volcanic vent.

Hazard See *Natural hazard*.

Headland A small peninsula on an irregularly shaped shoreline that is more resistant to erosion than the surrounding earth material.

Headwaters Tributaries of a river that feed into it near its uppermost reach.

Heat energy The property of a system that enables it to do work through random molecular motion. This property may be transferred by conduction, convection, or radiation.

Heat index A value on a temperature scale that describes the human body's perception of air temperature, taking into account relative humidity.

Heat waves A prolonged period of extremely high air temperature that is both longer and hotter than normal. The criteria for establishing what constitutes longer and hotter than normal varies geographically with climate and living conditions.

High pressure center An area of elevated atmospheric pressure where the wind blows clockwise in the Northern Hemisphere. Also called an *anticyclone* or a *high*.

Hot spot A hypothesized, nearly stationary heat source located below the lithosphere that feeds overlying volcanic processes near Earth's surface.

Hot spring A natural discharge of groundwater at a temperature higher than that of the human body.

Hot tower A rain cloud that reaches the top of the troposphere in a hurricane. The release of latent heat in its formation warms the air at the high altitude.

Hummocky An irregular land surface marked by numerous small mounds and depressions.

Hurricane Tropical cyclone characterized by sustained winds of 119 km (118 km in Canada or 74 mi. per hour); known as a typhoon in the western North Pacific and South China Sea, severe tropical cyclone in the southwest Pacific and southern Indian Oceans, and severe cyclonic storm in the northern Indian Ocean.

Hurricane warning An alert issued by weather forecasters for an area where hurricane conditions are expected in 24 hours or less. In Canada this alert is also issued for areas likely to experience high waves and coastal flooding, but not necessarily hurricane-strength winds.

Hurricane watch An alert issued by weather forecasters for an area that may experience hurricane conditions within 36 hours. In Canada this alert is not restricted to a 36-hour time frame.

Hydraulic chilling With respect to volcanoes, the use of water to cool and solidify flowing lava; a method used to divert lava flows threatening property.

Hydrogen sulfide (H_2S) A toxic, flammable gas that smells like rotten eggs and is emitted by volcanoes.

Hydrograph A graph of the discharge (flow) of a stream with time.

Hydrologic cycle Circulation of water from the oceans to the atmosphere and back to the oceans by way of precipitation, evaporation, runoff from streams, and groundwater flow.

Hydrology The study of surface and subsurface water.

Hydrophobic layer Lower layer of debris on forest floors or brushland that has accumulated water-repellant organic chemicals; especially common in drier climates after very hot fires.

Hypocenter See *Focus*.

Hypothermia A medical condition characterized by rapid loss of core body heat causing intense shivering, loss of muscle coordination, mental sluggishness, and confusion. This condition can develop in an improperly dressed person in cool, wet, windy weather or in one immersed in water that is 25°C (~77°F) or less; unless treated, the condition leads to unconsciousness and eventually death.

Ice storm A prolonged period of freezing rain during which thick layers of ice accumulate on all cold surfaces.

Iceberg Large block of floating glacial ice that has broken from the front of a glacier, dropping into the water by a process called *calving*.

Icelandic-type eruption An effusive to mildly explosive volcanic eruption that ranks between 0 and 1 on the volcanic explosivity index. This eruption type is char-

acterized by fire curtains and lava flows typical of Icelandic shield volcano eruptions. An elongate fissure, in contrast to a Hawaiian-type eruption where lavas erupt from central caldera, typifies the volcanic vent.

Igneous rock An aggregate of minerals formed from the solidification or explosion of magma; extrusive if it crystallized on or very near the surface of Earth, and intrusive if it crystallized well beneath the surface.

Impact With respect to hazardous events, the effect or influence of an action.

Impact crater A circular-to-elliptical depression produced by collision of a large object, such as an asteroid, with a planet, moon, or other asteroid.

Impervious cover With respect to urban hydrology, surfaces covered with concrete, roofs, or other structures that impede the infiltration of water into the soil. In general, as urbanization proceeds, the percentage of the land that is under impervious cover increases.

Inactive fault A fracture in the Earth's crust along which rock has not moved in the past 2 million years.

Indirect effect A change that depends upon intervening factors. In a natural accident, disaster, or catastrophe, such effects could include emotional distress; the donation of money, goods, and services; or the payment of taxes to finance recovery; also called a *secondary effect*.

Injection well An artificial, generally cylindrical, hole excavated for pumping fluids, such as liquid hazardous waste, underground.

Inner core See *Core*.

Instrumental intensity With respect to earthquakes, the direct measurement of ground motion during an earthquake with a high-quality seismograph. Used to immediately produce a map showing perceived shaking and potential damage.

Insurance The guarantee of monetary compensation for a specified loss in return for payment of a premium.

Integrated coastal zone management Management that promotes ecological function of the coastal zone through sustainable solutions that minimizes conflicts from development in the coastal zone.

Intensity With respect to earthquakes, a measure of the effects of an earthquake at a specific place; measured as the effects on people and structures using the Modified Mercalli Scale or the direct measurement of ground motion by a sensitive seismograph; see *Instrumental intensity*. With respect to cyclones, the strength of the storm as indicated by sustained wind speeds and lowest atmospheric pressure.

Interglacial interval A portion of Earth history when continental glaciation was minimal or absent.

Intraplate earthquake Sudden movement along a fault caused by the abrupt release of accumulated strain in the interior of a lithospheric plate, far away from any plate boundary.

Ion An electrically charged atom or molecule formed by a loss or gain of electrons.

Iridium A platinum-group metal that is more abundant in meteorites than in earth materials. Its high concentration in certain clay deposits is attributed to their formation during or after impact of a large extraterrestrial body.

Isostasy The principle stating that thicker, more buoyant crust is topographically higher than crust that is thinner and denser. Also, with respect to mountains, the weight of rocks of the upper crust is compensated by buoyancy of the mass of deeper crystal rocks; that is, mountains have "roots" of lighter crustal rocks extending down into the denser mantle rocks, like icebergs in the ocean.

Isotope A variety of a chemical element distinguished by its number of neutrons; may be stable or radioactive.

Jet stream A concentrated flow of air near the top of the troposphere, characterized by strong winds.

Jetty A very long, narrow structure of rock, concrete, or other material generally constructed perpendicular to the shore; commonly constructed in pairs at the mouth of a river or inlet to a lagoon, estuary, or bay; designed to stabilize a channel, control deposition of sediment, and deflect large waves.

Joule The basic unit of energy in the metric system; equivalent to the work done by a force of one Newton when its point of application moves one meter in the direction that the force is acting.

Karst See *Karst topography*.

Karst plain A generally flat land surface containing numerous sinkholes.

Karst topography A landscape characterized by sinkholes, caverns, and diversion of surface water to subterranean routes that results from dissolution of subsurface rocks by groundwater.

Kinetic energy The property of a system that enables it to do work through motion.

K soil horizon A calcium carbonate-rich horizon in which the carbonate often forms laminar layers parallel to the surface; carbonate completely fills the pore spaces between soil particles.

