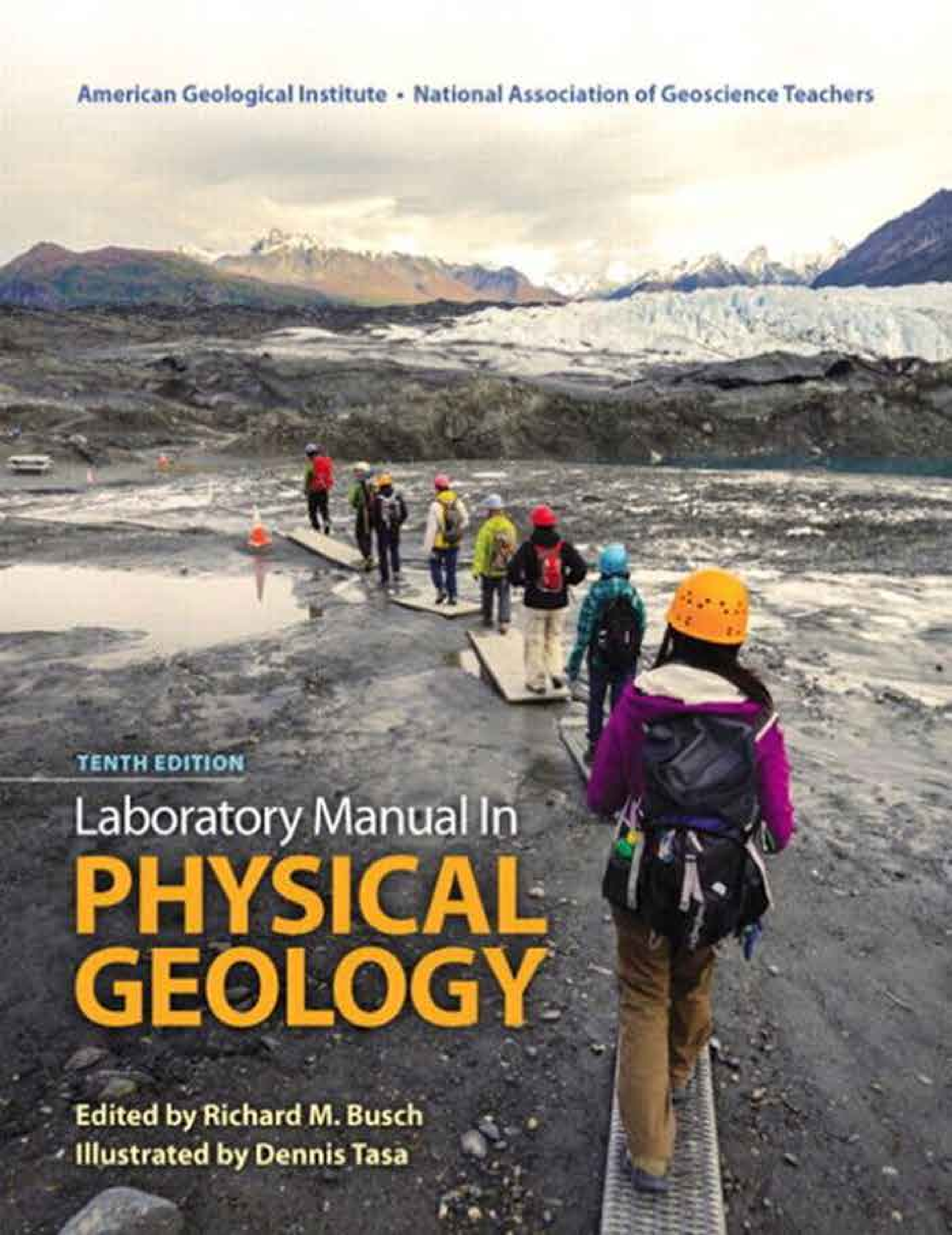

American Geological Institute • National Association of Geoscience Teachers

TENTH EDITION

Laboratory Manual In PHYSICAL GEOLOGY

Edited by Richard M. Busch
Illustrated by Dennis Tasa

TENTH EDITION

Laboratory Manual in PHYSICAL GEOLOGY

PRODUCED UNDER THE AUSPICES OF THE

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Tasa Graphic Arts, Inc.

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*The opinions contributed by this person do not officially represent opinions of the U.S. Environmental Protection Agency.

Contents

Preface

Laboratory Manual in Physical Geology is produced under the auspices of the American Geosciences Institute (AGI) and the National Association of Geoscience Teachers (NAGT). For decades it has been the most widely adopted manual available for teaching laboratories in introductory geology and geoscience. This new edition is more user-friendly than ever, with a new pedagogical format and many more teaching and learning options. It is now backed by MasteringGeology, the most effective and widely used online homework, tutorial, and assessment platform in the Geosciences, GeoTools (ruler, protractor, UTM grids, sediment grain size scale, etc.), an Instructor Resource Guide, and resources on the Instructor's Resource DVD.

The idea for this jointly sponsored laboratory manual was proffered by Robert W. Ridky (past president of NAGT and a member of the AGI Education Advisory Committee), who envisioned a manual made up of the "best laboratory investigations written by geology teachers." To that end, this product is the 28-year evolution of the cumulative ideas of more than 225 contributing authors, faculty peer reviewers, and students and faculty who have used past editions.

New to This Edition

In the tenth edition there are numerous new activities and figures, dynamic pedagogical changes, and practical revisions that have been made at the request of faculty and students who have used past editions. The new features in this edition are listed below:

Pre-Lab Videos

Pre-Lab videos are found on the chapter-opening spreads of each lab, and are accessed via QR code or direct web-link. These videos will ensure students come to lab better prepared and ready to immediately jump into the lab exercise. No longer do instructors have to spend the first portion of hands-on lab time lecturing. The videos will review key concepts relevant to the lab exercise during the students' own preparatory time. The videos, created by Callan Bentley, are personable and friendly, and assure students that they will be able to successfully complete the lab activities by following a clear series of steps.

