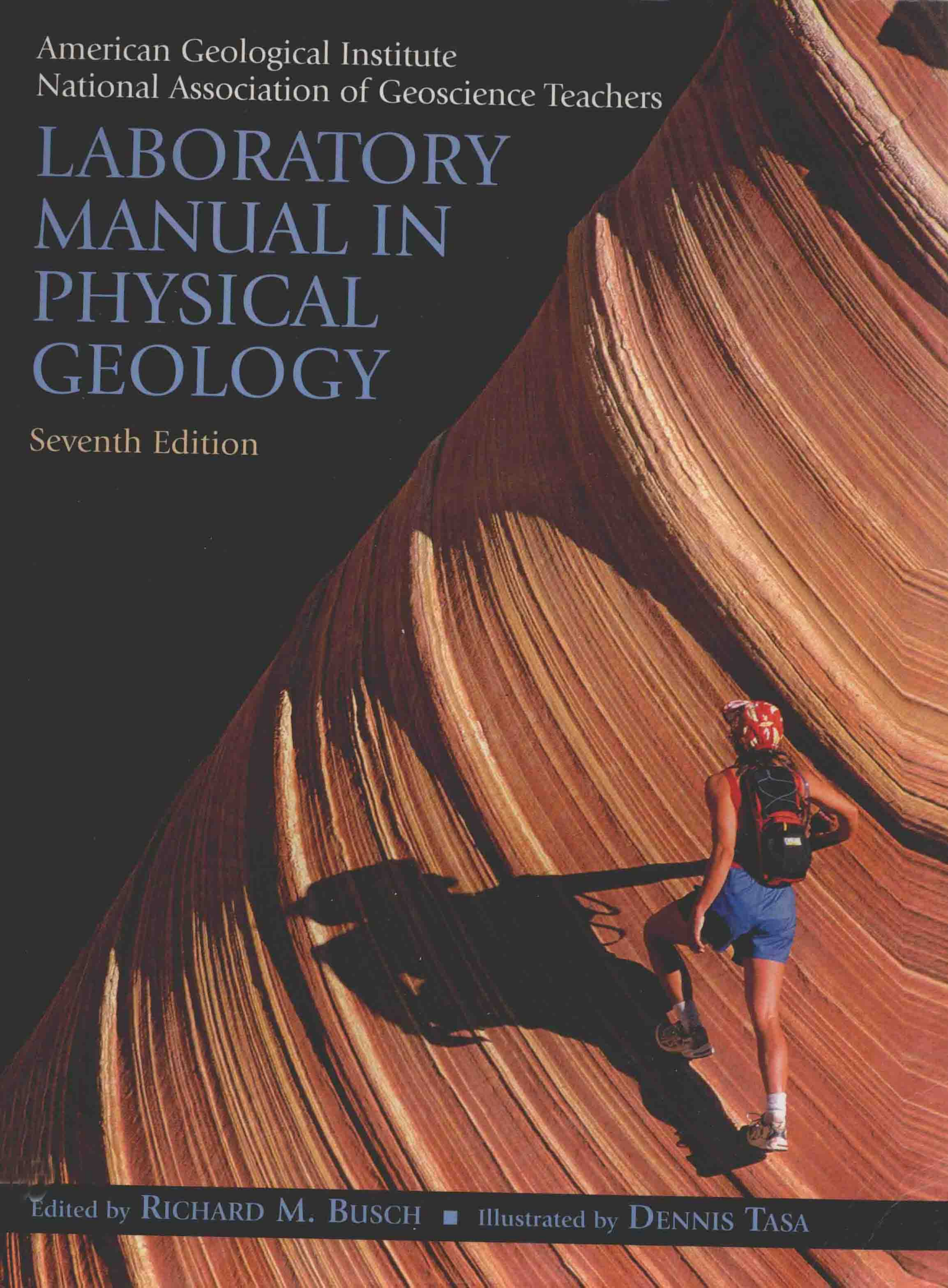
American Geological Institute
National Association of Geoscience Teachers