K-T boundary The interface in the geologic record where earth materials that formed during the Cretaceous Period are in contact with earth materials that formed during the Tertiary Period; dated as approximately 65 million years old.

Kyoto Protocol International agreement to reduce emissions of greenhouse gases in an effort to manage global warming; now legally binding in at least 175 countries, including Canada, Russia, and the European Union. The United States has not honored its original agreement to implement this protocol.

Lag time The time interval between the greatest amount of precipitation and peak discharge of a stream. Urbanization generally decreases the lag time.

Lahar A type of volcanic mudflow or debris flow that is triggered by melting of surface snow and or ice, potentially in the form of large glaciers, due to heating by volcanic gasses or ash during an eruption.

Landslide Specifically, rapid downslope movement of rock or soil; also a general term for all types of downslope movement.

Landslide hazard map A two-dimensional representation of the land surface that identifies areas that are likely to experience landslides and the appropriate land uses in those areas.

Landslide risk map A two-dimensional representation of the land surface that identifies areas that are likely to experience a rapid mass movement of earth material, states the probability that one of these events will occur, and assesses potential losses.

Land-use planning The preparation of an overall master plan for future development of an area; the plan may recommend zoning restrictions and infrastructure both practical and appropriate for the community and its natural environment; based on mapping and classification of existing human activities and environmental conditions, including natural hazards.

Lapilli Gravel-size pyroclastic debris ranging in size from 2 to 64 mm (~0.08 to 2.5 in.).

Latent heat Energy created by random molecular motion that is either absorbed or released when a substance undergoes a phase change, such as during evaporation or condensation.

Latent heat of vaporization Energy absorbed by water molecules as they evaporate.

Lateral blast Type of volcanic eruption characterized by explosive activity that is more or less parallel to the surface of Earth. A lateral blast may take place when the side of a volcano fails.

Lava Molten material that flows onto the land surface from a volcano, or rock that solidifies from such molten material.

Lava dome Relatively small volcano type composed of highly viscous magma, usually rhyolitic in composition, that is often restricted to the vent region. Lava domes often found plugging the vent within the volcanic crater of a recently erupted stratovolcano.

Lava flow Eruption of magma at Earth's surface that generally moves as a liquid mass downslope from a volcanic vent.

Lava tube A natural enclosed conduit or tunnel through which magma moves down the slope of a volcano (sometimes many kilometers); eventually the magma may again emerge at the surface; after the volcanic eruption, a tube commonly remains as an open void and forms a type of cave.

Levee A mound or embankment parallel to a stream channel; it may consist of fine sediment deposited from overbank flow during a flood or be an earthen embankment constructed by humans to protect adjacent land from flooding.

Lichenometry An absolute dating technique using measurements of the diameter of lichens on a rock surface to determine how long the surface has been exposed to the atmosphere and sunlight.

Lightning A natural, high-voltage electrical discharge between a cloud and the ground, between clouds, or within clouds. The discharge takes a few tenths of a second and emits a flash of light that is followed by thunder.

Linkage With respect to natural hazards, a relationship between two phenomena.

Liquefaction Transformation of water-saturated granular material from the solid state to a liquid state.

Lithification The hardening of loose earth material into rock, commonly by cementation and compaction.

Lithosphere Outer layer of Earth, approximately 100 km (~60 mi.) thick, which comprises the tectonic plates that contain the ocean basins and continents; includes both Earth's crust and the solid, upper part of the mantle.

Littoral transport Movement of sediment in the nearshore environment as a result of return flow from waves that have washed up on the shore; sediment is moved by both the longshore current and by beach drift.

Local tsunami A series of gravity waves in the ocean originating from a source that is close to the shoreline that is inundated. These waves are produced by the displacement of the entire water column by either an underwater earthquake, landslide, volcanic eruption, or extraterrestrial impact.

Loess Deposit of windblown silt and clay.

Longitudinal profile With respect to streams, a graph that shows the decrease in elevation of a stream bed between its head and its mouth. This graph of elevation versus distance generally produces a line that is concave up.

Longshore bar and trough Elongated depression and adjacent underwater ridge of sand roughly parallel to shore; produced by wave action.

Longshore current Waterflow parallel to shore that develops in the surf zone as the result of waves that strike the land at an angle. Responsible for longshore drift.

Longshore drift The sediment transported in the nearshore environment parallel to the shore by a wave-generated current.

Longshore trough See *Longshore bar and trough*.

Loose-snow avalanche A rapid downslope flow of granular snow and ice.

Love wave A type of earthquake-generated surface oscillation in which molecular vibrations within the Earth are transverse to the direction the oscillation is moving.

Low pressure center A parcel of the atmosphere that has relatively low air pressure, often referred to as a *low*. see *Cyclone*.

Luster With respect to mineralogy, the way that light is reflected from a mineral; may be catagorized as metallic or nonmetallic.

Magma Naturally occurring molten rock material formed deep within the crust or in the mantle.

Magma chamber A large pool of molten rock that accumulates in the subsurface and is the primary source of lava, and volcanic gasses and debris that are extruded to the surface during an eruption.

Magma evolution Refers to the increase in silica content of a magma as it ascends toward the surface. The change results from crustal assimilation and chemical processes within the magma as it rises.

Magnetic reversal Involves the change of Earth's magnetic field between normal polarity and reverse polarity; also sometimes known as geomagnetic reversal.

Magnitude With respect to natural hazards, especially earthquakes, the amount of energy released.

Magnitude-frequency concept The idea that the intensity and extent of an event are inversely proportional to how often it occurs.

Mainshock The primary, highest magnitude earthquake in a series of earthquakes in a given area during a limited time interval.

Major earthquake A sudden rupture along a geologic fault in which the release of energy has a moment magnitude of 7 to 7.9.

Managed retreat With respect to coastal erosion, a strategy involving the landward movement of buildings and associated infrastructure away from a shoreline to remove the property from an area susceptible to flooding by seawater.

Mantle An internal layer of Earth approximately 3000 km (~1900 mi.) thick composed of rocks that are primarily iron and magnesium-rich silicates. The lower boundary of the mantle is with the core, and the upper boundary is with the crust. The boundary is known as the Mohorovičić discontinuity (also called the *Moho*).

Mass extinction Sudden loss of large numbers of plant and animal species relative to new species being added.

Mass wasting A comprehensive term for any type of downslope movement of earth materials.

Material amplification Increase in the amplitude of seismic shaking caused by some earth materials. Such increase is generally associated with soft sediments, such as silt and clay deposits.

Mature stage With respect to thunderstorm development, the second phase in

which downdrafts move and precipitation falls from the base of a cumulonimbus cloud. With regard to tornado development, the phase in which a visible funnel extends from the thunderstorm to the ground.

Meander With respect to streams, a bend in the channel that migrates back and forth across the floodplain, depositing sediment on the inside of the bend on a point bar, and eroding the outside of the bend into a cutbank.

Meandering A stream channel pattern that is sinuous and is characterized by gentle bends that migrate back and forth across a floodplain.

Meandering river See *Meandering stream*.

Meandering stream A single, sinuous channel of flowing water that moves through gentle bends that migrate back and forth across a floodplain.