New Format and Pedagogical Framework

- **Big Ideas and Engaging Chapter Openers.** Every laboratory opens with an engaging image and Big Ideas, which are the overall conceptual themes upon which the laboratory is based. Big Ideas are concise statements that help students understand and focus on how all parts of the laboratory are related.
- **Think About It—Key Questions.** Every activity is based on a key question that is linked to the Big Ideas and can be used for individualized or think-pair-share learning before or after the activity. Think About It questions function as the conceptual "lenses" that frame student inquiry and promote critical thinking and discourse. ***Schematic questions*** target the cognitive domain of psychology, are meant to help students assimilate to the topic (apply their existing schemata), and lay a constructivist conceptual foundation for scaffolding to new concepts and skills of the topic. ***Engaging questions*** target the affective domain of psychology, are open ended questions with more than one possible answer, and are meant to foster interest in the topic. When used in a brief think-pair-share or class brainstorming activity at the start of an activity, these questions often foster curiosity and cognitive disequilibrium that leads to ***authentic questions*** by students.
- **Guided and Structured Inquiry Activities.** Every laboratory begins with a guided inquiry activity. It is designed to be both engaging and schematic and could be used for individualized or cooperative learning. The guided inquiry activity is followed by activities that are more structured, as in past editions. All of the activities have objectives framed in relation to Bloom et al. levels of critical thinking.
- **Reflect and Discuss Questions.** Every activity concludes with a Reflect and Discuss question designed to foster greater accommodation of knowledge by having students apply what they learned to a new situation or to state broader conceptual understanding.
- **Manipulatives.** Manipulatives are integrated with most activities. They provide opportunities for assimilation and accommodation based on real objects or models, are designed to target the psychomotor domain of psychology, and can be used to foster curiosity and cognitive disequilibrium that leads to *authentic questions* by students.

- **Continuous Assessment Options.** The new pedagogical framework and organization provides many options for continuous assessment such as Think About It questions and guided inquiry activities that provide options for pre-assessment, activity worksheets, and the Reflect and Discuss questions. When students tear out and hand in an activity for grading, their manual will still contain the significant text and reference figures that they need for future study. Grading of students' work is easier because all students submit their own work in a similar format. Instructors save time, resources, and money because they no longer need to photocopy and hand out worksheets to supplement the manual.

New and Revised Activities and Text

- **20% More Activities.** Abundant new activities provide more options for students to learn content that was ranked "essential" or "most important" by faculty peer reviewers and past faculty and student users of the manual. There are now 98 activities that can be mixed or matched at the instructor's discretion accoding to course content and level of difficulty. And because many activities do not require sophisticated equipment, they can also be assigned for students to complete as pre-laboratory assignments, lecture supplements, or recitation topics.
- **Every Past Activity Has Been Revised.** Every past activity has been revised with new directives, questions, clarity, or format on the basis of user input. All activities now follow the new pedagogical framework and have at least one summative Reflect and Discuss question.
- **35% of Written Materials Are New or Rewritten.** These changes have been made on the basis of reviews by faculty and students, current trends in the geosciences, and the new pedagogical framework.

Revised Art Program and Enhanced Learning Options

- **Greater Visual Clarity and Appeal.** This edition contains almost twice as many photgraphs and images as the ninth edition. One-fourth of the figures are new, and one-fourth have been revised. Many maps have been revised or replaced. Dennis Tasa's brilliant artwork reinforces the visual aspect of geology and enhance student learning.
- **Transferable Skill Development and Real-World Connections.** Many activities have been newly designed or revised for students to develop transferrable skills and make real-world connections to their lives and the world in which they live. For example, they learn how to obtain and use data and maps that will enable them to make wiser choices about where they live and work. They evaluate their use of Earth resources in relation to questions about resource management and sustainability. They make real-world connections using U.G. Geological Survey, JPL-NASA, NOAA, Google Earth™, and other online sources for analysis and evaluation of Earth and its resources, hazards, changes, and management.
- **The Math You Need (TMYN) Options.** Throughout the laboratories, students are refered to online options for them to review or learn mathematical skills using *The Math You Need, When You Need it* (TMYN). TMYN consists of modular math tutorials that have been designed for students in any introductory geoscience course by Jennifer Wenner (University of Washington–Oshkosh) and Eric Baer (Highline Community College).
- **QR Codes.** Quick Response (QR) codes have been added to give students with smartphones or other mobile devices rapid access to supporting content and websites.
- **Enhanced Instructor Support.** Free instructor materials are available online in the Instructor Resource Center (IRC) at www.pearsonhighered.com/irc, and Instructor Resource DVD. Resources include the enhanced Instructor Resource Guide (answer key and teaching tips), files of all figures in the manual, PowerPoint™ presentations for each laboratory (including video clips), the Pearson Geoscience Animation Library (over 100 animations illuminating the most difficult-to-visualize geological concepts and phenomena in Flash files and PowerPoint™ slides), and Mastering Geology™ options.

NEW! MasteringGeology

The MasteringGeology™ platform delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand difficult concepts. Robust diagnostics and unrivalled gradebook reporting allow instructors to pinpoint the weaknesses and misconceptions of a student or class to provide timely intervention.

- **NEW! Pre-lab video quizzes** can be assigned. These will ensure students come to lab better prepared and ready to immediately jump into the lab exercise.
- **NEW! Post-lab quizzes** assess students' understanding and analysis of the lab content.

Learn More at www.MasteringGeology.com

Learning Catalytics

Learning Catalytics™ is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics you can

- assess students in real time, using open-ended tasks to probe student understanding.
- understand immediately where students are and adjust your lecture accordingly.
- improve your students' critical-thinking skills.
- access rich analytics to understand student performance.

- add your own questions to make Learning Catalytics fit your course exactly.
- manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with MasteringGeology. www learningcatalytics.com

Outstanding Features

This edition contains the tried-and-tested strengths of nine past editions of this lab manual published over nearly three decades. The outstanding features listed below remain a core part of this title.

Pedagogy for Diverse Styles/Preferences of Learning

Hands-on multisensory-oriented activities with samples, cardboard models, and GeoTools appeal to *concrete /kinesthetic learners*. High quality images, maps, charts, diagrams, PowerPoints^{TM}, cardboard models, and visualizations appeal to *visual/spatial learners*. Activity sheets, charts, lists, supporting text, and opportunities for discourse appeal to *linguistic/verbal/read-write learners*. PowerPoints^{TM} and video clips appeal to *auditory/aural learners*. Numerical data, mathematics, models, graphs, systems, and opportunities for discourse appeal to *logical/abstract learners.*

Terminology of the American Geosciences Institute (AGI)

All terms are consistent with AGI's latest *Glossary of Geology,* which was developed by the AGI federation of 48 geoscientific and professional associations. The glossary is available in print, online for a 30-day free trial period, or as an app for the iPhone, iPod, and iPad from the App Store. See http://www.agiweb.org/pubs/glossary.

Materials

Laboratories are based on samples and equipment normally housed in existing geoscience teaching laboratories (page xiii).

GeoTools, GPS, and UTM

There are rulers, protractors, a sediment grain size scale, UTM grids, and other laboratory tools to cut from transparent sheets at the back of the manual. No other manual provides such abundant supporting tools! Students are introduced to GPS and UTM and their application in mapping. UTM grids are provided for most scales of U.S. and Canadian maps.

Support for Geoscience!

Royalties from sales of this product support programs of the American Geosciences Institute and the National Association of Geoscience Teachers.

