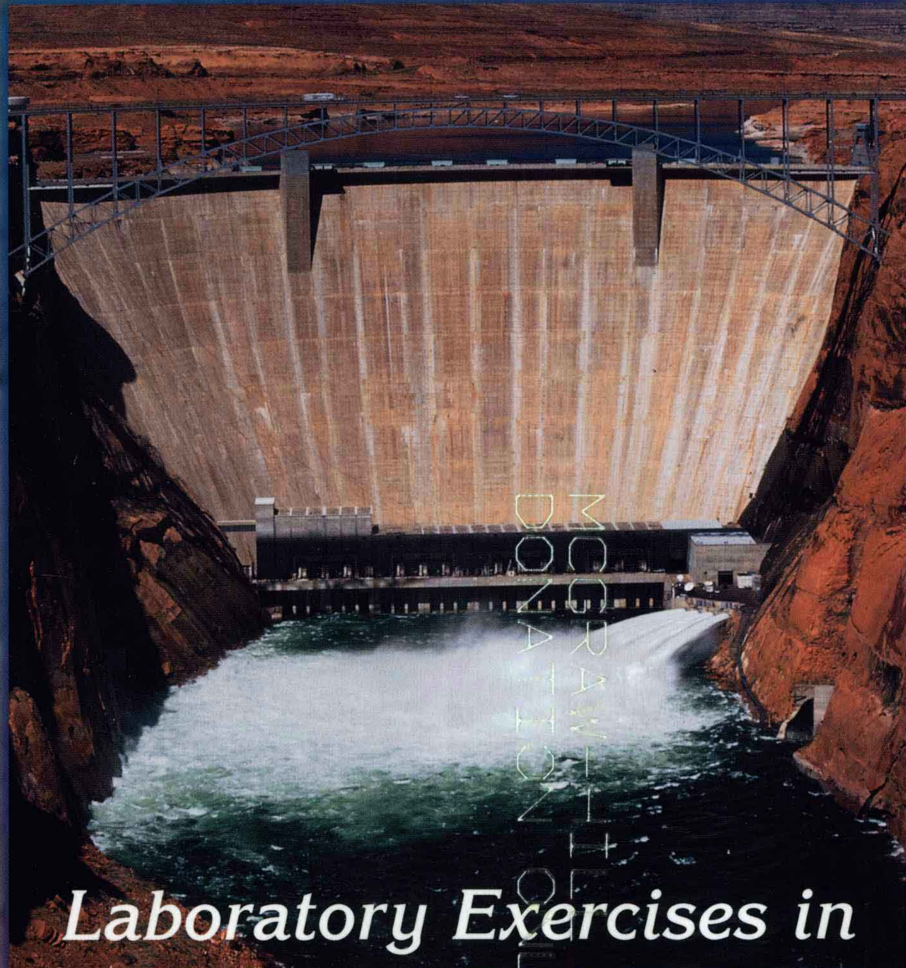
HARVEY BLATT



Laboratory Exercises in

ENVIRONMENTAL GEOLOGY

Second Edition

WCB
McGraw-Hill

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WCB McGraw-Hill

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INTRODUCTION

The past decade has witnessed an explosion of interest in the relationship between geology and the everyday concerns of the average citizen. But why should someone who is not a professional geologist care about planet Earth? So what if the earth's surface is composed of plates, rather than an unbroken, homogeneous skin? Why should anyone care whether or not a rock layer contains oriented clay minerals? Will the fact that calcium carbonate is more soluble than quartz affect *your* life in any meaningful way?

The answers to these questions reveal that the average citizen can indeed be affected by such concerns. The fractured, platy character of the earth's crust, for example, affects the cost of house insurance in California and elsewhere. The presence of oriented clay minerals predisposes inclined rock layers to slide downhill in many parts of the United States. The difference in solubility between calcium carbonate and quartz causes some Florida homes to collapse into huge pits.

The relationship between geology and short-term human concerns (periods of no more than a few hundred years) is termed *environmental geology.* The purpose of this laboratory manual is to provide examples of how rocks and minerals exposed at the earth's surface and geological processes affect the natural environment.

At most schools, environmental geology is taught at the first-year level, commonly as an alternative to a standard Physical Geology course, and is designed for students who need to fulfill a college science requirement. The course also serves as an elective for students interested in the environment. Because of the dual function of this course, students in the class often have quite varied science backgrounds. Some have had a previous university science course, while others have had none, and might even have avoided science and mathematics in high school. To help accommodate the needs of both groups, the exercises in this laboratory manual typically contain more questions than can be answered within a standard two- to three-hour laboratory class, and the questions vary in difficulty. In addition, each exercise contains a mixture of hands-on and thought-provoking questions that deal with social, ethical, or political issues of environmental relevance. The instructor can use whichever questions seem most appropriate.

The manual also contains more than enough exercises for the normal 14 labs per semester, so instructors can choose the exercises most suitable for their geographic area. For example, problems of floods and coastal erosion seem more immediate in Louisiana than in Idaho.

This manual is designed to be used in conjunction with textbooks on physical geology and environmental geology. For this reason I have avoided the lengthy theoretical discussions normally included in those texts. I have, however, described some of the basic principles that underlie each laboratory exercise.