LABORATORY MANUAL IN PHYSICAL GEOLOGY

Seventh Edition



Edited by RICHARD M. BUSCH ■ Illustrated by DENNIS TASA

SEVENTH EDITION

LABORATORY MANUAL IN PHYSICAL GEOLOGY

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

PREFACE

Laboratory Manual in Physical Geology is the most widely adopted, user-friendly manual available for teaching laboratories in introductory geology and geoscience. The manual has been produced under the auspices of the American Geological Institute (AGI) and the National Association of Geoscience Teachers (NAGT). It is backed up by an Internet site, GeoTools (ruler, protractor, UTM grids, sediment grain size scale, etc.), Instructor Resource Guide, Instructor Transparency Set, and an Instructor Resource Center (IRC) on CD-ROM.

The idea for such a 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 20-year evolution of the cumulative ideas of more than 170 contributing authors, faculty peer reviewers, and students and faculty who have used past editions. Undergraduate students have field tested all parts of this seventh edition and helped make it the most student-friendly edition ever.

OUTSTANDING FEATURES

This edition contains the strengths of six past editions published over twenty years and new features developed at the request of peer reviewers and faculty and students who have used previous editions. The most outstanding features of this new edition are as follows.

16 Basic Laboratories

There are 16 laboratories on topics ranked most important by faculty peer reviewers. Each lab has 3–6 parts that can be mixed or matched at the instructor's discretion.

Consistent Focus, Pedagogy, and AGI Terminology

Each laboratory engages students in learning principles of geology and their applications to everyday life in terms of natural resources, natural hazards, and human risks. Students develop skills and infer results by analysis of maps/samples/photos, measuring, experimenting, making models, classifying, charting, graphing, and calculating. Terms are consistent with AGI's *Glossary of Geology.*

Materials

Laboratories are based on samples and equipment normally housed in existing geoscience teaching laboratories (page ix). No expensive items to buy. In addition, a new partnership with WARD'S Natural Science, the premier provider of rock and mineral samples, has resulted in the creation of both instructional and student rock and mineral sets designed to support users of this manual. (For more information, see page xiv.)

New Introduction to Satellite Remote Sensing

A concise, engaging section has been added on principles and applications of satellite remote sensing to study Earth. Students analyze and apply MODIS, Landsat, and ASTER satellite images to prospect for copper ore, evaluate volcanic activity, and predict changes in Africa's Lake Chad.

Greater Emphasis on the Process of Geologic Inquiry

Students visualize Earth materials and processes of change using satellite imagery and infer how the geologic record is similar in some ways, yet different in others, from a book of Earth history to be "read." They explore ways that geology is a logical, testable process of scientific inquiry, "ground truthed" with data obtained by direct observation, investigation, and measurement in the field and laboratory.

Greater Visual Clarity and Appeal

The manual is more richly illustrated than any other manual on the market. Nearly 300 high-quality photographs, images, stereograms, maps, and charts reinforce the visual aspect of geology and enhance student learning. About one third of these are revised or newly created for this edition on the basis of peer reviews and student feedback.

Hands-On Experimental Labs

Laboratory One engages students in geologic inquiry using satellite imagery, Earth materials, and standard laboratory equipment and techniques to measure materials, experiment with simple models, calculate numerical relationships, and evaluate how rock densities and isostasy influence global topography. Laboratory Two challenges students to explore and evaluate plate tectonics, mantle convection, and the origin of magma using seismic tomography, lava lamps, physical and graphical models of partial melting, maps, and calculations.

Personal GeoTools
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.

Emphasis on GPS and UTM
Students are introduced to these topics and their application in mapping and geology. UTM grids are provided for most scales of U.S. and Canadian maps.

Enhanced Instructor Support
Free instructor materials include a transparency set of all figures in the manual plus an Instructor Resource Center (IRC) CD-ROM containing the Instructor Resource Guide (answer key), files of most figures in the manual, and animations of geological concepts.

Outstanding Mineral and Rock Labs
Mineral and rock labs are better than ever with enhanced student-tested illustrations, identification flowcharts, and the five-page mineral database. (Please see page xiv for more information on the rock and mineral sets available through Prentice Hall and WARD'S Natural Science.)