Acknowledgments

We acknowledge and sincerely appreciate the assistance of many people and organizations who have helped make possible this tenth edition of *Laboratory Manual in Physical Geology.* Revisions in this new edition are based on suggestions from faculty who used the last editon of the manual, feedback from students using the manual, and market research by Pearson. New activities were field tested in Introductory Geology laboratories at West Chester University.

Development and production of this highly-revised 10th edition of *Laboratory Manual in Physical Geology* required the expertise, dedication, and cooperation of many people. The very talented publishing team at Pearson Education led the effort. Andy Dunaway's knowledge of market trends, eternal quest to meet the needs of faculty and students, and dedication to excellence guided the vision for this extraordinary 10th edition. Jonathan Cheney's pre-revision memos and developmental editing framed the revision goals for each topic and ensured that all writing was practical and purposeful. Crissy Dudonis set revision schedules, tracked revision progress, and efficiently coordinated the needs and collaborative efforts of team members. Sarah Shefveland managed accuracy reviews of revision drafts. Connie Long managed the production process. Her expertise and dedication to excellence enabled her to locate, manage, and merge disparate elements of lab manual production. Page design and proofing was expertly managed by Jacki Russell, GEX Publishing Services. The team at GEX Publishing Services, lead by Alison Smith and Erin Hernandez, composited pages for publication. This process was especially difficult when it came to the activity worksheets, and we thank Alison and Erin for addressing every challenge and achieving our product goals.

We thank the following individuals for their constructive criticisms and suggestions that led to improvements for this edition of the manual:

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Maps, map data, aerial photographs, and satellite imagery have been used courtesy of the U.S. Geological Survey; Canadian Department of Energy, Mines, and Resources; Surveys and Resource Mapping Branch; U.S. Bureau of Land Management; JPL-NASA; NOAA; and the U.S./Japan ASTER Science Team.

We also thank Jennifer Wenner (University of Washington–Oshkosh) and Eric Baer (Highline Community College) for making possible the online options for students to review or learn mathematical skills using *The Math You Need, When You Need It* (TMYN) modules.

The continued success of this laboratory manual depends on criticisms, suggestions, and new contributions from persons who use it. We sincerely thank everyone who contributed to this project by voicing criticisms, suggesting changes, and conducting field tests.

Unsolicited reactions to the manual are especially welcomed as a barometer for quality control and the basis for many changes and new initiatives that keep the manual current. Please continue to submit your frank criticisms and input directly to the editor: Rich Busch, Department of Geology and Astronomy, Merion Hall, West Chester University, West Chester, PA 19383 (rbusch@wcupa.edu).

P. Patrick Leahy, *Executive Director, AGI*
Ann Benbow, *Director of Education,Outreach, and Development, AGI*
Richard M. Busch, *Editor*

Measurement Units

People in different parts of the world have historically used different systems of measurement. For example, people in the United States have historically used the English system of measurement based on units such as inches, feet, miles, acres, pounds, gallons, and degrees Fahrenheit. However, for more than a century, most other nations of the world have used the metric system of measurement. In 1975, the U.S. Congress recognized that global communication, science, technology, and commerce were aided by use of a common system of measurement, and they made the metric system the official measurement system of the United States. This conversion is not yet complete, so most Americans currently use both English and metric systems of measurement.

The International System (SI)

The International System of Units (SI) is a modern version of the metric system adopted by most nations of the world, including the United States. Each kind of metric unit can be divided or multiplied by 10 and its powers to form the smaller or larger units of the metric system. Therefore, the metric system is also known as a "base-10" or "decimal" system. The International System of Units (SI) is the official system of symbols, numbers, base-10 numerals, powers of 10, and prefixes in the modern metric system.

SYMBOL	NUMBER	NUMERAL	POWER OF 10	PREFIX
T	one trillion	1,000,000,000,000	10^{12}	tera-
G	one billion	1,000,000,000	10^{9}	giga-
M	one million	1,000,000	10^{6}	mega-
k	one thousand	1000	10^{3}	kilo-
h	one hundred	100	10^{2}	hecto-
da	ten	10	10^{1}	deka-
	one	1	10^{0}	
d	one-tenth	0.1	10^{-1}	deci-
c	one-hundredth	0.01	10^{-2}	centi-
m	one-thousandth	0.001	10^{-3}	milli-
μ	one-millionth	0.000001	10^{-6}	micro-
n	one-billionth	0.000000001	10^{-9}	nano-
p	one-trillionth	0.000000000001	10^{-12}	pico-

Examples

1 meter (1 m) = 0.001 kilometers (0.001 km), 10 decimeters (10 dm), 100 centimeters (100 cm), or 1000 millimeters (1000 mm)
1 kilometer (1 km) = 1000 meters (1000 m)
1 micrometer (1μm) = 0.000,001 meter (.000001 m) or 0.001 millimeters (0.001 mm)
1 kilogram (kg) = 1000 grams (1000 g)
1 gram (1 g) = 0.001 kilograms (0.001 kg)
1 metric ton (1 t) = 1000 kilograms (1000 kg)
1 liter (1 L) = 1000 milliliters (1000 mL)
1 milliliter (1 mL or 1 ml) = 0.001 liter (0.001 L)

Abbreviations for Measures of Time

A number of abbreviations are used in the geological literature to refer to time. Abbreviations for "years old" or "years ago" generally use SI prefixes and "a" (Latin for *year*). Abbreviations for intervals or durations of time generally combine SI symbols with "y" or "yr" (*years*). For example, the boundaries of the Paleozoic Erathem are 542 Ma and 251 Ma, so the Paleozoic Era lasted 291 m.y.

ka = kiloannum—thousand years old, ago, or before present
Ma = megannum—million years old, ago, or before present
Ga = gigannum—billion years old, ago, or before present
yr (or y) = year or years
Kyr or k.a. = thousand years
Myr or m.y. = million years
Gyr (or Byr or b.y) = gigayear—billion years