Megafloods Extremely large floods capable of causing a catastrophe that may be expected to reoccur every few hundred years.

Megathrust earthquake A term used to describe large earthquakes (Magnitude 8.0 and greater) that occur along low-angle faults at subduction zones.

Mesocyclone A region of rotating clouds, typically around 3 to 10 km (~2 to 6 mi.) in diameter on the flank of a supercell thunderstorm.

Mesoscale convective system (MCS) A large, circular, long-lived and interacting group of thunderstorms that are commonly identifiable on satellite images; generally contain severe thunderstorms and often produce tornadoes.

Mesosphere A zone in the upper atmosphere from about 50 to 80 km (~31 to 50 mi.) where the temperature decreases with altitude; directly above the stratosphere.

Metamorphic rock An aggregate of minerals that formed beneath Earth's surface from preexisting rock by the effects of heat, pressure, and chemically active fluids. In foliated metamorphic rocks, mineral grains are preferentially aligned parallel to one another or light and dark minerals are segregated into bands; nonfoliated metamorphic rocks have neither characteristic.

Meteor Extraterrestial particle from dust to several centimeters in size that is burned up from frictional heat upon entry into Earth's atmosphere; light emitted from the burning meteor forms a "shooting star."

Meteorite Extraterrestrial particle from dust to asteroid size that hits Earth's surface.

Meteoroid Extraterrestrial particle in space that is smaller than 10 m and larger than dust size; may form from breakup of asteroids.

Meteor shower Large numbers of meteoroids entering the atmosphere and producing light from frictional heating; commonly occurs when Earth's orbit passes through the tail of a comet.

Microburst A strong, localized downburst from a thunderstorm that affects an area of 4 km (~2.5 mi.) or less.

Microearthquake Sudden movement along a geologic fracture or fault in which the release of energy has a moment magnitude less than 3. Patterns of these very small quakes may be precursors to larger-magnitude earthquakes; also called a *very minor earthquake*.

Microzonation With respect to earthquakes, the detailed location and land-use planning of areas having various earthquake hazards.

Mid-ocean ridge A seafloor mountain range commonly found in the central part of oceans characterized by seafloor spreading. An example is the Mid-Atlantic Ridge.

Milankovitch cycles Natural variations in the intensity of solar radiation that reaches Earth's surface that recur at approximately 20,000-, 40,000-, and 100,000-year intervals.

Mineral A naturally occurring, inorganic crystalline substance with an ordered atomic structure and a specific chemical composition.

Mitigation The avoidance of, lessening, or compensation for anticipated harmful effects of an action, especially with respect to the natural environment.

Modified Mercalli Intensity scale A scale with 12 divisions on which the amount and severity of shaking and damage from an earthquake can be ranked.

Moho See *Mohorovičić discontinuity*.

Mohorovičić discontinuity Compositional boundary that separates the less dense crust from the underlying higher-density mantle.

Moisture content The amount of water in a soil as a percent (weight of water to weight of the solid soil particles as a percent). Also called the *water content*.

Moment magnitude scale A numerical assessment of the amount of energy released by an earthquake on the basis of its seismic moment, which is the product of the average amount of slip on the fault that produced the earthquake, the area that actually ruptured, and the shear modulus of the rocks that failed.

Mudflow A slurry of fine, unconsolidated earth materials and water that flows rapidly downslope or down a channel; also referred to as an *earth flow* or type of *debris flow*.

Multiple hypotheses Several proposed explanations for a phenomenon that are being considered concurrently; also referred to as *multiple working hypotheses*.

Natural hazard A potential danger that poses a threat to people or property that exists or is caused by nature; generally one that is not made or caused by humans.

Natural service function A benefit that arises from an event caused by nature that is also a hazard to people or the environment.

Near-Earth Asteroid Tracking Project (NEAT) NASA-supported program started in 1996 to study the size, distribution, and dynamic processes associated with near-Earth objects and to identify those objects having a diameter of about 1 km (~3300 ft.) or greater.

Near-Earth object (NEO) Asteroids that reside and orbit between Earth and the sun or have orbits that intersect Earth's orbit.

Newton Measure of force in the metric system in which 1 Newton is the force necessary to accelerate a 1 kg (~2.2 lb.) mass 1 m (~3.3 ft.) per second each second that it is in motion.

Nor'easter An extratropical cyclone that tracks along the East Coast of the contiguous United States and Canada and which has continuously blowing northeasterly winds just ahead of the storm; commonly characterized by hurricane-strength winds, heavy snows, intense precipitation, and large waves along the coast.

Normal fault A generally steep fracture or fracture system along which the hanging wall has moved down relative to the footwall in the direction that the fracture dips.

North Atlantic Oscillation A North Atlantic atmospheric pressure phenomenon that fluctuates in intensity affecting the path of westerly winds that flow from North America toward northern Europe and consequently the winter weather on these two continents.

Nowcasting With respect to weather, the near real-time prediction of the movement and behavior of weather systems,

such as severe storms, that have formed or are in the process of forming.

Nuée ardente See *Pyroclastic flow*

O soil horizon Soil horizon that contains plant litter and other organic material; found above the *A* soil horizon.

Ocean acidification An increase in the acidity of seawater due primarily to dissolving additional atmospheric carbon dioxide. This condition results from higher levels of carbon dioxide in the atmosphere and is threatening the growth of corals and other marine organisms that make skeletal material from calcium carbonate.

Ocean conveyor belt A large-scale circulation pattern in the Atlantic, Indian, and southwestern Pacific Oceans that is driven by differences in water temperature and density; also referred to as a *thermohaline current*. Northward-flowing warm water in this current maintains the moderate climate of northern Europe; if this current were to slow or stop, ice-age conditions might return to portions of the Northern Hemisphere.

Occluded front An atmospheric boundary between two air masses of contrasting temperature along which the colder air mass advances into a cool air mass and elevates warmer air above the boundary.

Organic soil A surficial, in-place accumulation of partially decayed plant material, such as peat.

Organizational stage With regard to tornado development, the initial phase in which a funnel cloud forms from rotating winds within a severe thunderstorm.

Outer core See *Core*.

Outflow boundary A line separating thunderstorm-cooled air from the surrounding air. This line behaves like a cold front with both a wind shift and drop in temperature. In large thunderstorm complexes this boundary may persist for more than 24 hours and provide instability that fosters development of new storms.

Overbank flow Moving floodwaters that have exceeded the capacity of a stream channel and have spread outward beyond its sides.

Overwash Flooding of the beach, dunes, and in some cases an entire barrier island by a storm surge; commonly transports sand from the beach and dunes inland; see *Washover channel*.

Ozone (O3) A pungent, strongly reactive form of oxygen gas that is most abundant in the stratosphere, where it protects the Earth surface from high levels of ultraviolet radiation. In the lower atmosphere it is an air pollutant.

Ozone depletion Stratospheric loss of triatomic oxygen; related to release of halocarbons and other gases that destroy triatomic oxygen in the atmosphere.

P wave The fastest type of earthquake vibration within the body of Earth; also called a *primary or compressional wave*, this vibration oscillates in the direction that it travels.

