

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

PRODUCED UNDER THE AUSPICES OF THE
AMERICAN GEOLOGICAL INSTITUTE

<http://www.agiweb.org>

AND THE
**NATIONAL ASSOCIATION
OF GEOSCIENCE TEACHERS**

<http://www.nagt.org>

RICHARD M. BUSCH, EDITOR
WEST CHESTER UNIVERSITY OF PENNSYLVANIA

ILLUSTRATED BY
DENNIS TASA • *TASA GRAPHIC ARTS, INC.*



UPPER SADDLE RIVER, NJ 07458

Executive Editor: Patrick Lynch
Director of Marketing, Science: Linda Taft-MacKinnon
Executive Managing Editor: Kathleen Schiaparelli
Production Editor: Tim Flem/PublishWare
Manufacturing Manager: Alexis Heydt-Long
Buyer: Alan Fischer
Art Director: Maureen Eide
Senior Managing Editor, Art Production and Management: Patricia Burns
Manager, Production Technologies: Matthew Haas
Managing Editor, Art Management: Abigail Bass
Art Production Editor: Jess Einsig
Illustrations: Dennis Tasa
Project Manager: Dorothy Marrero
Assistant Managing Editor, Science Supplements: Becca Richter
Director of Creative Services: Paul Belfanti
Cover Designer: Daniel Conte
Cover photos: *Front*: Hiking *The Wave*, an outcrop of cross-bedded Navajo Sandstone in Arizona (© Charlie Munsey Photography). *Back*: 9th graders examining a rock (© Will Hart); detail from Geologic Map of the Eastern Part of Grand Canyon National Park, Arizona 1996 edition, published by Grand Canyon Association; all other photos © Richard M. Busch.
Page Layout: PublishWare



© 2006, 2003, 2000, 1997 by American Geological Institute
Published by Pearson Education, Inc.
Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

Third edition © 1993 by American Geological Institute, published by Macmillan Publishing Company.
Second edition © 1990 by Macmillan Publishing Company.
First edition © 1986 by Merrill Publishing Company.

Photographs © Richard M. Busch, unless otherwise noted. Used with permission.

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission from the publisher.

Pearson Prentice Hall™ is a trademark of Pearson Education, Inc.

Printed in the United States of America

10 9 8 7 6 5 4 3 2

ISBN 0-13-149745-6

Pearson Education LTD., London
Pearson Education Australia PTY, Limited, Sydney
Pearson Education Singapore, Pte. Ltd
Pearson Education North Asia Ltd, Hong Kong
Pearson Education Canada, Ltd., Toronto
Pearson Educación de México, S.A. de C.V.
Pearson Education—Japan, Tokyo
Pearson Education Malaysia, Pte. Ltd

CONTRIBUTING AUTHORS

THOMAS H. ANDERSON

University of Pittsburgh

HAROLD E. ANDREWS

Wellesley College

JAMES R. BESANCON

Wellesley College

JANE L. BOGER

SUNY-College at Geneseo

PHILLIP D. BOGER

SUNY-College at Geneseo

CLAUDE BOLZE

Tulsa Community College

JONATHAN BUSHEE

Northern Kentucky University

ROSEANN J. CARLSON

Tidewater Community College

CYNTHIA FISHER

West Chester University of
Pennsylvania

CHARLES I. FRYE

Northwest Missouri State
University

PAMELA J.W. GORE

Georgia Perimeter College

ANNE M. HALL

Emory University

EDWARD A. HAY

De Anza College

CHARLES G. HIGGINS

University of California, Davis

MICHAEL F. HOHELLA, JR.

Virginia Polytechnic Institute and
State University

MICHAEL J. HOZIK

Richard Stockton College
of New Jersey

SHARON LASKA

Acadia University

DAVID LUMSDEN

University of Memphis

RICHARD W. MACOMBER

Long Island University, Brooklyn

GARRY D. MCKENZIE

Ohio State University

CHERUKUPALLI E. NEHRU

Brooklyn College (CUNY)

JOHN K. OSMOND

Florida State University

CHARLES G. OVIATT

Kansas State University

WILLIAM R. PARROTT, JR.