Mathematical Conversions

To convert:	To:	Multiply by:	
kilometers (km)	meters (m)	1000 m/km	LENGTHS AND DISTANCES
	centimeters (cm)	100,000 cm/km	
	miles (mi)	0.6214 mi/km	
	feet (ft)	3280.83 ft/km	
meters (m)	centimeters (cm)	100 cm/m	
	millimeters (mm)	1000 mm/m	
	feet (ft)	3.2808 ft/m	
	yards (yd)	1.0936 yd/m	
	inches (in.)	39.37 in./m	
	kilometers (km)	0.001 km/m	
	miles (mi)	0.0006214 mi/m	
centimeters (cm)	meters (m)	0.01 m/cm	
	millimeters (mm)	10 mm/cm	
	feet (ft)	0.0328 ft/cm	
	inches (in.)	0.3937 in./cm	
	micrometers (μm)*	10,000 μm/cm	
millimeters (mm)	meters (m)	0.001 m/mm	
	centimeters (cm)	0.1 cm/mm	
	inches (in.)	0.03937 in./mm	
	micrometers (μm)*	1000 μm/mm	
	nanometers (nm)	1,000,000 nm/mm	
micrometers (μm)*	millimeters (mm)	0.001 mm/μm	
nanometers (nm)	millimeters (mm)	0.000001 mm/nm	
miles (mi)	kilometers (km)	1.609 km/mi	
	feet (ft)	5280 ft/mi	
	meters (m)	1609.34 m/mi	
feet (ft)	centimeters (cm)	30.48 cm/ft	
	meters (m)	0.3048 m/ft	
	inches (in.)	12 in./ft	
	miles (mi)	0.000189 mi/ft	
inches (in.)	centimeters (cm)	2.54 cm/in.	
	millimeters (mm)	25.4 mm/in.	
	micrometers (μm)*	25,400 μm/in.	
square miles (mi2)	acres (a)	640 acres/mi^2	AREAS
	square km (km^2)	2.589988 km^2/m	
square km (km2)	square miles (mi^2)	0.3861 mi^2/km^2	
acres	square miles (mi^2)	0.001563 mi^2/acr	
	square km (km^2)	0.00405 km^2/acr	
gallons (gal)	liters (L)	3.78 L/gal	VOLUMES
fluid ounces (oz)	milliliters (mL)	30 mL/fluid oz	
milliliters (mL)	liters (L)	0.001 L/mL	
	cubic centimeters (cm^3)	1.000 cm^3/mL	
liters (L)	milliliters (mL)	1000 mL/L	
	cubic centimeters (cm^3)	1000 cm^3/mL	
	gallons (gal)	0.2646 gal/L	
	quarts (qt)	1.0582 qt/L	
	pints (pt)	2.1164 pt/L	
grams (g)	kilograms (kg)	0.001 kg/g	WEIGHTS AND MASSES
	pounds avdp. (lb)	0.002205 lb/g	
ounces avdp (oz)	grams (g)	28.35 g/oz	
ounces troy (ozt)	grams (g)	31.10 g/ozt	
pounds avdp. (lb)	kilograms (kg)	0.4536 kg/lb	
kilograms (kg)	pounds avdp. (lb)	2.2046 lb/kg	

To convert from degrees Fahrenheit (°F) to degrees Celsius (°C), subtract 32 degrees and then divide by 1.8 To convert from degrees Celsius (°C) to degrees Fahrenheit (°F), multiply by 1.8 and then add 32 degrees.

*Formerly called microns (μ)

LABORATORY EQUIPMENT

Also refer to the GeoTools provided at the back of this laboratory manual.


NORTH AMERICA
Political & Physical Map
Metropolitan areas more than 20 million
Metropolitan areas 10–20 million
Metropolitan areas 5–9.9 million
Metropolitan areas 1–4.9 million
Selected smaller metropolitan areas
Plate boundaries
ELEVATION IN METERS
4000+
2000–4000
500–1,999
200–499
0–199
Below sea level
Sea Level
0 300 Miles
0 300 Kilometers
Anchorage
Bering Sea
Aleutian Islands
0 250 500 Miles
0 250 500 Kilometers
PACIFIC OCEAN
Kauai
Oahu
Honolulu
Maui
HAWAII
Hawaii
0 100 Miles
0 100 Kilometers
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
Gulf of Alaska
Hudson Bay
Baffin Bay
Bering Strait
Prudhoe Bay
Brooks Range
Alaska Range
Anchorage
NORTH AMERICAN PLATE
PACIFIC PLATE
JUAN DE FUCA PLATE
EURASIAN PLATE
Greenland
Baffin Island
YUKON TERRITORY
Whitehorse
NORTHWEST TERRITORIES
NUNAVUT
Great Slave Lake
Mackenzie R.
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUÉBEC
NEWFOUNDLAND AND LABRADOR
Newfoundland
Prince Edward Island
P.E.I.
NEW BRUNSWICK
NOVA SCOTIA
C A N A D A
Coast Mountains
Vancouver Island
Vancouver
Edmonton
Calgary
Saskatoon
Regina
Winnipeg
Lake Winnipeg
Quebec City
Saint John
Halifax
Montréal
Ottawa
St. Lawrence R.
Toronto
Hamilton
ROCKY MOUNTAINS
GREAT PLAINS
UNITED STATES
Puget Sound
Columbia R.
Seattle
Portland
Cascade Range
Coast Ranges
Boise
Teton Range
Great Basin
Great Salt Lake
Salt Lake City
Sierra Nevada
Central Valley
Sacramento
San Francisco
San Jose
Las Vegas
Colorado R.
Grand Canyon
Colorado Plateau
Los Angeles
Riverside
San Diego
Salton Sea
Phoenix
Tucson
Albuquerque
El Paso
Denver
Missouri R.
Platte R.
Arkansas R.
Red R.
Rio Grande
Minneapolis-St. Paul
L. Superior
L. Michigan
L. Huron
L. Ontario
L. Erie
Milwaukee
Chicago
Detroit
Buffalo
Cleveland
Pittsburgh
Columbus
Indianapolis
Cincinnati
Ohio R.
Louisville
St. Louis
Kansas City
Ozark Mtns.
Ouachita Plateau
Oklahoma City
Dallas-Fort Worth
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San Antonio
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Florida Keys
MEXICO
Arctic Circle

LABORATORY 1

Thinking Like a Geologist

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Global Positioning System (GPS) devices, like this one on Mount St. Helens, are used to detect changes in the elevation of the volcano as magma moves beneath it. A rise in elevation of the volcano often precedes an eruption.

PRE-LAB VIDEO

BIG IDEAS

Geology is the science of Earth, so geologists are Earth scientists or "geoscientists." Geologists observe, describe, and model the materials, energies, and processes of change that occur within and among Earth's spheres over time. They apply their knowledge to understand the present state of Earth, locate and manage resources, identify and mitigate hazards, predict change, and seek ways to sustain the human population.

FOCUS YOUR INQUIRY

THINK About It How and why do geologists observe Earth materials at different scales (orders of magnitude)?

THINK About It What materials, energies, and processes of change do geologists study?

THINK About It How and why do geologists make models of Earth?

THINK About It How and why do geologists measure Earth materials and graph relationships among Earth materials and processes of change?

THINK About It How is the distribution of Earth materials related to their density?

Introduction

Regardless of your educational background or interests, you probably have already done some thinking like a geologist. This lab will help you think and act even more like a geologist.

What Does It Mean to Start Thinking Like a Geologist?

You start thinking like a geologist when you focus on questions about planet Earth and try to answer them. You were thinking like a geologist if you ever observed an interesting landform, rock, or fossil, and wondered about how it formed. You were also thinking like a geologist if you ever wondered where your drinking water comes from, the possibility of earthquakes or floods where you live, where to find gold, how to vote on environmental issues, or what environmental risks may be associated with buying or building a home.