Pahoehoe A type of lava with a smooth to ropy surface texture that forms when a flow solidifies; most common in basalt.

Paleomagnetism Refers to the study of magnetism of rocks and the intensity and direction of the magnetic field of Earth in the geologic past.

Paleoseismicity The occurrence of earthquakes in space and time in the geologic past.

Parcel With respect to weather, an imaginary balloonlike blob of air several hundred cubic meters in volume that acts independently of the surrounding air.

Parent isotope An unstable variety of a chemical element distinguished by its number of neutrons and its potential for radioactive decay. Measuring the proportions of parent and daughter isotopes in a substance is the basis for most absolute dating.

Particulate With respect to the atmosphere, a piece of dust, pollen, soot, ash, or other very fine material that is suspended in the air.

Peat Organic-rich sediment composed primarily of partially decayed plant material, such as moss, leaves, and sticks; typically forms in bogs and swamps and has a high water content.

Peds The natural soil fragment or clod, the soil naturally breaks into these fragments that children may call dirt clods.

Peléan-type eruption A severe volcanic eruption that ranks between 3 and 4 on the volcanic explosivity index. This eruption type is characterized by a moderate to large eruption column with plume heights between 3 and 15 km (~2–9 mi.) and are typical of lava dome eruptions triggered by dome collapse.

Permafrost Earth material in the ground with a temperature that is below freezing continuously for at least two years; commonly cemented with ice; underlies about 20 percent of the world's land area.

Permanent gas A substance in the atmosphere, such as nitrogen or oxygen, that cannot be compressed with pressure alone and is present in generally constant proportions.

Permeability A measure of the ability of an earth material to transmit fluids such as water or oil.

Phreatomagmatic See *Vulcanian-type eruption*.

Pineapple Express An atmospheric flow of tropical moisture and extratropical storms originating in the region of the Hawaiian Islands and directed toward the West Coast of the United States.

Plate tectonics An all-encompassing, global scientific theory that explains the characteristics and origin of most earthquakes, volcanoes, and other Earth features; based on the subdivision of the entire lithosphere into more than a dozen large, rigid blocks that move horizontally and interact to cause deformation, melting, and other changes.

Pleistocene Epoch Geologically recent interval of Earth history characterized by widespread continental glaciation and commonly referred to as the "Ice Age"; the subdivision of the Quaternary Period before the Holocene Epoch.

Plinian-type eruptions A cataclysmic volcanic eruption that ranks from 4 to 6 on the volcanic explosivity index. This eruption type is characterized by a towering eruption column with a plume height that may exceed 35 km (~22 mi.) and is typical of stratovolcano eruptions.

Plunging breaker A type of water wave in which the wave crest rises up and falls into its own trough as it strikes a relatively steep shoreline; tends to be associated with beach erosion.

Point bar Accumulation of sand and other sediment on the inside of a meander bend of a stream.

Polar desert An arid region near the North or South Pole where the annual precipitation averages less than 250 mm (~10 in.) per year.

Polar jet stream A concentrated flow of air near the top of the troposphere that, in the Northern Hemisphere, typically crosses southern Canada or the northern conterminous United States and is characterized by strong winds blowing from west to east.

Pool Common bed form produced by scour in meandering and straight stream channels with relatively low channel slope; characterized at low flow by slow-moving, deep water; generally, but not exclusively, found on the outside of meander bends.

Porosity The percentage of void or empty space in earth material such as soil or rock.

Potential energy The property of a system that enables it to do work by virtue of an object's position above some reference level.

Potentially active With respect to earthquakes, a term applied to a geologic fault that shows evidence of movement in the Pleistocene Epoch, but not in the past 10,000 years.

Power With respect to physics, the rate of doing work.

Precursor With respect to natural hazards, a physical, chemical, or biological phenomenon that occurs before a hazardous event such as an earthquake, volcanic eruption, or landslide.

Precursor event See *Precursor*.

Prediction With respect to a hazardous event, such as an earthquake, the advance determination of the date, time, and size of the event.

Preignition Initial phase of a wildfire during which fuel is brought to a temperature and water content that favors ignition; involves both preheating and pyrolysis.

Preparedness A state of readiness achieved by an individual or group of people, such as for a natural hazard or war; see *Disaster preparedness*.

Prescribed burn A fire purposely set and contained within a designated area to reduce the amount of fuel available for a wildfire; also called a *controlled burn*.

Primary effect See *Direct effect*.

Prismatic structure A soil structure consisting of clay-rich columns.

Process With respect to natural hazards, the physical, chemical, or biological ways by which events, such as volcanic eruptions, earthquakes, landslides, and floods, affect Earth's surface.

Proxy data With respect to climate, proxy data refers to data that is not strictly climate in nature, but can be used to infer, indirectly, changes in the climate record.

Punctuated uniformitarianism Concept that the geologic record of gradual mountain building, canyon erosion, and landscape construction was periodically interrupted by catastrophic events that caused rapid changes to topography or biota.

Pyroclastic activity Eruptive or explosive volcanic activity in which all types of volcanic debris, from ash to very large particles, are physically blown from a volcanic vent.

Pyroclastic debris Volcanic material that is explosively erupted from a volcano. The material ranges in size from fine ash to large blocks and may be composed of low-density magma, which cooled in the atmosphere during the eruption or of cold dense rock ripped from the interior of the volcano.

Pyroclastic deposit An accumulation of particles forcefully ejected from a volcanic vent, explosive in origin, containing volcanic ash particles and those of larger size such as blocks and bombs.

Pyroclastic flow Extremely hot and rapid flow of eruptive material down the flank of a volcano; consists of volcanic gases, ash, and other materials that move rapidly; commonly forms upon the collapse of an eruption column; may also be known as an *ash flow*, *fiery cloud*, or *nuée ardente*.

Pyroclastic rock Lithified igneous earth material composed of fragments of volcanic glass, mineral crystals, and fragments of other rocks that were ejected during a volcanic eruption.

Pyrolysis In a fire, a group of chemical processes by which heat divides or splits large fuel molecules into smaller ones. Products from these processes include volatile gases, mineral ash, tars, and carbonaceous char.

Quick clay Deposit of very fine sediment that when disturbed, such as by seismic shaking, may spontaneously liquefy and lose all shear strength.

R soil horizon Consolidated bedrock that underlies the soil.

Radiation With respect to physics, the transfer of energy as electromagnetic waves or as moving subatomic particles. A primary way that heat is transferred from the sun to Earth, the Earth to the atmosphere, and to a lesser extent from a wildfire to the atmosphere.

Radioactive isotope Unstable variety of a chemical element distinguished by its number of neutrons and its emission of ionizing radiation.

Rain band Precipitation-producing clouds that spiral around a hurricane.

Reactive With respect to natural hazards, a person's action or response to a hazard that occurs after an event, such as a natural accident, disaster, or catastrophe.

Recurrence interval The time between natural events, such as floods or earthquakes. Commonly given as the average recurrence interval, which is determined by averaging a series of intervals between events.

Red flag warning With respect to wildfires, a notice from the National Weather Service or other governmental agency that an extreme fire condition is occurring or is likely to occur within 24 hours.