These principles cannot be discussed without reference to size and distance. How far is a house from an unstable hillside? Is the hill slope steep or gentle? Scientists usually use a metric scale in answering such questions; engineers and other professionals use the familiar, nonmetric scale of feet and inches. Scale problems arise with temperature measurements. Scientists use the centigrade or Kelvin scale rather than the Fahrenheit scale more familiar to American students. To help students gain familiarity with various systems, this manual uses different scales in different exercises. Students also need to learn how to convert easily from one set of units to another; therefore, numerous conversion factors are included in Appendix A.

During the past 25 years, the increasing importance of environmental problems has led to the publication of many books that are important references for environmental concerns. Books that deal with geological influences on the environment include the following:

Blatt, H., 1997. *Our Geologic Environment.* New York, Prentice-Hall, 541 pp.

Coates, D. R., 1981. *Environmental Geology.* New York, John Wiley & Sons, 701 pp.

Coates, D. R., 1985. *Geology and Society.* New York, Chapman and Hall, 406 pp.

Costa, J. E., and Baker, V. R., 1981. *Surficial Geology.* New York, John Wiley & Sons, 498 pp.

Dennen, W. H., and Moore, B. R., 1986. *Geology and Engineering.* Dubuque, Iowa, Wm. C. Brown, 378 pp.

Garrels, R. M., Mackenzie, F. T., and Hunt, C., 1975. *Chemical Cycles and the Global Environment: Assessing Human Influences.* Los Altos, California, William Kaufmann, 206 pp.

Goudie, A., 1990. *The Human Impact on the Natural Environment,* 3rd ed. Cambridge, Massachusetts, MIT Press, 388 pp.

Griggs, G. B., and Gilchrist, J. A., 1983. *Geologic Hazards, Resources, and Environmental Planning,* 2nd ed. Belmont, California, Wadsworth, 502 pp.

Keller, E. A., 1996. *Environmental Geology,* 7th ed. New York, Prentice-Hall, 560 pp.

Legget, R. F., 1973. *Cities and Geology.* New York, McGraw-Hill, 624 pp.

Leveson, D., 1980. *Geology and the Urban Environment.* New York, Oxford University Press, 386 pp.

Lundgren, L., 1986. *Environmental Geology.* New York, Prentice-Hall, 576 pp.

McCall, G. J. H., DeMulder, E. F. J., and Marker, B. R. (eds.), 1996. *Urban Geoscience.* Rotterdam, Holland, A. A. Belkema, 273 pp.

Montgomery, C. W., 1998. *Environmental Geology,* 5th ed. Dubuque, Iowa, The McGraw-Hill Companies, Inc., 544 pp.

Murck, B. W., Skinner, B. J., and Porter, S. C., 1996. *Environmental Geology.* New York, John Wiley, 535 pp.

Pipkin, B. W., and Trent, D. D., 1997. *Geology and the Environment, 2d edition.* Belmont, California, Wadsworth Publishing Company, 522 pp.

Ward, K. (ed.), 1989. *Great Disasters.* Pleasantville, New York, Reader's Digest Association, 320 pp.

I hope students will finish this laboratory manual with a better understanding and appreciation of the ground beneath their feet. I encourage both faculty and student users of this manual to send suggestions for improving any of the exercises to either the author or the publisher.

INTRODUCTION TO THE SECOND EDITION

This second edition of *Laboratory Exercises in Environmental Geology* has been heavily revised based on suggestions made by users of the first edition. For example, the three exercises on rocks have been condensed into a single exercise to make room for additional exercises on environmental topics. Other exercises in the first edition were either eliminated or combined with others. New exercises in this edition include those on the nature of environmental geology, swelling soils, water pollution, mineral resources, air pollution, and alternative energy sources. The number of exercises has been cut from 24 to 21. In addition, reference lists have been updated and shortened and a glossary has been added.

Perhaps the most frequent complaint by users of the first edition was the level of mathematics. It was considerably greater than is traditional in geology laboratories. In response to this concern, most of the math has been either abbreviated or eliminated in this edition of the manual. Another objection to the first edition was the use in several exercises of chemical equations to illustrate what occurs in nature. Many of the students who take this course are not science majors and therefore do not have the necessary background to handle these equations. Hence, the amount of chemistry in this edition has been considerably reduced.

I again encourage the inclusion of field trips in the environmental geology course, either as a substitute for laboratory time or as weekend excursions. Governmental agencies and companies involved with environmental problems are usually more than happy to explain what they do and why. These include the U.S. Geological Survey and state geological surveys, groundwater companies, companies that operate sanitary landfills, mining companies, and companies that deal with sources of alternative energy, such as wind power and solar power.

As with the first edition, I hope students will finish their environmental geology course with an increased understanding of the world in which they live. If this laboratory manual contributes to this understanding, I will feel my writing effort was worthwhile. Once again, I encourage users of the manual to send their suggestions for improvement to the publisher.

REVIEWERS

I wish to extend a special thanks to the following people for their thoughtful comments and suggestions in prepublication reviews:

First Edition Reviewers:
John R. Huntsman
University of North Carolina at Wilmington
Rob Sternberg
Franklin and Marshall College
Mary P. Anderson
University of Wisconsin–Madison
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St. Louis Community College at Meramec
George P. Merk
Michigan State University
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William D. Nesse
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Eastern New Mexico University
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Second Edition Reviewers:
Michael Whitsett
University of Iowa
Barbara Ruff
University of Georgia

Their contributions were enlightening, challenging, and encouraging throughout the development process.

C O N T E N T S

EXERCISE 1

What Is Environmental Geology?