Wondering or inquiring about such things leads one to fundamental questions about Earth and how it operates. **Science** is a way of answering these questions by *gathering data* (information, evidence) based on investigations and careful observations, *thinking critically* (applying, analyzing, interpreting, and evaluating the data), *engaging in discourse* (verbal or written exchange, organization, and evaluation of information and ideas), and *communicating inferences* (conclusions justified with data and an explanation of one's critical thinking process). **Geology** is the science of Earth. Its name comes from two Greek words, *geo* = Earth and *logos* = discourse. So geologists are also Earth scientists or geoscientists.

Why Think Like a Geologist?

The products of geologic science are all around you—in the places where you live, the products you enjoy, the energy you use, and the government's environmental codes and safety policies that you must follow. For example, your home contains bricks, concrete, plaster wall boards (sheetrock), glass, metals, and asphalt roof shingles made with raw materials that were located by geologists. The safe location of your home was likely determined with the help of geologists. The wooden materials and foods in your home were processed with tools and machines containing metals that were extracted from ore minerals found by geologists. The electricity you use comes from generating plants that are fueled with coal, gas, oil, or uranium that was found by geologists. The safe location of the generating plants was evaluated by geologists, and the electricity is transported via copper wires made from copper ore minerals located by geologists. Even your trash and sewage are processed and recycled or disposed of in accordance with government policies developed with geologists and related to surface and groundwater. So geologists are Earth detectives who try to locate and manage resources, identify and mitigate hazards, predict change, and help communities plan for the future. These things lay the foundation upon which all industrial societies are based. Yet the growing societies of the world are now testing the ability of geoscientists to provide enough materials, energy, and wisdom to sustain people's wants and needs. Now, more than ever, geologists are addressing fundamental questions about natural resources, the environment, and public policies in ways that strive to ensure the ability of Earth to sustain the human population.

How to Start Thinking and Acting Like a Geologist. As you complete exercises in this laboratory manual, think and act like a geologist or Earth detective. **Focus on questions** about things like Earth materials and history, natural resources, processes and rates of environmental change, where and how people live in relation to the environment, and how geology contributes to sustaining the human population. **Conduct investigations and use your senses and tools to make observations** (determine and characterize the qualities and quantities of materials, energies, and changes). As you make observations, **record data** (factual information or evidence used as a basis for reasoning). **Engage in critical thinking**—apply, analyze, interpret, and evaluate the evidence to form tentative ideas or conclusions. **Engage in discourse** or collaborative inquiry with others (exchange, organization, evaluation, and debate of data and ideas). **Communicate inferences**—write down or otherwise share your conclusions and justify them with your data and critical thinking process.

These components of doing geology are often not a linear "scientific method" to be followed in steps. You may find yourself doing them all simultaneously or in odd order. For example, when you observe an object or event, you may form an initial interpretation of it or a hypothesis (tentative conclusion) about it. However, a good geologist (scientist) would also question these tentative conclusions and investigate further to see if they are valid or not. Your tentative ideas and conclusions may change as you make new observations, locate new information, or apply a different method of thinking.

How to Record Your Work. When making observations, you should observe and record **qualitative data** by describing how things look, feel, smell, sound, taste, or behave. You should also collect and record **quantitative data** by counting, measuring or otherwise expressing in numbers what you observe. Carefully and precisely record your data in a way that others could use it.

Your instructor will not accept simple yes or no answers to questions. He or she will expect your answers to be complete inferences justified with data and an explanation of your critical thinking (in your own words). Show your work whenever you use mathematics to solve a problem so your method of thinking is obvious.

ACTIVITY 1.1 Geologic Inquiry

THINK About It **How and why do geologists observe Earth materials at different scales (orders of magnitude)?**

OBJECTIVE Analyze and describe Earth materials at different scales of observation, then infer how they are related to you and thinking about geology.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Just focus on **FIGURE 1.1**. Use your current knowledge to start thinking like a geologist, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   ____ Activity 1.1 Worksheets (pp. 25–26) and pencil with eraser
2. **Answer every question on the worksheets in a way that makes sense to you** and be prepared to compare your ideas with others.
3. **After you complete the worksheets**, read below about scales of observation and direct and remote observation of geology. Be prepared to discuss your observations and inferences with others.

Scales of Earth Observation

The most widely known geologic feature in the United States is undoubtedly the Grand Canyon. This canyon cuts a mile deep, through millions of rock layers that are like pages of an immense stone book of geologic history called the **geologic record.** The layers vary in thickness from millimeters to meters. Each one has distinguishing features—some as tiny as microscopic fossils or grains of sand and some as large as fossil trees, dinosaur skeletons, or ancient stream channels. Yet when one measures and describes the layers, it can be done at the scale of a single page or at the scale of many pages, much the same as one might describe a single tree or the entire forest in which the tree is found. Each successive layer also represents a specific event (formation of the layer), which occurred at a specific time in Earth's long geologic history. Therefore, geologists are concerned with scales of observation and measurement in both space and time.

Spatial Scales of Observation and Measurement

Geologists study all of Earth's materials, from the spatial scale of atoms (atomic scale) to the scale of our entire planet (global scale). At each spatial scale of observation, they identify materials and characterize relationships. Each scale is also related to the others. You should familiarize yourself with these **spatial scales of observation** as they are summarized in **FIGURE 1.2** and the tables of quantitative units of measurement, symbols, abbreviations, and conversions on pages xi and xii at the front of this manual. Terms such as regional, local, hand sample, and microscopic are hierarchical *levels of scale*, not measurements. When making measurements, geologists use these kinds of scales:

- **Bar scale**—A bar scale is a small ruler printed on an image or map. You use it to measure distances on the image or map. For example, all of the images in **FIGURE 1.1** are accompanied by bar scales so you can make exact measurements of features within them. If a bar scale is given in one unit of measurement, like miles, and you want to know distances in kilometers, then you must convert the measurement using the table on page xii at the front of the manual.
- **Magnification scale**—This scale tells you how many times larger or smaller an object is in a picture compared to its actual size in real life. Magnification scale can be expressed as a percentage or a multiplication factor. For example, if you take a picture of a rock and enlarge it to twice its actual (normal) size, then you should note a scale of 200%, 2x, or x2 on the picture. If you reduce the picture of the rock so it appears only half of its actual size, then you should note a scale of 50%, 0.5x, or x1/2 on the picture. It does not matter which units of measurement you magnify (multiply). For example, if you measure a distance of 6 millimeters on the image that has a scale of 200% or x2, then the distance is actually 12 millimeters in real life.
- **Fractional scale**—A fractional scale is used to indicate how much smaller something is than its actual size. It is like the magnification scale, but expressed as a fraction. Therefore, if a picture shows a rock at only half of its actual size, then you can use a fractional scale of *½ scale* to indicate it. It does not matter which units of measure you use, the actual size would still be half of what you measure in any units.
- **Ratio scale**—A ratio scale is commonly used when making models. The scale represents the proportional ratio of a linear dimension of the model to the same feature in real life. If a toy car is 20 centimeters long and the actual car was 800 centimeters long, then the ratio scale of model to actual car is 20:800, which reduces to 1:40. (Note: this is the same as a fractional scale of 1/40.) Ratio scales are commonly provided on maps, as well as three-dimensional models.