Internet Support at www.prenhall.com/agi
The companion web site supports all labs with additional information and links listed by laboratory topic or by state/province.

Support for Geoscience
Royalties from sales of this product support programs of the American Geological 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 seventh edition of *Laboratory Manual in Physical Geology*.

Revisions in this new edition are based on user-based peer reviews, unsolicited criticisms and suggestions from faculty who used the last editon of the manual, feedback from students using the manual at West Chester University of Pennsylvania, and market research by Pearson Prentice Hall. As changes were made to the laboratories, they were field tested in Introductory Geology laboratories at West Chester University. These field tests led to final revisions that helped make the manual more practical and user friendly.

We thank the following faculty peer reviewers for their extensive user-based evaluations and suggested revisions for this edition:

Alan Elser, Georgia State University
Erika Gonzalez, Tulane University
Stephanie Jones, Clemson University
Scott Preston, Texas A&M University
Elizabeth Rhodes-King, College of Charleston
Steven Schimmrich, SUNY–College at Ulster

We also thank the following faculty for their independent constructive criticisms and suggestions that led to improvements in this edition of the manual:

Steven Good, West Chester University of Pennsylvania
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Thomas Hanley, Columbus State University
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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, Ministry of Environment, Government of British Columbia; NASA; and the U.S./Japan ASTER Science Team.

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, conducting peer reviews, 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, Boucher Building, West Chester University, West Chester, PA 19383 (rbusch@wcupa.edu).

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LABORATORY EQUIPMENT

LABORATORY EQUIPMENT LIST

R = Required, O = Optional

EQUIPMENT	LABORATORY NUMBERS															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Laboratory Notebook	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Pencil with eraser	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Calculator	R	R	R					R	R		R	R		R		R
Ruler (GeoTools Sheet 1)	R	R			R	R	R	R	R	R	R	R	R	R	R	R
Protractor (GeoTools Sheet 3)								R	R							
Colored pencils		R		R				O		R				R	R	
Scissors	R	R			R	R	R	R	R	R	R	R	R	R	R	
Mineral analysis tools* (steel/wire nails, glass plate, streak plate, penny, small magnet)			R	R	R	R	R									
Set of mineral samples*			R													
Set of miscellaneous rock samples*				R												
Set of igneous rock samples*					R											
Set of sedimentary rock samples*						R										
Set of metamorphic rock samples*							R									
Hand (magnifying) lens*			O	O	O	O	O									
Dropper bottle of dilute HCl*			R	R		R	R									
Small graduated cylinder (10 mL)*	R		O													
Large graduated cylinder (500 mL)*	R		O													
Basalt fragment that fits into the large graduated cylinder*	R															
Granite sample that fits into the large graduated cylinder*	R															
Small lump of modeling clay*	R															
Wood block (about 8 x 10 x 4 cm)*	R															
Gram balance*	R		O													
Small plastic bucket with water*	R															
Wash bottle with water*	O	R	O													R
Dropper with water*		R			O											
Lava lamp**		R			O											
Hot plate*		R														
Aluminum foil (roll)**		R														
Sugar cubes (2 per hot plate)*		R														
Permanent felt-tip marker*		R														
Crucible tongs*		R														
Visual estimation of percent chart from GeoTools Sheet 1		R			R											
Sediment grain size scale from GeoTools Sheet 1						R										
UTM grids (GeoTools Sheets 1–3)									R							
Topographic quadrangle map*									O							
Geologic map*										O						
Pocket stereoscope									R		O		O	R	O	
Cardboard models 1–6 cut from the back of this manual										R						
String (about 30 cm long)											R					
Drafting compass																R
2 small plastic cups with dry sand*																R
Several coins per cup of sand																R

*Per group. **Per class.