Geology is the study of the earth: its history, its rocks, its waters, its atmosphere, and the life that exists on it. These are our surroundings. This is our environment. So, in a sense, the expression *environmental geology* contains an unnecessary word: *environment.* Geology is by definition an environmental subject. This has not always been obvious, however. For most of the 20th century and until recently, most geologists were involved in the search for underground supplies of oil and gas. The connection to human concerns at the earth's surface, such as landslides, soil quality and food production, or the occurrence of floods, was not obvious. So the term *environmental geology* arose to indicate those parts of geology that were clearly related to those human concerns that deal with surface processes. Environmental geology is a fast-growing area of study, and employment opportunities are increasing explosively for environmental geologists.

Most of you in this laboratory don't intend to become professional geologists. But all people will benefit by knowing something about their surroundings. A large and growing proportion of America's domestic concerns are environmental issues that every citizen is asked to vote on. Sometimes the issues are local, such as whether it is necessary to develop a new sanitary landfill in which to place the town's garbage or to enlarge the city sewage plant. Will the location of the landfill pose a threat to the underground water supply that feeds the town's wells? Sometimes the environmental issues are national, such as the question of how much federal money (your tax dollars) should be spent to decrease air pollution or to control global warming. Does your congressional representative reflect your view, industry's view, or the government's view? Other environmental issues whose outcome may affect you personally include the possibility of a flood in your area, acid rain on your newly painted house, the likelihood of a landslide on the neighboring hillside, and the stability of the soil your house stands on. The list is endless. All of these topics, and others, will be considered in this laboratory manual. They are also treated in your textbook in more detail.

Information

What do you need to know about the scientific aspects of our environment in order to have an informed opinion about environmental issues?

Earth Materials

Of what is the earth's surface composed (Figure 1.1)? What is a mineral? What is a rock? Do some minerals cause environmental problems? What is soil? How does soil form? Is all soil equally nourishing for crops? How does soil become polluted? Can soil pollution be prevented? How does well water get into the ground? Is it always safe to drink and, if not, why not?

Earth Locations

Which areas are environmentally at risk or dangerous? Is a landslide more likely here or there? Is a major flood likely where I live? Is sea level likely to rise and erode the beach and innundate my beach house (Figure 1.2)? Will there be an earthquake in my area soon? Surface mining of coal (strip mining) can cause water pollution. Where are the nearest coal deposits? The answers to these questions can be found only

Figure 1.1

Did the water in this flooded rice field originate in the mountains in the background? Why doesn't the water sink into the ground and disappear from view? What is the soil made of?

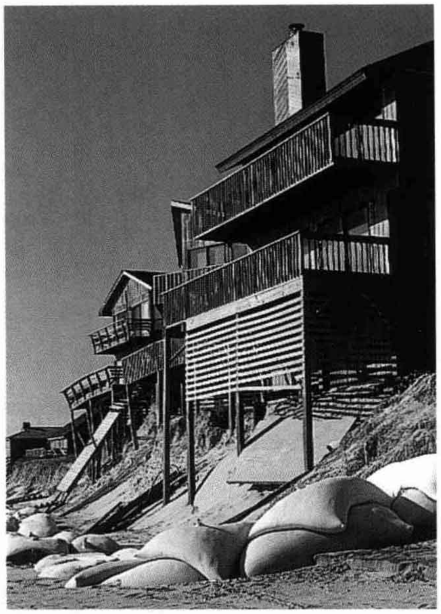
by referring to maps that show the shape of the land surface and maps that show the distribution of rocks and sediment.

Earth Underground

Most crops are irrigated, and most of the water for irrigation comes from underground. Will this underground water always be available? How do we know? Will the water flow faster if the rock layers below the ground are tilted toward my well? How serious a problem is pollution of my well water? Can polluted underground water be cleansed?

Figure 1.2

This beach house along the Atlantic shore in North Carolina is in danger of collapse during the next winter storm. Will the sandbags protect it? What else might be done? Should the house have been built in this location?



Why do earthquakes and volcanoes occur in some places but not in others? Is there a pattern to their locations that might be useful for predictions (Figure 1.3)? If so, what causes it? Is my house in danger?

Figure 1.3

Patterns of earthquake and volcanic activity based on historic records.