Richard Stockton College
of New Jersey

RAMAN J. SINGH

Northern Kentucky University

KENTON E. STRICKLAND

Wright State University

RICHARD N. STROM

University of South Florida,
Tampa

JAMES SWINEHART

University of Nebraska

RAYMOND W. TALKINGTON

Richard Stockton College
of New Jersey

MARGARET D. THOMPSON

Wellesley College

JAMES TITUS*

U.S. Environmental Protection
Agency

EVELYN M. VANDENDORFER

Arizona Geological Survey

NANCY A. VAN WAGONER

Acadia University

JOHN R. WAGNER

Clemson University

DONALD W. WATSON

Slippery Rock University

JAMES R. WILSON

Weber State University

MONTE D. WILSON

Boise State University

C. GIL WISWALL

West Chester University
of Pennsylvania

* 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 edition 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
Geoffrey Collins, Wheaton College, MA
Thomas Leonard, William Patterson University
Thomas Hanley, Columbus State University
Michael Heaney, Texas A&M University

We thank *Edwin Anderson* (Temple University), *Allen Johnson* (West Chester University), *Carrick Eggleston* (University of Wyoming), *Randall Marrett* (University of Texas at Austin), and *Paul Morin* (University of Minnesota) for the use of their personal photographs. Photographs and data related to St. Catherines Island, Georgia, were made possible by research grants to the editor from the St. Catherines Island Research Program, administered by the American Museum of Natural History and supported by the Edward J. Noble Foundation.

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).

Marcus E. Milling, *Executive Director, AGI*
Ann Benbow, *Director of Education, AGI*
Christopher Keane, *Director of Technology and Communications, AGI*
Richard M. Busch, *Editor*