Refraction Bending of a waveform. With respect to coastal processes, the bending of surface waves as they enter shallow water. This takes place where part of the wave "feels the bottom" and slows down while the remainder of the wave continues to move forward at a faster velocity.

Relative dating Placing geologic features, objects, earth materials, or events in chronological order in the geologic time scale without determining absolute ages.

Relative hardness With respect to minerals, the ability of one mineral or object to scratch another. Generally determined on the Mohs Hardness Scale in which diamond is assigned the highest value of 10 and talc the lowest value of 1. Other minerals, such as corundum, quartz, and calcite, have intermediate values of relative hardness.

Relative humidity A measure of the amount of water vapor in the air compared to the amount that would saturate the air at a given temperature and pressure; commonly expressed as a percentage.

Relative sea level The local or regional position of the sea at the shore that is influenced by uplift or subsidence of the land and changes in global eustatic sea level.

Relief With respect to topography, the difference in elevation between a higher point (as on a hilltop) and a lower one (as on a valley floor).

Residence time In natural systems, the duration that a substance spends at a specific place or in a specific compartment. A measure of how long a chemical element,

compound, or other substance stays in a specific part of a system.

Resisting force With respect to mass wasting, an influence that tends to oppose downslope movement.

Resonance With respect to earthquakes, the matching of the frequency of shaking with the natural vibrational frequency of an object. With respect to storm surge and tsunamis, the superposition of waves reflecting from one side of a narrow bay or lake with waves of water moving in another direction.

Resurgent caldera Uplift by rising magma of the central collapsed block of a giant volcanic crater; the giant crater resulted from an earlier explosion or collapse of the volcano summit; see *Caldera.*

Retreat With respect to glaciers, an interval of time when the area occupied by glacial ice decreased.

Retrofitting With respect to earthquakes, the renovation and physical modification of existing structures to withstand ground shaking and other effects of an earthquake.

Return interval The recurrence interval of wildfires; see *Recurrence interval*.

Return stroke In cloud-to-ground lightning, the component that involves the downward flow of electrons. Electron flow starts near the ground and is then initiated at successively higher points in a channel of ionized air. This flow produces the first bright light in a lightning flash.

Reverse fault A generally steep fracture or fracture system in which the hanging wall has moved up relative to the footwall in a direction opposite to the direction of fault dip. A low-angle reverse fault is called a *thrust fault*.

Rhyolite A fine-grained, light-colored volcanic rock consisting of feldspar, ferromagnesian minerals, and quartz with a relatively high silica content of about 70 percent; associated with volcanic events that may be very explosive.

Richter scale A semi-qualitative measurement of the size of an earthquake based on the amount of ground shaking as determined by maximum S-wave amplitude measured on a seismogram. The scale is not absolute and is affected by local geologic conditions and distance from the earthquake epicenter.

Ridge With respect to weather, an elongated area of high atmospheric pressure.

Riffle A section of stream channel, which at low flow is shallow, fast-flowing water moving over a gravel streambed.

Rift In tectonics, a long, narrow trough that is bounded by normal faults; a surface rupture produced by extension of the lithosphere.

Ring of Fire A popular name given to the chain of volcanoes on islands and on the continents surrounding the Pacific Ocean; actual combustion is much less common than the red-hot glow of lava fountains and flows.

Rip current A seaward flow of water in a confined narrow area from a beach to beyond the breaker zone.

Riprap Layer or assemblage of large broken stones placed to protect an embankment or shoreline against erosion by running water or breaking waves.

Risk From a natural hazards viewpoint, risk may be considered as the product of the probability of an event times the consequences.

Risk analysis An evaluation that estimates the probability that an event will occur.

River A large, natural stream that carries a considerable volume of flowing surface water.

River system Consists of three zones from headwater to river mouth known respectively as the zone of sediment and water production, zone of transport of water and sediment, and zone of sediment deposition.

Rock In geology, a solidified natural aggregate of one or more minerals, natural glass, or solid organic remains. In engineering or design applications, a solidified natural material that requires blasting for excavation or removal.

Rock cycle Group of interrelated processes by which igneous, metamorphic, and sedimentary rocks can each be produced from the others.

Rogue wave A single crest of an oscillation of the surface of the ocean that is much higher than usual. Commonly caused by the constructive interference of smaller waves.

Rope stage With regard to tornado development, the final decaying phase in which the upward-spiraling air in the funnel contacts down-drafts from the thunderstorm, and the tornado begins to move erratically.

Rotational With respect to landslides, a type of sliding downslope movement that develops on a well-defined, upward-curving slip surface in homogeneous earth material.

Rule of Vs As applied to topographic maps, the principle that all contour lines must form a shape similar to the letter V when they cross a stream valley and that the apex of the V points upstream.

Runoff Water moving over the surface of Earth as overland flow on slopes or as stream flow; that part of the hydrologic cycle represented by precipitation or snowmelt that results in overland flow to a stream.

Runup With respect to waves, the up-rush of the wave along the shore; also, the combined vertical and horizontal distance that a tsunami moves inland from the shoreline.

S wave One type of earthquake vibration that occurs within the body of Earth; also called a *secondary* or *shear wave*, vibrations from this type of oscillation are perpendicular to the direction that it travels.

Safety factor With respect to landsliding, the ratio of resisting to driving forces; a safety factor greater than 1 suggests that a slope is stable.

Sand storm High winds, generally in the desert, that carry fine (~0.05 to 2 mm) mineral particles to heights less than 2 m (~7 ft.) above the ground.

Saturated flow Type of flow in soil where all pores are filled with water.

Scale In maps, the relationship between the distance between features on the map and their actual distance apart on Earth's surface. Expressed either as a ratio, such as 1:24,000, or as a bar scale, a segmented line on the map.

Scarp Steep slope or cliff at the head of a landslide or along a geologic fault; produced by the downslope movement of a slump or slide or by the displacement of earth materials in an earthquake.

Scoria cone See *Cinder cone*.

Sea cliff Steep, commonly nearly vertical bluff adjoining a beach or other coastal environment; produced by a combination of wave erosion and erosion from the land, such as landsliding and runoff of surface water. Groundwater seepage may also contribute to its development.

Seafloor spreading The plate tectonics concept that new crust is continuously added to the edges of lithospheric plates at divergent plate boundaries as a result of upwelling of magma along mid-ocean ridges.

Sea wall A structure, commonly made of concrete, large stone blocks, wood or steel pilings, or cemented sand bags, built parallel to the coastline to protect buildings and infrastructure from wave and flood damage.

Secondary effect With respect to natural hazards, phenomena that are indirectly the result of a hazardous event, such as wildfires that are ignited by lava flows or water pollution that occurs after flooding has damaged a sewage treatment plant; applies to those phenomena that are caused by the primary or direct effects of a hazardous event.

Secondary succession With respect to ecology, the regular pattern of colonization and replacement of plant species in a biological community that was partially destroyed in a hazardous event, such as a wildfire, flood, or lengthy volcanic ash fall.

Sediment Transported particulate material created by weathering, biological activity, or chemical precipitation.