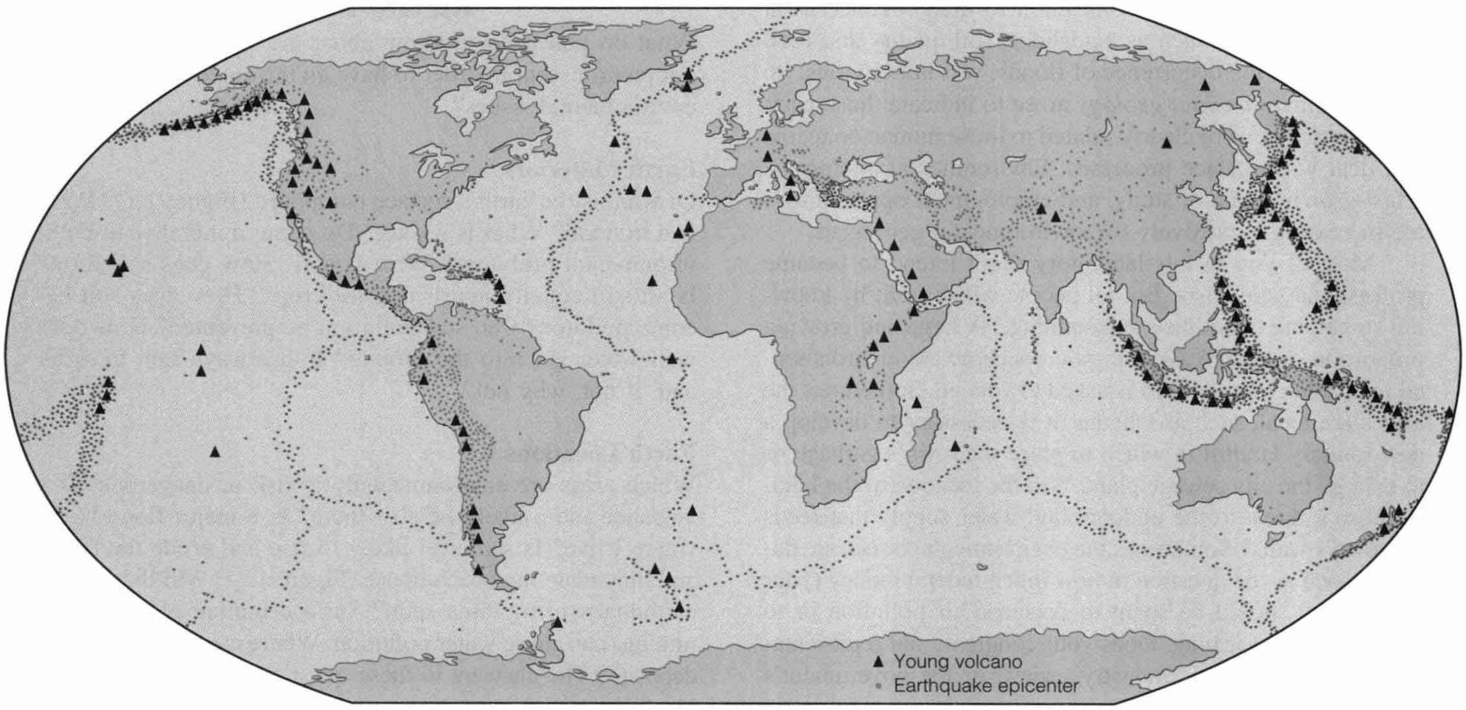


Figure 1.4

Aerial photograph showing the result of the most destructive landslide in the history of Hong Kong, June 18, 1972. Almost 26 inches of rain fell during the preceding two days, saturating and undermining the steep slope, which is composed of soil and underlying unlithified coarse sediment. The slope failure was 220 feet wide and destroyed a 4-story building and a 13-story apartment building; 67 people were killed. Hong Kong's population density and topographic relief make it impossible to completely avoid construction in unsafe areas.

Why do oil and natural gas occur where they do? Are we running out of these resources? Where and why? Are there any practical alternatives to these sources of energy that we rely on to fuel our industrial society?

The Air We Breathe

TV tells me there is some evidence that the climate is becoming warmer and wetter because of the *greenhouse effect.* What is the greenhouse effect, and can anything be done about it? And what is the *ozone hole?* For that matter, what is ozone? Will alternatives to petroleum help to keep the air clean? Why? Do I need to be concerned about radon gas entering my house from the soil below?

Numbers

Finally, there is the question of numbers. Numbers tell us

How far. Is the unstable slope near enough to threaten my house (Figure 1.4)? Am I located so close to the river that the next flood is likely to wipe me out?

How soon. Will the harmful chemical from the railroad accident sink into the ground and contaminate my underground water supply next week, next year, or in 50 years? When will the retreating shoreline become a problem for my coastal city?

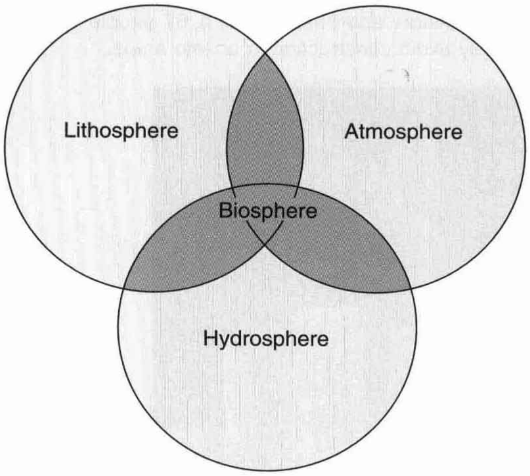
How serious. Are the amounts of lead and arsenic in my drinking water too high for safety? Is the amount of soot in the air high enough to damage my lungs?

Relationships among things. Does the rise in air pollution parallel the increase in automobile use? Does the dumping of chemicals in the water upstream correlate with an observable increase in rectal cancer downstream? Is the relationship between these things strong enough to make us believe it is meaningful, or might it just be coincidental? Cigarettes and lung cancer? Dioxin and birth defects? Coal dust and emphysema?

Numbers are essential for evaluating the significance of environmental information, as will be evident in many of the exercises.

Figure 1.5

Spheres of the earth.



INTERRELATIONSHIPS

Everything is connected to everything else. Water (hydrosphere), rocks (lithosphere), air (atmosphere), and living matter (biosphere) are interrelated (Figure 1.5). Rain hits the land and dissolves rocks and minerals. This "impure" water is taken in by plant roots, which use many of the impurities as nutrients. However, some impurities are pollutants to both the plant and to the animals that eat the plant. And, of course, humans drink the stream water that has flowed through the surface rocks and soil.