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	1,000	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	0.000,001	10^{-6}	micro-
n	one-billionth	0.000,000,001	10^{-9}	nano-
p	one-trillionth	0.000,000,000,001	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 (1 μm) = 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) = 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. Some of these abbreviations combine SI symbols with "yr" (*years*). Some abbreviations combine SI symbols with "a," for annum (*years before the present*).

yr (or y) = year
kyr = kiloyear—thousand years
Myr (or m.y.) = megayear—million years
Gyr (or Byr or b.y.) = gegayear—billion years
ka = kiloannum—thousand years before present or thousand years ago
Ma = megannum—million years before present or million years ago
Ga = gegannum—billion years before present or billion years ago

MATHEMATICAL CONVERSIONS

To convert:	To:	Multiply by:	
kilometers (km)	meters (m)	1000 m/km	LENGTHS AND DISTANCES
	centimeters (cm)	100000 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)*	10000 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)	1000000 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 (mi^2)	acres (a)	640 acres/mi^2	AREAS
	square km (km^2)	2.589988 km^2/mi^2	
square km (km^2)	square miles (mi^2)	0.3861 mi^2/km^2	
acres	square miles (mi^2)	0.001563 mi^2/acre	
	square km (km^2)	0.00405 km^2/acre	
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	
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

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LABORATORY ONE

Observing and Measuring Earth Materials and Processes

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OBJECTIVES

A. Know what the "geologic record" is and how it is similar to, yet different from, a book.

B. Understand basic principles and tools of satellite remote sensing used by geoscientists and apply these principles and tools with your skills of observation to identify Earth materials, observe and describe processes of change, and make predictions.

C. Know that geology is based on a logical, testable process of scientific inquiry that is "ground truthed" with data obtained by direct observation, investigation, and measurement in the field (out of doors, in natural context) and in the laboratory.

D. Measure or calculate length, area, volume, mass, and density of Earth materials using basic scientific equipment and techniques.

E. Develop and test physical and quantitative models of isostasy based on floating wood blocks and icebergs. Then apply your quantitative model and your measurements of basalt and granite density to calculate the isostasy of average blocks of oceanic and continental crust.

F. Analyze Earth's global topography in relation to your work and a hypsographic curve, and infer how Earth's global topography may be related to isostasy.

MATERIALS

Part 1A: Pencil, eraser, laboratory notebook. **Parts 1B–1D:** Pencil, eraser, laboratory notebook, metric ruler, small (10 mL) graduated cylinder, large (500 mL) graduated cylinder, pieces of basalt and granite that will fit into the large graduated cylinder, small lump of modeling clay (marble size), water, wood block (about 8 cm × 10 cm × 4 cm), small bucket to float wood block, gram balance, wash bottle or dropper (optional), and calculator (optional).

INTRODUCTION

Science is a process of *logic* (critical thinking) and *investigation* (gathering information to verify or falsify ideas) that people use to answer questions and solve problems. **Geology** is the branch of science that deals with Earth, especially its rocky sphere and 4.55 billion-year-long history. The name geology comes from two Greek words, *geo* = Earth and *logos* = study of. Thus, geologists are also Earth scientists or geoscientists.

Geologists use their senses and tools (microscopes, rock hammers, rulers, etc.) to make direct observations about Earth materials and processes of change. They also rely on computer technologies to make accurate, precise, remote, and automated observations. These collective observations serve as a growing body of *data* (information, or evidence) that enable geologists to:

- characterize and classify Earth materials
- identify relationships of cause (process) and effect (product)

- form questions and **hypotheses** (tentative ideas to be tested)
- investigate and experiment (design and conduct tests of materials and hypotheses)
- design **models** (physical, conceptual, mathematical, graphical, or artistic representations of something to test or demonstrate how it works)
- make **inferences** (ideas justified with reasonable logic and evidence)

All of these things are components of scientific inquiry—the processes that scientists use to study the natural world and propose explanations (inferences) based on reasonable logic and the evidence (information, data) derived from their work. For example, as geologists make observations, they develop questions and hypotheses about Earth materials, processes, and changes. They examine books and other sources of information to see what is already known and plan and conduct new investigations to gather more information, test ideas, and answer questions. They use tools to gather, analyze, and interpret data. They use data and reasonable logic to make inferences, and they communicate their procedures and inferences to others. Thus, other geologists can apply and test the procedures and inferences to falsify (reject), verify (confirm), or modify them as part of a growing body of knowledge and understanding about Earth and science.