A. ASTER satellite images of Escondida open-pit copper mines region, Chile

ASTER Bands 1, 2, 3: true color and near infrared

ASTER Bands 4, 6, 8: false colored red, green, blue

B. Ground view of Escondida open-pit mine

Search these coordinates in Google Earth™: 24 16 12S, 69 04 16W

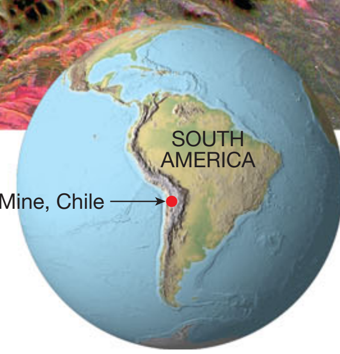


FIGURE 1.1 Earth materials to explore. ASTER images courtesy of NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team: **asterweb.jpl.nasa.gov.**; Escondida copper mine photograph courtesy of Rio Tinto: **www.riotinto.com**

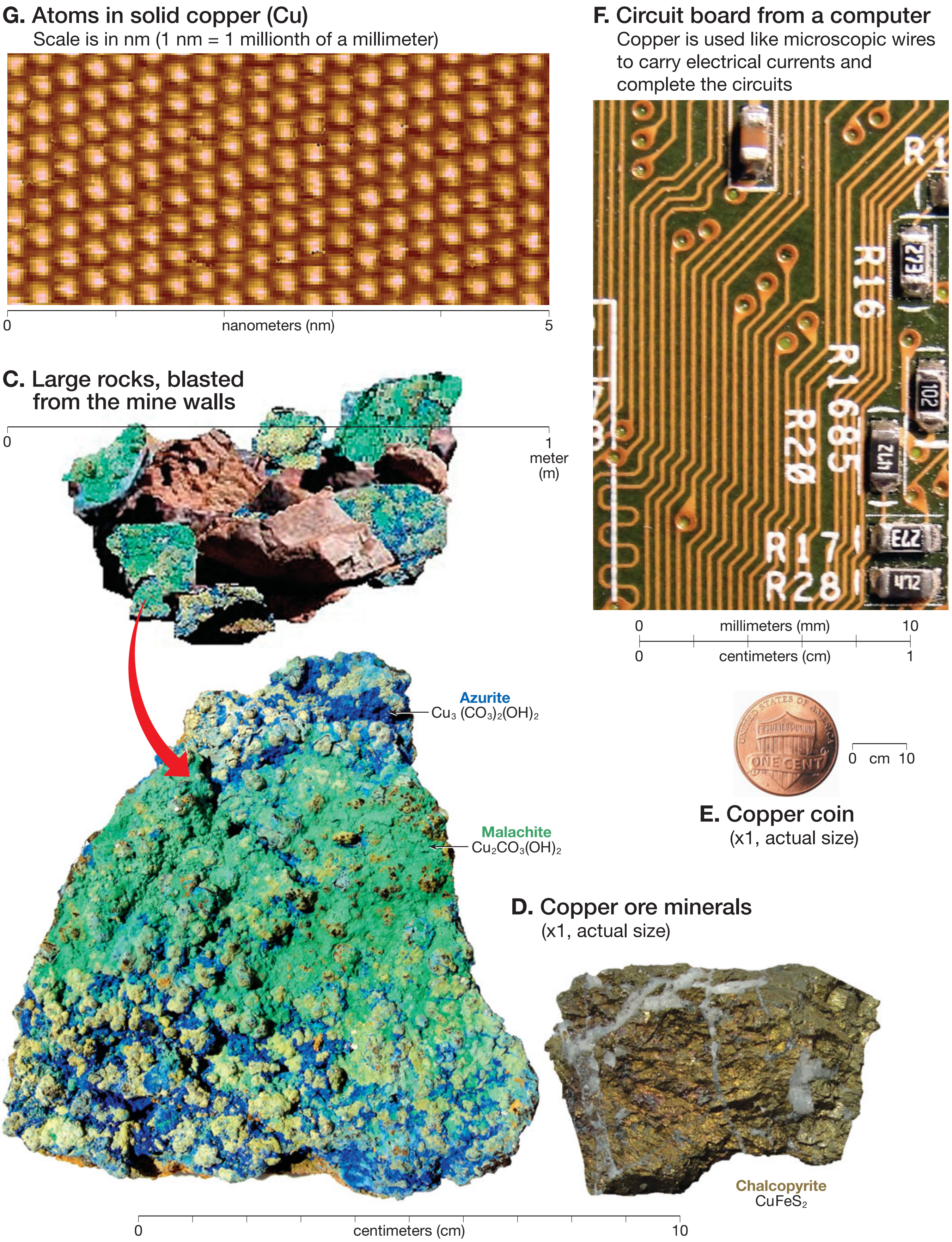


FIGURE 1.1 (continued)

SPATIAL SCALES OF OBSERVATION USED BY GEOLOGISTS			
Scale of observation		Used to study things like…	Measured in…
Global	Macroscopic: visible with the naked eye	Entire planet and its interactive "spheres"	Thousands of kilometers (km) or miles (mi)
Regional	Macroscopic: visible with the naked eye	Portions of oceans, continents, countries, provinces, states, islands	Kilometers (km), miles (mi)
Local (outcrop or field site)	Macroscopic: visible with the naked eye	Specific locations that can be "pin-pointed" on a map	Meters (m), feet (ft)
Hand sample (field/lab. sample)	Macroscopic: visible with the naked eye	Sample of a mineral, a rock, air, water, or an organism that can be held in your hand	Centimeters (cm), millimeters (mm), inches (in.) 0 1 cm / 0 10 mm
Microscopic		Features of a hand sample that can only be seen with a hand lens (magnifier) or microscope	Fractions of millimeters (mm), micrometers (μm)
Atomic (or molecular)		Arrangements of the atoms or molecules in a substance	Nanometers (nm), angstroms (Å)

FIGURE 1.2 Spatial scales. Geologists use different scales of observation in their work.