Plant roots are rooted in soil ("dirt") that was produced by the rotting of rocks caused by chemical reactions between rock (lithosphere), rain (hydrosphere), and atmospheric gases. The soil also contains organic material (biosphere) from dead and decomposing plants and animals (plant leaves, worm skins, and other carcass parts you'd rather not think about).

Figure 1.6

What should be done about the colored plumes coming from these smokestacks? Imagine thousands of factories worldwide spewing these fumes. Do you want to breathe this stuff? Will your lungs suffer?

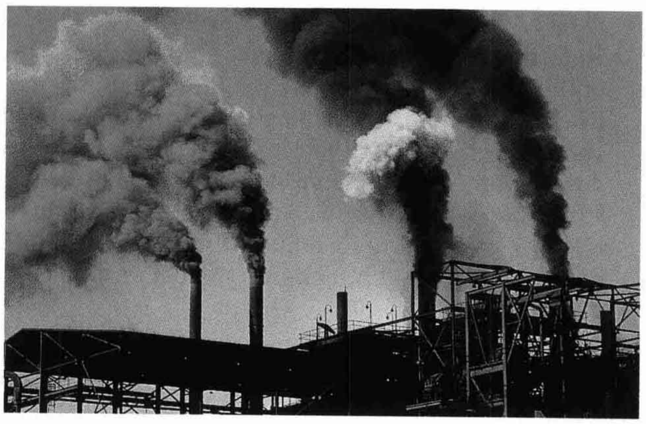
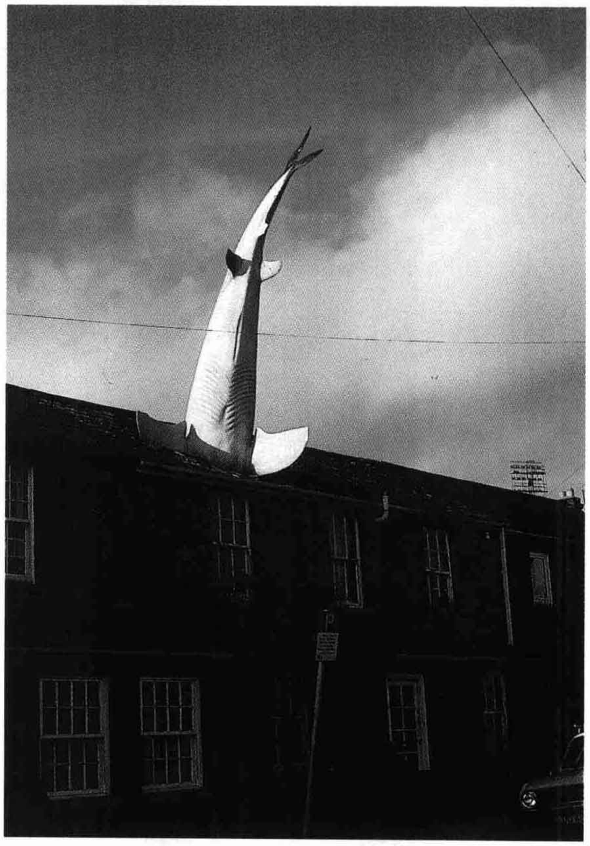


Figure 1.7

Shark in roof, Oxford U.K.



Some of the water that fell as rain or snow evaporates directly back to the atmosphere to raise the humidity. Some runs off on the ground surface toward the ocean. Also entering the air we breathe are various harmful chemicals that pour from industrial smokestacks (Figure 1.6). These include the gases that are implicated in global warming.

What we do to one thing we do to everything.

METHODOLOGY

The goal of science is to discover the interrelationships among the objects in our physical world. Environmental geologists, like other scientists, approach problems in a certain way, commonly called the *scientific method.*

1. A scientist observes a phenomenon. This may be water flowing in a stream, a building shaking in an earthquake, a mass of rock hurtling downslope toward a village below, or some unexpected event (Figure 1.7).
2. The scientist establishes a *hypothesis* to explain the observation. A hypothesis is a statement of the scientist's first guess at the explanation for the observed event.
3. The scientist makes additional observations or measurements or conducts experiments to test the hypothesis. Every effort is made to exclude personal bias from the observations.

4. The scientist analyzes the results of all observations and experiments to determine whether they are expected or are consistent with the hypothesis. After a sufficiently large number of observations have been made and found to be consistent with the hypothesis, the scientist becomes confident enough in the hypothesis to upgrade the explanation to the status of a *theory.* After much additional testing over an extended period of time, usually many years, the theory may be upgraded to the status of a *law.*
5. Based on observations, the scientist looks for patterns. These patterns are used to create models that may explain how parts of nature work. The models of science may be mathematical, such as the law of gravity:

$$F = c\,\frac{m_1 m_2}{r^2}$$

where F = force of gravity
c = a universal constant
m_1 = mass (density $\times$ volume) of the first object
m_2 = mass of the second object
r = distance between the centers of the two masses

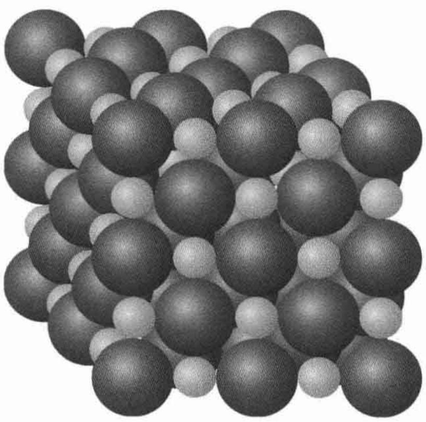
The models may also be physical, such as the internal structure of a mineral represented by a few colored balls and wires (Figure 1.8). Earth science, or environmental science, is basically a detective story with the scientist as the detective and the earth as the mystery.