Sediment flushing With respect to aftermath of wildfire, the transport of sediment from slopes to stream channels and eventually downstream from even moderate storm events.

Sedimentary rock Hard, compacted, and cemented particulate material that was created by weathering, biological activity, or chemical precipitation.

Seismic gap Area along an active fault zone that is capable of producing a large earthquake but has not produced one recently.

Seismic source The point at which vibrations from an earthquake are generated.

Seismic wave A periodic disturbance of particles of Earth by an earthquake or other vibration that is propagated without the net movement of the particles.

Seismogram A written or digital graphic record made by a seismograph.

Seismograph Instrument that records earthquakes, also known as a seismometer.

Sensible heat Energy created by random molecular motion that may be physically sensed, such as by a thermometer.

Shake map A near-real-time, two-dimensional representation of the ground motion and potential damage from an earthquake.

Shear strength With respect to mass wasting, the internal resistance in earth material to shear stress; on slopes this strength resists failure by sliding or flowing.

Shield volcano A broad, convex volcanic mountain built up by successive lava flows; the largest type of volcanic mountain.

Shrinking stage With regard to tornado development, late phase in which the tornado thins and begins to tilt as its supply of warm moist air is reduced.

Shrink-swell clay Earth material composed of very fine mineral particles that decrease in volume (shrink) when they are dry and increase in volume (swell) when they are wet.

Silt particle Small particles 1/256 to 1/16 mm.

Sinkhole Surface depression formed by the dissolution of underlying sedimentary rock or collapse over a subterranean void such as a cave.

Slab avalanche Downslope movement of snow and ice that starts out as large cohesive blocks; generally more dangerous and damaging than loose-snow avalanches.

Sliding With respect to mass wasting, the deformation or downslope movement of a nearly intact block of earth material along a slip surface.

Slip rate Long-term rate of displacement along a fault; usually measured in millimeters or centimeters per year.

Slope The slant or incline of the land surface.

Slope stability map A two-dimensional representation of the land surface that shows its susceptibility to mass wasting; commonly based on a survey of past landslides that includes a measurement of the steepness of the slopes on which they occurred.

Slow earthquake An event in which rupture and movement along a geologic fault takes days to months to complete; also referred to as a *silent earthquake*.

Slump Type of landslide characterized by downward slip of a mass of earth material, generally along a curved slip surface.

Slump block A mass of landslide material that has moved downslope along a curved slip surface.

Slumping With respect to mass wasting, the downslope movement of rock, sediment, or soil along a curved slip surface.

Smectite A group of clay minerals with extremely small crystals that can absorb large amounts of water; common constituent of expansive soil.

Snow avalanche Rapid downslope movement of snow, ice, and rock.

Soil In geology, a generally loose accumulation of surface earth material that has been altered by chemical weathering in the place that it accumulated and can serve as a medium for plant growth. In engineering and design applications, unconsolidated surface material that can be excavated or removed without blasting.

Soil chronosequence A series of soils arranged from youngest to oldest.

Soil erosion Physical processes such as running water and blowing wind that removes soil particles.

Soil horizons Collection of distinct soil layers parallel to the surface (for example, A, B, and C) each produced by vertical and horizontal movements of the materials in a soil that creates the soil profile.

Soil slip A type of mass wasting event in which a thin layer of unconsolidated earth material slides downslope along a narrow path; the slip surface for this type of mass movement is commonly in weathered slope deposits that are below the soil, but above unweathered bedrock; in California shallow soil slips are commonly referred to as *mudslides*.

Soil taxonomy A classification of soils used by agriculture and soil science.

Solar nebula A flattened, pancake-like rotating disk of hydrogen and helium dust. Around 5 billion years ago a solar nebula condensed to form the sun by accretion of matter from its flattened disk.

Solutional sinkhole A depression that develops by the dissolution of underlying bedrock, such as limestone.

Sorting In sediment, size distribution of the particles; poorly sorted sediment has a large range in particle size, and in well-sorted sediment most particles are close to the same size.

Spacewatch A program started in 1981 to inventory the region surrounding Earth for asteroids and comets with the goal of identifying those whose orbits cross Earth's orbit.

Specific gravity The density of a mineral or rock as compared with the density of water.

Spilling breaker A type of water wave in which the wave crest tumbles down its own forward slope as it strikes a gently sloping shoreline; tends to be associated with deposition of sand on a beach.

Spit A claw-shaped, sandy to gravelly coastal landform at the end of a peninsula or island formed by accretion of beach ridges in the direction of longshore drift.

Spot fire A small fire that is commonly ignited by wind-blown burning embers ahead of the flaming front of a wildfire.

Spreading center Synonymous with mid-ocean ridges where new crust is continuously added to the edges of lithospheric plates.

Spring With respect to groundwater, the natural outflowing of subsurface water where the groundwater system intersects Earth's surface.

Squall line A line of thunderstorms often accompanied by high wind and heavy rain; commonly forms in advance of a cold front or dryline and can produce tornadoes.

Stable isotope A variety of a chemical element distinguished by its number of neutrons and one that does not naturally undergo radioactive decay. In absolute dating, the product of radioactive decay, the daughter isotope, is stable.

Stage With respect to flowing water, the height of the water in a stream channel. Typically used in reference to the water level at which flooding begins to occur. Flood stage is commonly the water level that is likely to cause damage to personal property.

Stalactite A cylindrical or conical mineral deposit, most commonly of calcium carbonate, that has grown downward from the roof of a cave or other overhanging feature.

Stalagmite A column or ridge of mineral deposits, most commonly calcium carbonate, on the floor of a cave; forms as water drips from stalactites on the cave roof.

Stationary front Transition zone between two different air masses, commonly with contrasting temperature, that moves very little.

Stepped leader In cloud-to-ground lightning, a channel of ionized air that approaches the ground in a series of nearly invisible bursts. This channel becomes the path for the luminous return stroke.

Storm surge Wind-driven ocean waves, usually accompanying a hurricane, nor'easter, or similar storm, that pile water up on a coastline.

Strain Change in shape or size of a material as a result of applied stress.

Stratosphere Zone in Earth's atmosphere above the troposphere where the air temperature is either constant or warms with increasing altitude; contains significant quantities of ozone, which protects life from high levels of ultraviolet radiation.

Stratovolcano See *Composite volcano*.

Streak The color of a mineral in powdered form; commonly produced by rubbing a mineral specimen on an unglazed ceramic plate.

Stream With respect to surface water, a body of water that flows in a channel; includes a brook, creek, and river.

Strength In soil, the ability to resist deformation; the resistance results from cohesive and frictional forces in the soil. In rock, the mechanically applied compression necessary to break or fracture a specimen.

Stress A type of physical force. In geological terms, stress is the force applied to rocks that causes them to deform. The stress results from relative movement of plates along tectonic boundaries can either be compressional, tensional, or shearing, corresponding to convergent, divergent, and transform plate boundaries, respectively.

Strike-slip fault A fracture or fracture system along which a block of Earth's crust moves horizontally relative to the block on the opposite side of the fracture.

Strike and dip Two parameters measured by geologists to describe the three-dimensional orientation of features, including layering in rocks, that intersect Earth's surface.