PART 1A (PRELAB.): OBSERVING EARTH MATERIALS AND PROCESSES OF CHANGE THROUGH TIME

As you complete exercises in this laboratory manual, think of yourself as a geologist and scientist. Conduct tests and make careful observations. Record your observations in a laboratory notebook so you have a body of information (data) to justify your ideas (hypotheses, inferences). The quality of your ideas depends on your logic (method of thinking) and the information (your data) that you use to justify them. Your ideas may change as you make new observations, locate new information, or apply a different method of thinking. Your instructor will not accept simple yes or no answers to questions. S/he will expect your answers to be complete inferences justified with information and an explanation of your logic. Show your work whenever you use mathematics to solve a problem so your method of thinking is obvious.

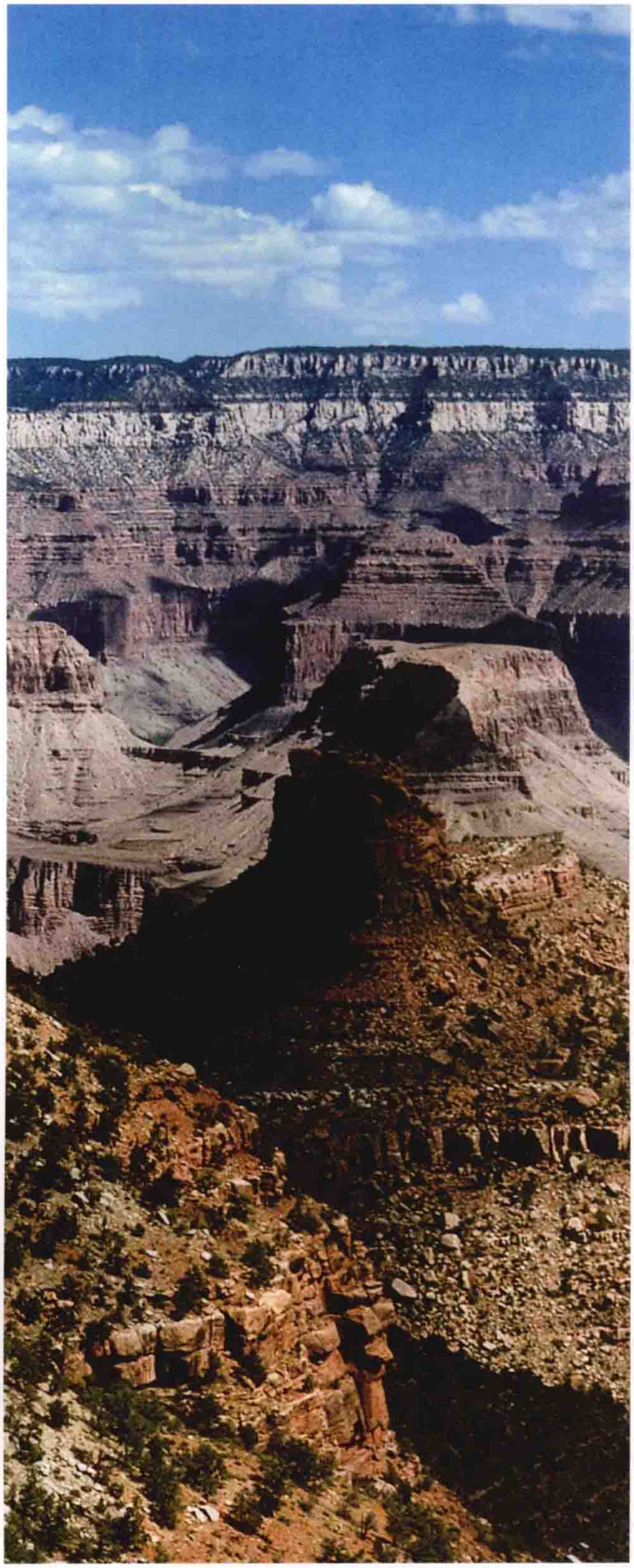

FIGURE 1.1 Photograph of a portion of the Grand Canyon, Arizona. Rocks exposed at the base of the canyon are more than a billion years old, yet some layers of sand along the Colorado River that runs through the canyon may have formed just seconds ago. (Photo by Allen Johnson)