Problems

1. Look in the telephone book to see whether any geologists are listed. If so, is there a subheading for environmental geologists? Are there any companies that deal with environmental issues, such as water testing and remediation, garbage disposal, earthquake-proofing of houses, or the manufacture of wind turbines or solar panels?

Figure 1.8

Atomic structure of halite, ordinary table salt (sodium chloride, NaCl). The large spheres are chlorine atoms, the smaller spheres are sodium atoms.



2. Does your state have a certification program for geologists, or can anyone claim expertise? Ask a geologist or the office of your state's geological survey. (Check the phone book again.)
3. What happens to the garbage you put in your trash can or dumpster that is picked up by the city garbage truck? Who handles this chore for your town? Where does the truck take it? To a big hole in the ground outside of town (a landfill) or to an incinerator to be burned? Is the disposal area filling up? How much garbage is collected each day, and how large is the hole it is put in? What does the town plan to do when the hole is full?
4. Who is responsible for monitoring the amount and purity of the drinking water in your town? How often is the water checked for contaminants? What contaminants does the person responsible look for?
5. Suppose you were worried about a geologic hazard in your town, such as a flood in the river that runs through the city, a volcano 10 miles away that is emitting plumes of smoke, flaking asbestos in city buildings, or an unpleasant taste and color in your drinking water. Where would you go for information and advice about such matters?
6. World population has reached 6 billion (6,000,000,000) people, with 100 million more (100,000,000) added yearly. Most of them are in the poorer areas of the world. Perhaps more frightening, the percentage of people living in urban areas is growing and has now reached about 50%. What types of environmental problems might these trends cause or make worse?
7. Consider a common object such as a pencil. What resources or materials from the earth were required to manufacture it? Which of them do you think might be renewable or inexhaustible, and which might we eventually run out of?
8. Suppose you wanted to conduct a survey to determine the views of those in your community about environmental issues. Prepare a list of five questions you would ask. Explain how you would choose the people to survey to get a balanced and fair representation of the "average person." What factors would you need to consider?

Further Reading/References

Blatt, Harvey, 1997. *Our Geologic Environment.* New York, Prentice-Hall, 541 pp.

Montgomery, Carla W., 1998. *Environmental Geology,* 5th ed. Dubuque, Iowa, WCB/McGraw-Hill, 544 pp.

Keller, Edward A., 1996. *Environmental Geology,* 7th ed. New York, Prentice-Hall, 560 pp.

Pipkin, Bernard W. and D. D. Trent, 1997. *Geology and the Environment.* Belmont, California, Wadsworth Publishing Company, 544 pp.

2 EXERCISE

MINERALS

Although our planet is composed of 90 chemical elements, they are not present in equal amounts. Eight elements form 99.4% by weight of the *crust*—the upper 30 miles under the land surface—while the other 82 elements total only 0.6%. The abundant elements are

Element	**Weight %**
Oxygen	46.4
Silicon	28.2
Aluminum	8.3
Iron	5.6
Calcium	4.1
Sodium	2.4
Magnesium	2.3
Potassium	2.1
All others	0.6

The composition and relative abundance of minerals reflect the chemical composition of the crust. The most abundant minerals are composed largely of oxygen, silicon, and aluminum.

Also noteworthy is the fact that most of the economically important elements are not among the eight most abundant elements. For example, titanium makes up only 0.57% of the crust of the earth, manganese is only 0.09%, chromium is only 0.01%, and other elements such as nickel, copper, and lead are even less abundant. Concentrations of most of these elements are uncommon—and are becoming even less so as our industrial civilization expands. Substitutes for most of them have yet to be found or synthesized.

Elements tend to combine into larger groupings because of their electronic structures. The change in electron distribution that results when elements combine determines the physical and chemical characteristics of the materials (e.g., minerals) produced. Unfortunately, however, the new chemical properties cannot be predicted from the properties of the individual, uncombined elements. For example, at room temperature sodium (Na) is a metal and chlorine (Cl) is a gas. But when the two combine as sodium chloride (NaCl, halite), they produce a solid—ordinary table salt. The properties of table salt (including very high solubility in water or in steak juice) are determined by the distribution of electrons in this sodium chloride aggregate, just as the properties of the uncombined sodium (metallic appearance, high melting temperature) and chlorine (irritating odor, greenish yellow color) are determined by *their* electronic structures.

Just as the properties of solid NaCl differ from those of uncombined sodium and chlorine, so do they also differ from the properties of sodium and chloride ions (charged atoms) dissolved in water. The "salty" taste sodium ions create in water (or saliva) is well known. The arrangement of electrons around atomic nuclei underlies the physical and chemical properties of all materials.

Two properties of great importance to environmental scientists studying minerals are hardness and solubility. Quartz (SiO_2) is very hard and relatively insoluble in water; calcite ($CaCO_3$) is soft and moderately soluble in water;

halite (NaCl) is very soft and very soluble in water. The importance of these chemical properties to drinking-water quality and to building construction in humid climates is obvious.