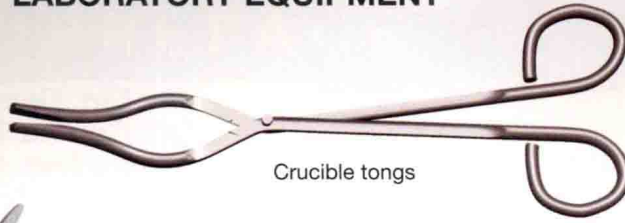
LABORATORY EQUIPMENT



Acid bottle



Hand lens



Crucible tongs



Wash bottle



Geologist's chisel tip pick



Geologist's pointed tip pick



Pocket knife with steel blade



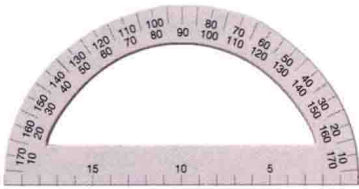
Ruler



Streak plate



Drafting compass



Protractor



Graduated cylinder



Pocket stereoscope



Dropper



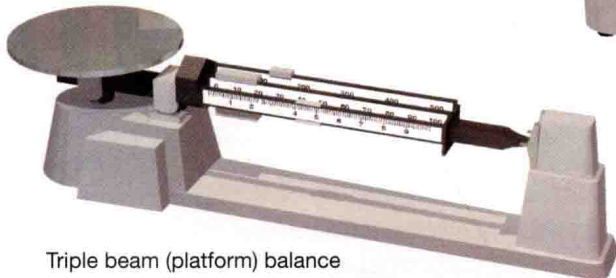
Safety goggles



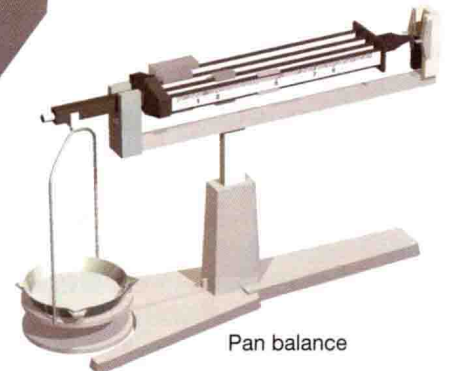
Hot plate



Digital electronic balance



Triple beam (platform) balance



Pan balance

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									
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.) = geoyear—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		
centimeters (cm)	miles (mi)	0.0006214 mi/m		
	meters (m)	0.01 m/cm		
	millimeters (mm)	10 mm/cm		
	feet (ft)	0.0328 ft/cm		
	inches (in.)	0.3937 in./cm		
millimeters (mm)	micrometers (μm)*	10000 $\mu\text{m}/\text{cm}$		
	meters (m)	0.001 m/mm		
	centimeters (cm)	0.1 cm/mm		
	inches (in.)	0.03937 in./mm		
	micrometers (μm)*	1000 $\mu\text{m}/\text{mm}$		
	nanometers (nm)	1000000 nm/mm		
micrometers (μm)*	millimeters (mm)	0.001 mm/ μm		
	nanometers (nm)	0.000001 mm/nm		
nanometers (nm)	millimeters (mm)	0.000001 mm/nm		
	kilometers (km)	1.609 km/mi		
miles (mi)	feet (ft)	5280 ft/mi		
	meters (m)	1609.34 m/mi		
	centimeters (cm)	30.48 cm/ft		
	meters (m)	0.3048 m/ft		
	inches (in.)	12 in./ft		
feet (ft)	miles (mi)	0.000189 mi/ft		
	centimeters (cm)	2.54 cm/in.		
	millimeters (mm)	25.4 mm/in.		
	micrometers (μm)*	25,400 $\mu\text{m}/\text{in.}$		
square miles (mi ²)	acres (a)	640 acres/mi ²	AREAS	
	square km (km ²)	2.589988 km ² /mi ²		
	square miles (mi ²)	0.3861 mi ² /km ²		
	square km (km ²)	0.001563 mi ² /acre		
acres	square km (km ²)	0.00405 km ² /acre		
gallons (gal)	liters (L)	3.78 L/gal	VOLUMES	
	fluid ounces (oz)	30 mL/fluid oz		
	milliliters (ml)	0.001 L/mL		
	liters (L)	cubic centimeters (cm ³)		1.000 cm ³ /mL
		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		
	kilograms (kg)	0.4536 kg/lb		
pounds avdp. (lb)	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

GEO TIMES



From ecology and evolution to climate change and discoveries on Mars, *Geotimes* covers the latest earth, environment and energy news that affects the global community. Read about new trends and initiatives in research, education, technology and resources.

FREE TRIAL ISSUE!

Just go to:
www.geotimes.org
and click on
"Order your free trial copy!"

Fossils

Ecology

Archaeology

Water quality

Science policy

Climate change

Oil and natural gas

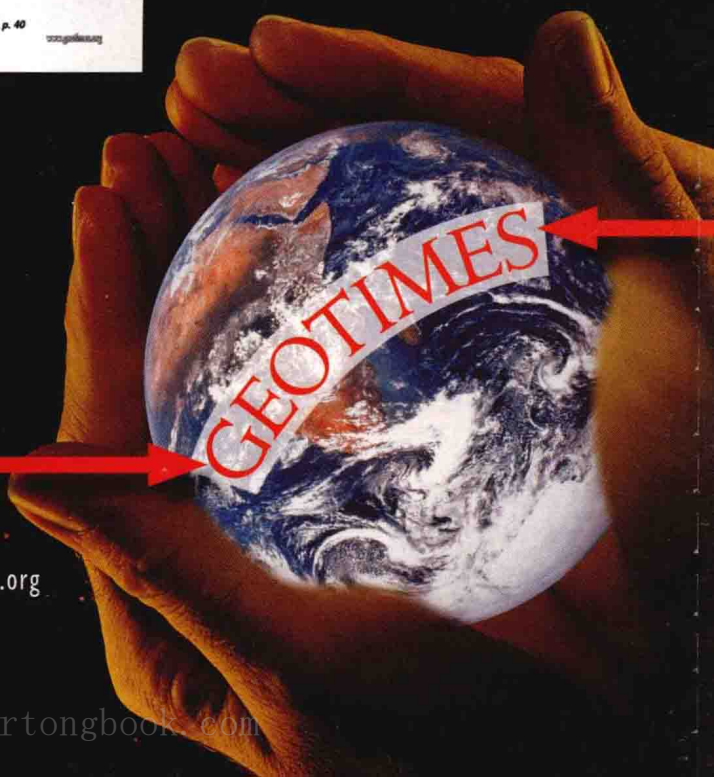
GEO TIMES! Connect to Your Earth

American Geological Institute
4220 King Street
Alexandria, VA 22302-1502
U.S.A.