Time Scales of Observation and Measurement

Geologists also think about **temporal scales of observation.** As geologic detectives, they analyze rock layers as stone pages of the geologic record for evidence of events and relationships. As geologic historians, they group the events and relationships into paragraphs, chapters, sections, and parts of geologic history that occurred over epochs, periods, eras, and eons of time. The index to this book of geologic history is called the **geologic time scale** (FIGURE 1.3). Notice that the geologic time scale is a chart showing named intervals of the geologic record (rock units), the sequence in which they formed (oldest at the bottom), and their ages in millions of years. The intervals have been named and dated on the basis of more than a century of cooperative work among scientists of different nations, races, religions, genders, classes, and ethnic groups from throughout the world. What all of these scientists have had in common is the ability to do science and an intense desire to decipher Earth's long and complex history based on evidence contained in the rock layers that are the natural record of geologic history.

Direct and Remote Investigation of Geology

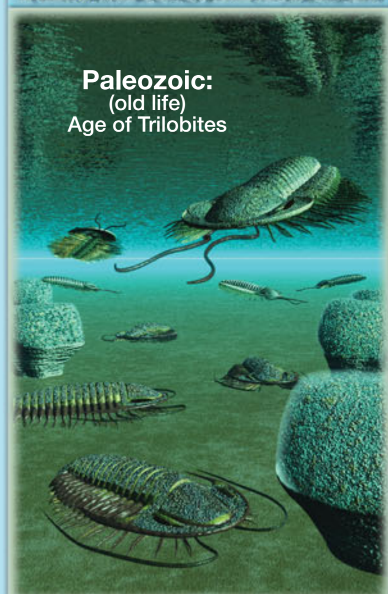
The most reliable information about Earth is obtained by direct observation, investigation, and measurement in the field (out of doors, in natural context) and laboratory. Most geologists study *outcrops*—field sites where rocks *crop out* (stick out of the ground). The outcrops are made of rocks, and rocks are made of minerals.

Samples obtained in the field (from outcrops at field sites) are often removed to the laboratory for further analysis using basic science. Careful observation (use of your senses, tactile abilities, and tools to gather information) and critical thought lead to questions and hypotheses (tentative ideas to test). Investigations are then designed and carried out to test the hypotheses and gather data (information, evidence). Results of the investigations are analyzed to answer questions and justify logical conclusions.

Refer to the example of field and laboratory analysis in FIGURE 1.4. Observation 1 (in the field) reveals that Earth's rocky geosphere crops out at the surface of the land. Observation 2 reveals that outcrops are made of rocks. Observation 3 reveals that rocks are made of mineral crystals such as the mineral *chalcopyrite*. This line of reasoning leads to the next **logical question:** *What is chalcopyrite composed of?* Let us consider the two most

THE GEOLOGIC TIME SCALE

A chart showing the sequence, names, and ages of Earth's rock layers (oldest at the bottom)

Eon of time Eonothem of rock	Era of time Erathem of rock	Period of time System of rock**	Epoch of time Series of rock	Millions of years ago (Ma)	Some notable fossils in named rock layers
Phanerozoic	 Cenozoic: (new life) Age of Mammals	Quaternary (Q)	Holocene	.0117	First *Homo* fossils, 70–100% extant mollusks+
			Pleistocene	2.6	
		Tertiary: Neogene (N)	Pliocene	5.3	First humans (Hominidae), 15–70% extant mollusks+
			Miocene	23	
		Tertiary: Paleogene (P_G)	Oligocene	34	More mammals than reptiles, <15% extant mollusks+
			Eocene	56	
			Paleocene	66	
	 Mesozoic: (middle life) Age of Reptiles	Cretaceous (K)		145	Last dinosaur fossils: including *Tyrannosaurus rex*
		Jurassic (J)		201	First bird fossil: *Archaeopteryx*
		Triassic (TR)		252	First dinosaur, mammal, turtle, and crocodile fossils
	 Paleozoic: (old life) Age of Trilobites	Permian (P)		299	Last (youngest) trilobite fossils
		Carboniferous (C)*: Pennsylvanian (ℙ)		323	First reptile fossils
		Carboniferous (C)*: Mississippian (M)		359	First fossil conifer trees
		Devonian (D)		419	First amphibian, insect, tree, and shark fossils
		Silurian (S)		443	First true land plant fossils
		Ordovician (O)		485	First fossils of coral and fish
		Cambrian (Ꞓ)		541	First trilobite fossils First abundant visible fossils
Proterozoic	Precambrian: An informal name for all of this time and rock.			2500	Oldest fossils: mostly microscopic life, visible fossils rare
Archean		Oldest fossils of visible life (stromatolites)		3500	
				4000	
Hadean		Acasta Gneiss, northwestern Canada		4030	
		Nuvvuagittuq greenstone belt, Quebec, Canada		4280	
		Zircon mineral crystals in the Jack Hills Metaconglomerate, Western Australia		4400	
	Oldest meteorites			4550	

*European name
**Symbols in parentheses are abbreviations commonly used to designate the age of rock units on geologic maps.
+Extant mollusks are mollusks (clams, snails, squid, etc.) found as fossils and still living today.

FIGURE 1.3 The geologic time scale. Absolute ages in millions of years ago (Ma) follow the International Commission on Stratigraphy, 2013. See their website for more detailed versions and recent updates of the international geological time scale (**http://www.stratigraphy.org/index.php/ics-chart-timescale**).