Important Properties of Minerals

A mineral is a naturally occurring, inorganic solid with a regular, periodic internal structure and a fairly definite chemical composition (Table 2.1). Because of this fixed internal structure and chemical composition, the physical and chemical properties of a mineral are constant and can be used to identify it. The following properties are those most useful in mineral identification:

1. *Hardness,* defined as the ability of a mineral to resist abrasion, is determined by scratching the mineral with an object of known hardness. Harder minerals scratch softer ones. Geologists use a hardness scale devised in 1824 by a German mineralogist, Friedrich Mohs, and known as the *Mohs hardness scale* (Table 2.2). Surface alteration can decrease hardness; therefore, hardness must be determined on a fresh mineral surface.
2. *Cleavage.* The strength of chemical bonds in a mineral differs for different pairs of elements. Because of this difference, and because the elements occur in fixed positions in its crystal structure, a mineral can have some planar surfaces across which bonding is weaker. When hit, the mineral tends to break along these weaker planes, which are called *cleavage surfaces* (Figure 2.1). Minerals can have one, two, three, four, or six different cleavage directions, and these can be diagnostic for the mineral. For example, micas have one cleavage direction and cleavages occur as sheets. In a highly micaceous rock, slippage and slope failure tend to parallel oriented groups of mica flakes.

   Some minerals do not show cleavage, either because their cleavage surfaces are poorly developed or because their chemical bonds are nearly equal in all directions. Quartz is a mineral with no obvious cleavage.

   Cleavage faces should not be confused with crystal faces. Cleavage faces are planar surfaces of preferential breakage that reflect planes of weakness in a crystal structure. Crystal faces, in contrast, are external planar surfaces that form as a mineral grows from a solution; they reflect the geometry of the internal structure. Only rarely is the shape of cleavage fragments of a mineral the same as the shape of its fully formed crystals.

TABLE 2.1

Common Rock-Forming Minerals

Mineral	Chemical composition
Abundant	
Quartz	SiO_2
Orthoclase feldspar	$KAlSi_3O_8$
Plagioclase feldspar	$NaAlSi_3O_8$ to $CaAl_2Si_2O_8$
Biotite mica	hydrous K, Fe, Mg, Al silicate
Muscovite mica	$KAl_3AlSi_3O_{10}(OH)_2$
Hornblende	Ca, Na, Mg, Fe, Al silicate
Augite	Ca, Mg, Fe, Al silicate
Olivine	$(Mg, Fe)_2SiO_4$
Chlorite	hydrous Mg, Fe, Al silicate
Illite clay	hydrous K, Al, Fe, Mg silicate
Montmorillonite clay	hydrous Na, Ca, Al, Fe, Mg silicate
Kaolinite clay	$Al_2Si_2O_5(OH)_4$
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halite	NaCl
Hematite	Fe_2O_3
Less Abundant but Still Common	
Mineral	**Chemical composition**
Garnet	Fe, Mg, Ca, Al silicate
Kyanite	Al_2SiO_5
Sillimanite	Al_2SiO_5
Staurolite	Fe, Mg, Al silicate
Epidote	Ca, Fe, Al silicate
Magnetite	Fe_3O_4
Illmenite	$FeTiO_3$
Pyrite	FeS_2
Graphite	C

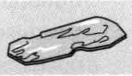
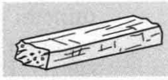
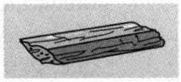
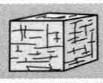
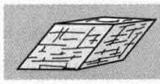
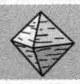
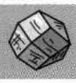
TABLE 2.2

Mohs Hardness Scale

Relative Hardness	Index Mineral	Common Objects
10	Diamond	
9	Corundum	
8	Topaz	
7	Quartz	
		Steel file—6.5
6	Orthoclase	
		Glass, knife, nail—5.5
5	Apatite	
4	Fluorite	
3	Calcite	Copper penny—3.0
		Fingernail—2.5
2	Gypsum	
1	Talc	

Figure 2.1

Cleavage patterns of minerals. Few common minerals have more than three cleavage directions.

Number of cleavage directions	Shape	Sketch
0 No cleavage, only fracture	Irregular masses (quartz)	
1	Flat sheets (micas)	
2 at 90°	Elongated form with rectangular cross-section (prism: spodumene)	
2 not at 90°	Elongated form with parallelogram cross-section (prism: hornblende)	
3 at 90°	Cube (halite)	
3 not at 90°	Rhombohedron (calcite)	
4	Octahedron (fluorite)	
6	Dodecahedron (sphalerite)	

Crystals normally are bounded by many more surfaces intersecting at different angles than are cleavage fragments. Among the few examples of cleavage fragments identical to fully formed crystals are halite cubes, galena cubes, and dolomite rhombohedra.