phone: (703)379-2480
fax: (703)379-7563
E-mail: geotimes@agiweb.org

No purchase obligation, no cancellation necessary.
Offer available for US addresses only. One trial issue per customer or address.

试读结束：需要全本请在线购买：www.ertongbook.com



National Association of Geoscience Teachers



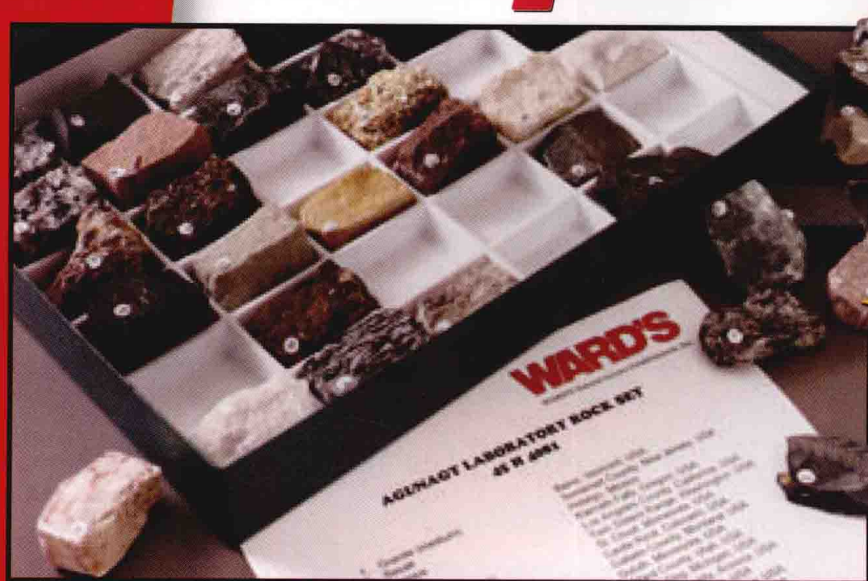
Journal of Geoscience Education

Supporting this generation of
educators and the next



For subscription & membership information:
NAGT, Box 5443, Bellingham, WA 98227

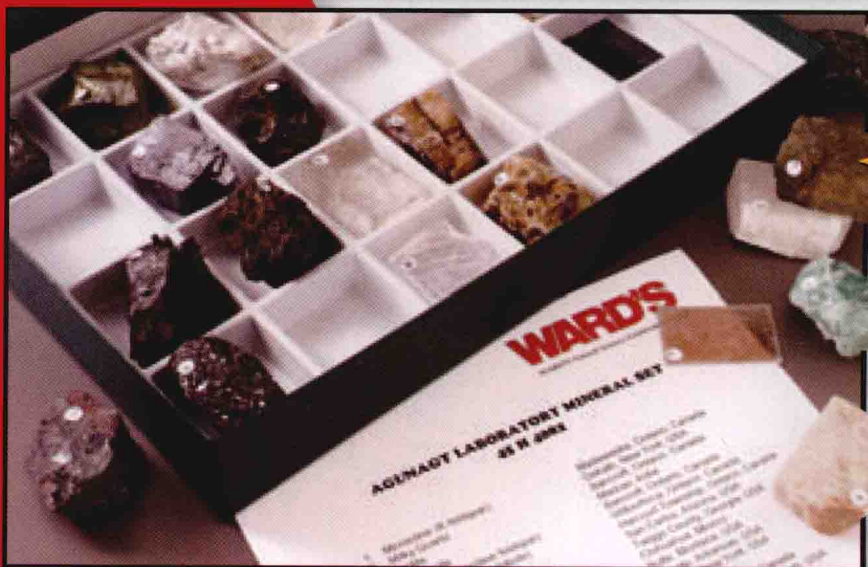
the Only Resource for All Your Geology and Specimen Needs