Strombolian-type eruption A mildly explosive volcanic eruption that ranks between 1 and 2 on the volcanic explosivity index. This eruption type is characterized by ejection of incandescent cinders that usually accumulate around the vent region, giving rise to the formation of a cinder cone volcano.

Strong earthquake Earthquake in which the release of energy has a moment magnitude of 6 to 6.9.

Subduction zone Convergence of tectonic plates where one plate dives beneath another and is consumed in the mantle.

Submarine landslide An underwater mass movement, often caused by an earthquake that can occur on a sloping seafloor, such as the wall of an underwater canyon, the continental slope, or the seafloor surrounding an island.

Submarine trench A relatively narrow, long (often several 1000s of kilometers), deep (often several kilometers) depression on the ocean floor that forms as a result of convergence of two tectonic plates with subduction of one.

Subsidence Sinking, settling, or other lowering of parts of the crust of Earth.

Subtropical jet stream A concentrated flow of air near the top of the troposphere that, in the Northern Hemisphere, typically crosses Mexico and Florida and is characterized by strong winds blowing from west to east.

Suction vortices Small, intense whirls within a larger tornado; these rapidly rotating winds may cause much of the intense damage done by tornadoes.

Sulfur dioxide (SO_2) A colorless gas with a pungent odor similar to a burnt match. This gas is emitted from volcanoes and burning of fossil fuels, and when dissolved in rainwater produces acid rain.

Supercell An unusually long-lived thunderstorm that has a rotating updraft that continually redevelops on the storm's flank.

Supercell storm See *Supercell*.

Surface fire Combustion in a wildfire that takes place primarily along the ground and consumes fuels such as grass, shrubs, dead and downed limbs, and leaf litter.

Surface wave One type of vibration produced by an earthquake in which the oscillation moves along the boundary between the air and land; generally strongest close to the epicenter where it causes much of the damage to buildings and other structures.

Surf zone The area between the breaking waves and the swash zone along the shore.

Swash zone Area along the shore where waves run up on the beach face and then back again into the water.

Swell With respect to coastal processes, the sorting out of storm-produced waves into wave sets having more or less uniform heights and lengths. This sorting allows groups of waves to move long distances from storms to coastal areas with relatively little loss of energy.

Talus Pieces of rock that have accumulated at the base of a cliff or steep slope; may form individual piles or a continuous slope composed of blocks of rock that have fallen from above.

Tectonic Pertaining to forces involved in large-scale crustal movement.

Tectonic creep Slow, more or less continuous, movement along a fault; also called *fault creep*.

Tectonic cycle A repetitive sequence of events and processes that create and destroy the Earth's crust and its ocean basins and mountain ranges.

Tectonic framework The geometry and spatial patterns of faults and seismic sources that define a specific region.

Tectonic plate A very large, fault-bounded block of Earth's crust and underlying upper mantle that moves as a coherent mass on top of the asthenosphere; also called a *lithospheric plate*. This type of block commonly forms at a mid-ocean ridge and is destroyed in a subduction zone.

Tectonic creep Slow, more or less continuous movement along a fault.

Tephra Any material ejected and physically blown out of a volcano; mostly ash.

Texture In rock, the size, shape, and arrangement of mineral grains and other particles. In soil, the size distribution of mineral and rock particles.

Thermal expansion With respect to the ocean, the increase in volume of seawater that occurs upon heating.

Thermal spring A place where heated groundwater flows from rock, sediment, or soil onto the land surface or into a body of surface water such as a river, lake, or ocean. Water temperature must be appreciably higher than the mean annual air temperature; includes both warm springs and hot springs.

Thermokarst An irregular terrain of sinkholes and mounds formed by the melting of permafrost.

Thermosphere With respect to weather, the outermost part of the atmosphere starting at about 80 km (~50 mi.) in altitude, characterized by an upward increase in temperature and very little gas; directly above the mesosphere.

Thrust fault A low-angle fracture or fractures in Earth's crust where older rocks are displaced over younger rocks.

Topographic map A two-dimensional representation of the relief of Earth's surface using contour lines of equal elevation.

Topographic profile A sideways view of the land surface with a curving line drawn to show how it changes in elevation from one point to another point.

Tornado A destructive, commonly funnel-shaped cloud of violently rotating winds that extends downward from a severe thunderstorm to reach Earth's surface.

Total load With respect to stream processes, the sum of the dissolved, suspended, and bed load that a stream or river carries.

Tower karst A landscape of steep-sided hills rising above a plain or above sinkholes. Commonly developed by extensive dissolution of limestone in a humid tropical climate.

Transform boundary Interface between two tectonic plates where one plate slides horizontally past another, such as along the San Andreas fault in California; synonymous with a *transform fault*.

Transform fault Type of fracture of Earth's crust associated with offsets of mid-ocean ridges where one plate is displaced horizontally; may form a plate boundary, such as the San Andreas fault in California.

Translational With respect to landslides, a type of sliding downslope movement that develops on a well-defined, planar slip surface, most commonly in layered or jointed rock or along a weak clay layer.

Triangulation The location of a point using distances from three points.

Tributary A small stream that flows into a larger stream.

Triple junction Areas where three tectonic plates and their boundaries join.

Troglobite An organism, such as a blind salamander, that lives its entire life underground in a cave.

Tropical cyclone General term for large thunderstorm complexes rotating around an area of low pressure that formed over warm water in the tropics or subtropics; includes low-intensity tropical depressions and tropical storms and high-intensity storms called hurricanes, typhoons, severe tropical cyclones, or severe cyclonic storms.

Tropical depression A circular atmospheric low-pressure center in the tropics whose winds are less than 63 km (~39 mi.) per hour; the threshold for a tropical storm.

Tropical disturbance An area of disorganized, but persistent thunderstorms and associated low-pressure trough that may be in the formative stages of a tropical depression.

Tropical storm An organized system of thunderstorms around a circular low-pressure center that derives its energy from warm ocean waters and has winds between 63 km (~39 mi.) and 119 km (~74 mi.) per hour; stronger than a tropical depression, but weaker than a hurricane.

Tropopause The boundary between the troposphere and the stratosphere.

Troposphere Lowermost layer of the atmosphere defined by a general decrease in temperature with increasing height above Earth's surface.

Trough With respect to weather, an elongated area of low atmospheric pressure.

Tsunami A series of gravity waves caused by the large-scale displacement of the entire water column of the ocean or rarely a large lake. Most commonly the result of a large earthquake deforming the seafloor, although may also be caused by a large underwater or seacliff landslide, collapse of part of a volcano into the ocean, a submarine volcanic explosion, or the ocean impact of an asteroid. These waves are not tidal waves and, in a few cases, are not seismic sea waves.

Tsunami ready A certification issued by the National Oceanic and Atmospheric Administration or other governmental agency that a community has taken appropriate preparedness measures for future tsunamis.

Tsunami runup map A two-dimensional representation of the level to which a tsunami has inundated or is projected to inundate a coastal zone.

Tsunami warning An emergency notice from a governmental agency that a tsunami has been detected and is heading toward the area receiving the alert.