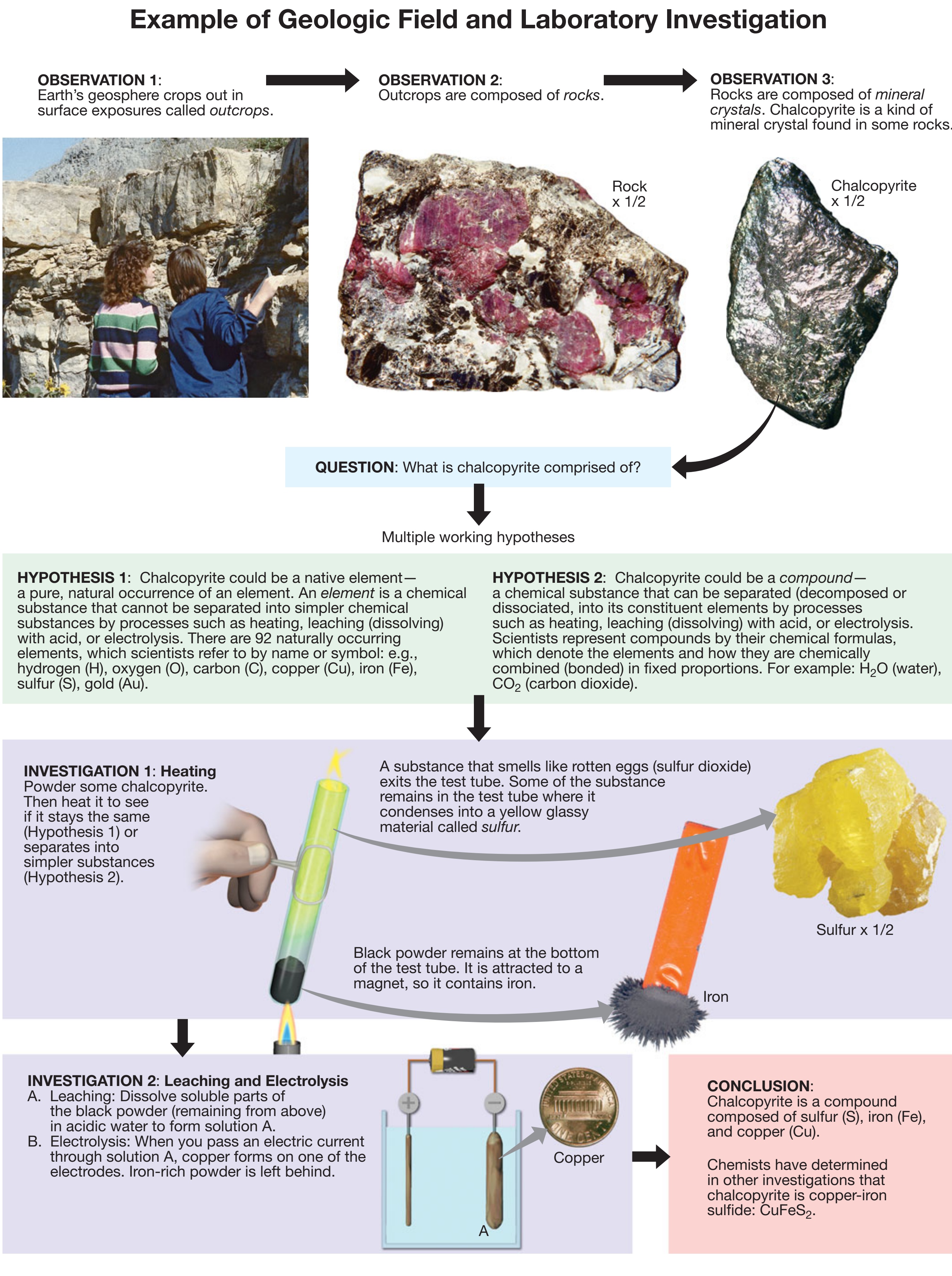


FIGURE 1.4 Example of geologic field and laboratory investigation.

logical possibilities, or **working hypotheses** (tentative ideas to investigate, test). It is always best to have more than one working hypothesis.

1. Chalcopyrite may be a pure substance, or chemical *element*. What investigating and gathering of evidence could we do to reasonably determine if this is true or false?
2. Chalcopyrite may be a *compound* composed of two or more elements. What investigating and gathering of evidence could we do to reasonably determine if this is true or false? If true, then how could we find out which elements make up chalcopyrite?

Let us conduct two **investigations** (activities planned and conducted to test hypotheses, gather and record data, make measurements, or control and explore variables). In Investigation 1, the chalcopyrite is ground to a powder and heated. This investigation reveals the presence of sulfur and at least one other substance. The remaining substance is attracted to a magnet, so it may be iron or a compound containing iron. When the powder is leached (dissolved in acidic water) and subjected to electrolysis (Investigation 2), copper separates from the powder. The remaining powder is attracted to a magnet, indicating the presence of iron. **Analysis of the results** of these two investigations leads us to the **logical conclusion** that Hypothesis 2 was correct (chalcopyrite is a compound). The results are also evidence that chalcopyrite is composed of three different elements: sulfur (S), iron (Fe), and copper (Cu). Chemists call chalcopyrite copper-iron sulfide ($CuFeS_2$). Since chalcopyrite contains a significant proportion of copper, it is also a *copper ore* (natural material from which copper can be extracted at a reasonable profit).

This same laboratory procedure is applied on a massive scale at copper mines. Because most copper-bearing rock contains only a small percentage of chalcopyrite or another copper-bearing mineral, the rock is mined, crushed, and powdered. It is then mixed with water, detergents, and air bubbles that float the chalcopyrite grains to the surface of the water. When these grains are removed, they are smelted (roasted and then melted) to separate impure copper from the other parts of the melted chalcopyrite (that cool to form *slag*). The impure copper is then leached in sulfuric acid and subjected to electrolysis, whereupon the copper is deposited as a mass of pure copper on the positive electrode (cathode).

Satellite Remote Sensing of Geology

There are times when geologists cannot make direct observations of Earth and must rely on a technology to acquire and record information remotely (from a distance, without direct contact). This is called *remote sensing*. One of the most common kinds of remote sensing used by geologists is satellite remote sensing.

Electromagnetic (EM) Radiation. The electromagnetic (EM) spectrum of radiation is a spectrum of electric and magnetic waves that travel at the speed of light (300,000,000 meters/second, or 3×10^8 m/s). The spectrum is subdivided into **bands**—parts of the EM spectrum that are defined and named according to their wavelength (distance between two adjacent wave crests or troughs).

Instruments aboard satellites scan information from not only the visible bands of the electromagnetic spectrum, but also parts of the spectrum that are not visible to humans (e.g., infrared).The ASTER instrument scans 14 bands of electromagnetic radiation. Bands 1, 2, and 3 are visible (blue-green, red) bands (left side, **FIGURE 1.1**). Bands 4–9 are short wave infrared bands (SWIR) that are invisible to humans (right side, **FIGURE 1.1**). Bands 10–14 are thermal infrared (TIR) bands that are also invisible to humans.

True Color and False Color Images. Data from environmental satellite instruments must be rendered into an image that humans can see, either by giving objects in the image their true color or a false color. **True color** photographs and satellite images show objects in the colors that they would appear to be if viewed by the human eye However, since many bands of radiation detected by satellites are not visible to humans, the bands are given a **false color** in satellite images (right side of **FIGURE 1.1**).

ACTIVITY 1.2 Spheres of Matter, Energy, and Change

THINK About It What materials, energies, and processes of change do geologists study?

OBJECTIVE Analyze and describe the materials, energies, and processes of change within and among Earth's spheres.

PROCEDURES

1. **Before you begin**, read the following background information on matter and spheres, energy sources and sinks, and processes and cycles of change. This is **what you will need:**

   ___ Activity 1.2 Worksheets (pp. 27–29) and pencil with eraser

2. Then, **follow your instructor's directions** for completing the worksheets.

Matter and Spheres

Everything on Earth is made of matter and energy. Matter is anything that takes up space and has a mass that can be weighed. It is tangible materials and substances. At the global scale of observation, geologists conceptualize Earth as a dynamic planetary system composed of interacting *spheres* (subsystems) of living and nonliving materials.