WARD'S AGI/NAGT Laboratory Rock Set

Identification becomes an interesting hands-on experience when you use WARD'S Rock Set to enhance your lab activities. Specifically designed to supplement Laboratory Exercises Four, Five, Six, and Seven of your *AGI/NAGT Laboratory Manual in Physical Geology*, this unique set of 36 different rocks provides excellent examples of many key igneous, sedimentary, and metamorphic lithologies. The numbered samples average 1" x 1" to 1" x 1 1/2" in size, and are housed in a compartment collection box with an identification list.

WARD'S Item Number: **45 V 4081**



WARD'S AGI/NAGT Laboratory Mineral Set

Improve student understanding of mineral properties and uses with this comprehensive set of 24 important rock-forming and ore minerals customized to complement the testing activities found in Laboratory Three of your *AGI/NAGT Laboratory Manual in Physical Geology*. These high quality samples display excellent consistency and uniformity. Each specimen is numbered and housed in a compartment collection box along with an identification list. Samples average 1" x 1" to 1" x 2" in size.

WARD'S Item Number: **45 V 4082**

Also available:

WARD'S/Prentice Hall Personal Rock and Mineral Set.
See www.prenhall.com/geology for more details
on this inexpensive, home study set.

**Ordering All of Your Geology
Supplies & Specimens From
Ward's is Easy, Call Today!**

for prompt and personal customer care:

800 962-2660

for fast, easy, and secure online ordering:

www.wardsci.com



Since 1862, WARD'S has earned an unmatched reputation for consistent quality, value, and technical support in all geology specimen products. Our comprehensive line of rocks, minerals, and fossils is acquired from the corners of the globe to best serve your teaching, lab, and research needs. And, our technical staff of geologists is always available to discuss any special requirements you might have. At WARD'S, quality, service, and satisfaction are more than simple words—they're our tradition and our guarantee to you.

WARD'S
Natural Science

See wardsci.com for additional
information, pricing, and ordering details.

CONTENTS

LABORATORY ONE

Observing and Measuring Earth Materials and Processes 1

- Part 1A (Prelab.): Observing Earth Materials and
Processes of Change Through Time 2
- Part 1B: Measuring Earth Materials and
Relationships 19
- Part 1C: Density, Gravity, and Isostasy 23
- Part 1D: Isostasy and Earth's Global
Topography 27

LABORATORY TWO

Plate Tectonics and the Origin of Magma 30

- Part 2A: Is Earth's Size Increasing, Decreasing,
or Staying About the Same? 31
- Part 2B: What Drives Plate Tectonics? 35
- Part 2C: The Origin of Magma 39
- Part 2D: Measuring and Evaluating Plate
Tectonics 42

LABORATORY THREE

Mineral Properties, Uses, and Identification 47

- Part 3A: Mineral Properties and Uses 49
- Part 3B: Mineral Identification and
Appreciation 62
- Part 3C: Mineral Resources and
Commodities 62

LABORATORY FOUR

Rock-Forming Processes and the Rock Cycle 77

- Part 4A: Introduction to Rocks and the
Rock Cycle 83
- Part 4B: Rock Samples and the
Rock Cycle 86

LABORATORY FIVE

Igneous Rocks and Volcanic Hazards 91

- Part 5A: Igneous Processes and Rocks 91
- Part 5B: Description and Interpretation
of Igneous Rock Samples 107
- Part 5C: Volcanic Hazards and Human Risks 108

LABORATORY SIX

Sedimentary Rocks, Processes, and Environments 111

- Part 6A: Sedimentary Processes and Rocks 112
- Part 6B: Hand Sample Analysis
and Interpretation 120
- Part 6C: Sedimentary Structures and
Environments 125
- Part 6D: Interpretation of a Stratigraphic
Sequence 125