Tsunami watch An emergency notice from a governmental agency that an event has taken place—such as an earthquake, landslide, or volcanic explosion—which could cause a tsunami to strike the alerted area.

Typhoon See *Hurricane*.

Ultra-Plinian-type eruption A supercolossal volcanic eruption that ranks between 6 and 7 on the volcanic explosivity index. These eruptions occur when stratovolcanoes or continental calderas collapse during eruption causing the remaining subsurface magma to be forcibly erupted.

Unified soil classification system Classification of soils, widely used in engineering practice, based on amount of coarse particles, fine particles, or organic material.

Uniformitarianism Concept that the present is the key to the past; that is, we can read the geologic record by studying present processes.

Unsaturated flow Type of flow in soil where all pores are not filled with water.

Updrift Located in the direction from which a water current, such as a longshore current, is flowing.

Uplift An increase in land elevation that is commonly the result of tectonic or volcanic processes.

Urban heat island effect A local climatic condition resulting from various design and land-use practices in a city, large town, or other extensively developed area. This condition can intensify heatwaves and cause temperatures in a metropolitan area to be up to 12°C (~22°F) warmer than the surrounding rural area.

Valley fever A potentially fatal respiratory illness produced by fungal spores found in desert soils. Mass wasting caused by earthquakes can produce dust containing these spores.

Variable gas With respect to the atmosphere, a substance such as carbon dioxide or water vapor that cannot be compressed with pressure alone and is present in changing proportions.

Varve A very thin sedimentary layer or couplet of layers deposited in a single year; in glacial lake deposits it consists of a coarse layer deposited when ice melts in the summer and a fine layer deposited when very fine suspended sediment finally settles out in the winter.

Vein In geology, the filling of a fracture with earth material, especially minerals, that differs from the surrounding rock.

Vertical exaggeration (VE) Vertical scale of a diagram or model that is larger than the horizontal scale; used in many geologic cross-sections to show relationships more clearly.

Vertical wind shear A change in direction or speed of the wind with changing altitude.

Very minor earthquake See *Microearthquake*.

Viscosity The ease of flow of a fluid; controlled by the magnitude of the internal friction within a fluid. Thicker fluids have greater viscosities.

Vog A volcanic fog or smog of sulfur dioxide and other volcanic gases combined with aerosols of sulfuric acid and dust. In Hawaii, vog is commonly an acrid blue haze produced by gases emitted from Kilauea volcano.

Volatiles Chemical compounds, such as water (H_2O) or carbon dioxide (CO_2), that evaporate easily and exist in a gaseous state at the Earth's surface.

Volcanic ash eruption An explosive volcanic event in which a tremendous quantity of fine-grained rock and volcanic glass is shattered and expelled in clouds of very fine particles into the atmosphere.

Volcanic dome Type of volcano characterized by very viscous magma with a high silica content; activity is generally explosive.

Volcanic Explosivity Index (VEI) A relative scale by which different volcanic eruptions can be compared based on quantitative and qualitative measurement of explosivity, including the plume height, volume of ejected material, and frequency of eruption.

Volcanic vent Circular or elongated opening through which lava and pyroclastic debris are erupted.

Vortex With regard to weather, a spinning column of wind.

Vulcanian-type eruption A mild to severe explosive eruption that ranks between 2 and 3 on the volcanic explosivity index. These eruptions are triggered by the interaction between groundwater and rising magma, which causes episodic violent explosions when the water flashes to steam, in a process known as a preatomagmatic eruption.

Wadati-Benioff Zone Inclined zone of earthquakes produced as a tectonic plate is subducted.

Wall cloud A localized, persistent, and often abrupt lowering of condensed water vapor from the rain-free base of a severe thunderstorm. These clouds may rotate and are commonly associated with tornado formation.

Warning With respect to natural hazards, the announcement of a possible hazardous event, such as a large earthquake or flood, that could occur in the near future.

Warm front An atmospheric boundary between two air masses of contrasting temperature along which the warmer air mass advances into the cooler air mass.

Washover channel A narrow conduit of water eroded through a beach or coastal dunes by a storm surge.

Watch With respect to weather, an alert issued by a forecast office that meteorological conditions are favorable for severe weather, such as a tornado, hurricane, severe thunderstorm, winter storm, or flash flood.

Water content The amount of water in a soil as a percent (weight of water to weight of the solid soil particles as a percent); also called the *moisture content*.

Water–energy–food nexus The concept that water, energy, and food are inextricably tied together such that changes in one will effect change on one or both of the other factors.

Watershed Land area that contributes water to a particular stream system; generally used to describe the catchment area for a smaller tributary stream; see *Drainage basin*.

Waterspout A weak, generally funnel-shaped, wind vortex that most commonly develops under fairweather conditions and has all or part of its track over the sea or a lake; some of these whirlwinds are tornadoes that form or track over the water.

Water vapor The gas phase of water.

Watt The basic unit of power; generally expressed as units of energy per unit of time.

Wave front A long, continuous crest of a single oscillation, such as one on the surface of a lake or ocean.

Wave height Vertical distance between the crest and preceding trough of an oscillation, such as one on the surface of a lake or ocean.

Wave normal An imaginary line perpendicular to the crest of an oscillation, such as one on the surface of a lake or ocean.

Wave period The time in seconds for successive crests of an oscillation, such as one on the surface of a lake or ocean, to pass a reference point; the inverse of the frequency of the oscillation.

Wavelength With respect to physics, the horizontal distance between two successive crests or troughs of an oscillation. Used to describe characteristics of seismic, electromagnetic, water, and other oscillations.

Weather Atmospheric conditions, such as air temperature, humidity, and wind speed, at any given time and place.

Weathering Changes that take place in rocks and minerals at or near Earth's surface in response to physical, chemical, and biological activity; the physical, chemical, and biological breakdown of rocks and minerals.

Wicked Problem A natural hazard management problem that is resistant to resolution due to strong social, political, or economic implications.

Wide Area Augmentation System (WAAS) A network of global positioning system (GPS) receivers at fixed locations that act as reference points for transmitting positional corrections by satellite to mobile GPS receivers. Operated by the Federal Aviation Administration, this

system currently improves the accuracy of locations obtained from WAAS-enabled GPS receivers in the United States and parts of Canada.

Wildfire Uncontrolled combustion or burning of plants in a natural setting, such as a forest, grassland, brushland, or tundra.

Wildland–urban interface The area where natural undeveloped grassland, brushland, or forest is adjacent to land developed for homes, businesses, or recreation.

Wind chill The influence of wind on the perception and actual effect of cold air. Meteorological agencies in the United States and Canada have developed a wind chill index based on how the human body loses heat in the cold and wind.

Wind shear A change in the speed or direction of the wind along a given direction.

Work In physics, the exertion of a force to overcome resistance or to produce molecular change.

Younger Dryas A previously unexplained glacial interval from around 13,000 to 11,600 years ago that coincides with the extinction of many large mammals in the Northern Hemisphere and the disappearance of the Clovis culture. A recent hypothesis proposes that these events were caused by the airburst of a comet over the Canadian continental ice sheet.

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