3. *Color.* Many of the abundant or common rock-forming minerals have distinctive colors that are useful for identification. Some minerals (particularly quartz, fluorite, and calcite) can occur in a wide variety of colors, but one color is the most common. Colors generally result from the presence of impurities that selectively absorb wavelengths of light entering the mineral. Those wavelengths that are not absorbed give the mineral its color.
4. *Streak,* the color of the mineral powder, is determined by powdering a sample, usually by scratching it across a piece of unglazed porcelain (hardness 7). The mineral must be softer than the porcelain, or it will scratch (powder) the porcelain rather than being powdered itself. Most nonmetallic minerals have a white or colorless streak; hence, streak is not a helpful diagnostic tool for the abundant minerals, almost all of which are nonmetallic. Streak is more helpful for identifying metallic minerals, many of which are of great economic importance.
5. *Luster* is the appearance of a fresh mineral surface in reflected light. A mineral that appears metallic is said to have a *metallic* luster. Nonmetallic mineral surfaces can be *vitreous* (glassy luster), *resinous, pearly, silky, dull,* or *earthy.* As examples, quartz is vitreous, sphalerite is resinous, talc is pearly, satin spar gypsum is silky, and microcrystalline hematite is dull or earthy.
6. *Specific gravity* is the ratio between the weight of a mineral and the weight of an equal volume of water. Most minerals have specific gravities of between 2.6 and 3.5. In general, the higher the content of heavy elements such as iron and lead, the higher the specific gravity of the mineral. For example, the specific gravity of magnetite (Fe_3O_4) is 5.2; that of galena (PbS) is 7.5. Gold, at 19, has the highest specific gravity of any mineral.
7. Other physical properties are sometimes useful in mineral identification (Table 2.3). For example, calcite is the only important mineral that dissolves in cold, dilute hydrochloric acid. Magnetite is the only mineral attracted to a small hand magnet, while halite has a unique salty taste. Micas are elastic when bent. Minerals usually occur as aggregates composed of many crystals, rather than as single crystals. The most diagnostic properties of the common minerals are listed in Table 2.4.

Economic Mineralogy

A group of about 25 minerals includes probably 99%, by volume, of those present in the earth's crust. These abundant minerals predominate in the common rocks. But more than 3,500 different minerals are known, and many of the less common ones are important sources of chemical elements needed in our industrial civilization (Table 2.5). Others are used for decorative purposes, such as gems in jewelry. Many cities have gem and mineral societies that organize meetings and exhibitions to display and trade semiprecious gemstones.

Environmental Aspects of Minerals

Some minerals can cause environmental problems because of their physical properties and chemical compositions—for example, calcite, halite and gypsum, pyrite, and clay minerals.

Calcite is the essential mineral in *limestone* and is also one of the more easily dissolved of the abundant minerals. Because limestones are such widely distributed rocks, dissolution of the ground surface and shallow subsurface is a common phenomenon in many areas. Rainwater seeps into cracks in the limestone and within a few hundred to a few thousand years can create large holes in the rock. When this occurs at shallow depths, perhaps a few tens of feet below the ground surface, it produces caverns such as Carlsbad Cavern in New Mexico. The ground above such a cavern can collapse into it, carrying with it buildings, automobiles, and even people. Numerous cases of ground collapse have

TABLE 2.3

Mineral Classification Chart

Metallic Luster	Other Characteristics	Mineral
Gray streak	Perfect cubic cleavage; H = 2.5; heavy, sp. gr. = 7.6; silver gray color	Galena PbS
Black streak	Magnetic; black to dark gray; H = 6; sp. gr. = 5.2; commonly occurs in granular masses; single crystals are octahedral	Magnetite Fe_3O_4
Gray to black streak	Steel gray; soft, smudges fingers and marks paper, greasy feel; H = 1; sp gr. = 2; luster may be dull	Graphite C
Greenish black streak	Golden yellow color; may tarnish purple; H = 4; sp gr. = 4.3	Chalopyrite $CuFeS_2$
Greenish black streak	Brass yellow; cubic crystals; common in granular aggregates; H = 6–6.5; sp. gr. = 5; uneven fracture	Pyrite FeS_2
Reddish brown streak	Steel gray, black to dark brown, red to red-brown streak; granular, fibrous, or micaceous; single crystals are thick plates; H = 5–6; sp. gr. = 5; uneven fracture	Hematite Fe_2O_3
Yellow-brown streak	Yellow, brown, or black; hard structureless or radial fibrous masses; H = 5–5.5; sp. gr. = 3.5–4	Limonite $FeOOH \cdot nH_2O$
Nonmetallic Luster—Dark Color		
Harder than glass; Cleavage prominent	Cleavage—2 directions nearly at 90°; dark green to black; short prismatic 8-sided crystals; H = 6; sp. gr. = 3.5	Pyroxene Group Complex Ca, Mg, Fe, Al silicates
Harder than glass; Cleavage prominent	Cleavage—2 directions at approximately 60° and 120°; dark green to black or brown; long, prismatic 6-sided crystals; H = 6; sp. gr. = 3.35	Amphibole Group Complex Na, Ca, Mg, Fe, Al silicates
Harder than glass; Cleavage prominent	White to gray; good cleavage in two directions at approximately 90°; striations on cleavage planes; H = 6; sp. gr. = 2.62–2.76	Plagioclase Feldspar $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$
Harder than glass; Cleavage absent	Various shades of green; sometimes yellowish; commonly occurs in aggregates of small glassy grains; transparent to transluscent; glassy luster; H = 6.5–7; sp. gr. = 3.5–4.5	Olivine $(Mg, Fe)_2SiO_4$
Harder than glass; Cleavage absent	Red, brown, or yellow; glassy luster; conchoidal fracture resembles poor cleavage; commonly occurs in well-formed 12-sided crystals; H = 7–7.5; sp. gr. = 3.5–4.5	Garnet Group Fe, Mg, Ca, Al silicates
Harder than glass; Cleavage absent	Conchoidal fracture; H = 7; gray to gray-black; vitreous luster; sp. gr. = 2.65	Quartz SiO_2