LABORATORY SEVEN

Metamorphic Rocks, Processes, and Resources 133

- Part 7A: Metamorphic Processes
and Rocks 134
- Part 7B: Description and Interpretation
of Metamorphic Rock Samples 146

LABORATORY EIGHT

Dating of Rocks, Fossils, and Geologic Events 151

- Part 8A: Determining Relative Ages of Rocks
Based on Their Physical Relationships 152
- Part 8B: Using Fossils to Determine Age
Relationships 158
- Part 8C: Determining Absolute Ages by
Radiometric Dating 160
- Part 8D: Infer the Geologic History of
Two Field Sites 162
- Part 8E: Construct and Interpret a Subsurface
Geologic Cross Section 165

LABORATORY NINE**Topographic Maps, Aerial Photographs, and Satellite Images 167**

- Part 9A: Introduction to Topographic Maps 168
- Part 9B: Topographic Profiles and Vertical Exaggeration 186
- Part 9C: Analysis of the Ontario, California, Topographic Map 190
- Part 9D: Analysis of Your Topographic Quadrangle Map 191
- Part 9E: Aerial Photographs 191

LABORATORY TEN**Geologic Structures, Maps, and Block Diagrams 195**

- Part 10A: Structural Geology 195
- Part 10B: Block Diagrams 207
- Part 10C: Analysis of a Geologic Map 209

LABORATORY ELEVEN**Stream Processes, Landscapes, Mass Wastage, and Flood Hazards 210**

- Part 11A: Stream Processes and Landscapes 211
- Part 11B: Stream Processes and Landscapes near Voltaire, North Dakota 218
- Part 11C: Stream Processes and Landscapes near Ennis, Montana 222
- Part 11D: Rio Grande River Meander Evolution 222
- Part 11E: Stream Erosion and Mass Wastage at Niagara Falls 226
- Part 11F: Flood Hazard Mapping, Assessment, and Risks 227

LABORATORY TWELVE**Groundwater Processes, Resources, and Risks 230**

- Part 12A: Caves and Karst Topography 232
- Part 12B: Location and Movement of Groundwater in the Floridan Limestone Aquifer 237
- Part 12C: Land Subsidence Hazards Caused by Groundwater Withdrawal 239
- Part 12D: Home Septic Systems and Groundwater Contamination 244

LABORATORY THIRTEEN**Glacial Processes, Landforms, and Indicators of Climate Change 245**

- Part 13A: Glacial Processes and Landforms 246
- Part 13B: Glaciation in Wisconsin 256
- Part 13C: Comparing Topographic Profiles of Glaciated Valleys 256
- Part 13D: Glacier National Park, Montana 259
- Part 13E: Nisqually Glacier—A Global Thermometer? 261

LABORATORY FOURTEEN**Dryland Landforms, Hazards, and Risks 264**

- Part 14A: Eolian Processes, Dryland Landforms, and Desertification 265
- Part 14B: Death Valley, California 272
- Part 14C: Dryland Lakes 272
- Part 14D: Dryland Hazards and Risks in Nebraska's Sand Hills 273

LABORATORY FIFTEEN**Coastal Processes, Landforms, Hazards, and Risks 278**

- Part 15A: Dynamic Natural Coastlines 281
- Part 15B: Human Modification of Shorelines 286
- Part 15C: The Threat of Rising Seas 288

LABORATORY SIXTEEN**Earthquake Hazards and Human Risks 291**

- Part 16A: Simulate Earthquake Hazards to Estimate Risks 292
- Part 16B: Graphing Seismic Data and Locating the Epicenter of an Earthquake 294
- Part 16C: Analysis of Active Faults Using Aerial Photographs 298
- Part 16D: Determining Relative Motions Along the New Madrid Fault Zone 299
- Part 16E: Tracking Earthquake Hazards in Real Time and Assessing Their Impact on Risk Takers 302

LABORATORY ONE

Observing and Measuring Earth Materials and Processes

• CONTRIBUTING AUTHORS •

Cynthia Fisher • *West Chester University*

C. Gil Wiswall • *West Chester University*

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)

2 • Laboratory One

- 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)