LABORATORY MANUAL IN PHYSICAL GEOLOGY

American Geological Institute • National Association of Geoscience Teachers

SIXTH EDITION

Edited by
Richard M. Busch

Illustrated by
Dennis Tasa

SIXTH 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

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ILLUSTRATED BY

DENNIS TASA • *TASA GRAPHIC ARTS, INC.*

Prentice Hall

PEARSON EDUCATION, INC.

UPPER SADDLE RIVER, NJ 07458

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Back cover photo: Angular unconformity (at hammer head) developed locally in Lower Permian rocks of northeastern Kansas.
Page Layout: PublishWare

© 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.

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Printed in the United States of America

10 9 8 7 6 5 4 3

ISBN 0-13-046333-7

Pearson Education LTD., *London*
Pearson Education Australia PTY, Limited, *Sydney*
Pearson Education Singapore, Pte. Ltd
Pearson Education North Asia Ltd, *Hong Kong*
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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 Slide Set, Instructor Transparency Set, and a Digital Image Gallery (DIGIT) CD-ROM.

The idea for such a jointly sponsored laboratory manual was proffered by Robert W. Ridky (past president of NAGT and past 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 17-year evolution of the cumulative ideas of more than 160 contributing authors, faculty peer reviewers, and students and faculty who have used past editions. Undergraduate students have field tested all parts of this sixth edition and helped make it the most student-friendly edition ever.

OUTSTANDING FEATURES

This new edition contains the strengths of five past editions 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 and Pedagogy

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.

Materials

Laboratories are based on samples and equipment normally housed in existing geoscience teaching laboratories (page ix). No expensive items to buy.

Greater Visual Clarity and Appeal

The manual is more richly illustrated than any other manual on the market. More than 280 high-quality photographs, images, stereograms, maps, and charts reinforce the visual aspect of geology and enhance student learning. More than half of these are revised or newly created on the basis of peer reviews and student feedback.

New Hands-On Experimental Labs

New Laboratory One engages students in geologic observation, measurement, and experimentation using 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.

New 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.

New GeoTools

There are rulers, protractors, sediment grain size scales, UTM grids, and other laboratory tools to cut from transparent sheets at the back of the manual.

New 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 the Instructor Resource Guide, slides, transparencies of most illustrations, maps, and photographs, and a Digital Image Gallery (DIGIT) CD-ROM.

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.

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Internet Support
Enhanced 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 sixth edition of *Laboratory Manual in Physical Geology*.

Planning for this edition began in spring 2001 on the basis of user comments, market research by Prentice Hall, and peer reviews of the fifth edition. As laboratories were revised or replaced, 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 evaluations and suggested revisions:

Michael T. May, Western Kentucky University
Tom Dale, Kirtland Community College, Michigan
Joceline Boucher, Corning School of Ocean Studies, Maine Maritime Academy
Mike Farabee, Estrella Mountain Community College, Arizona
Cassi Paslick, Rock Valley College, Illinois
Kevin McCartney, University of Maine at Presque Isle
Alfred Esler, Georgia State University
Andrew Heckert, University of New Mexico
Keith McKain, Milford Senior High School, Delaware
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Steve Semken, Diné College, Arizona
Julian Gray, Georgia State University
Pamela Burnley, Georgia State University
Sven Morgan, Central Michigan University
Andrew Feldman, Florida State University
Sachin Shah, Georgia State University
Aaron Mango, Florida State University

We also thank the following faculty for their independent constructive criticisms and other contributions that have improved the manual:

Jennifer Smith, University of Pennsylvania
Vince Cronin, University of Wisconsin-Milwaukee
David H. Walz, J. Sargeant Reynolds Community College, West Virginia
Edward Butler, Montgomery College, Maryland
Alice M. Hawthorne Allen, Athens, West Virginia
Thomas Leonard, William Paterson University, New Jersey
Lary Jack, Las Vegas Community College, Nevada

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, and aerial photographs have been used courtesy of the U.S. Geological Survey; Canadian Department of Energy, Mines, and Resources; and Surveys and Resource Mapping Branch, Ministry of Environment, Government of British Columbia.

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, providing manuscript materials, 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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Director of Education, AGI

Richard M. Busch
Editor

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						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)

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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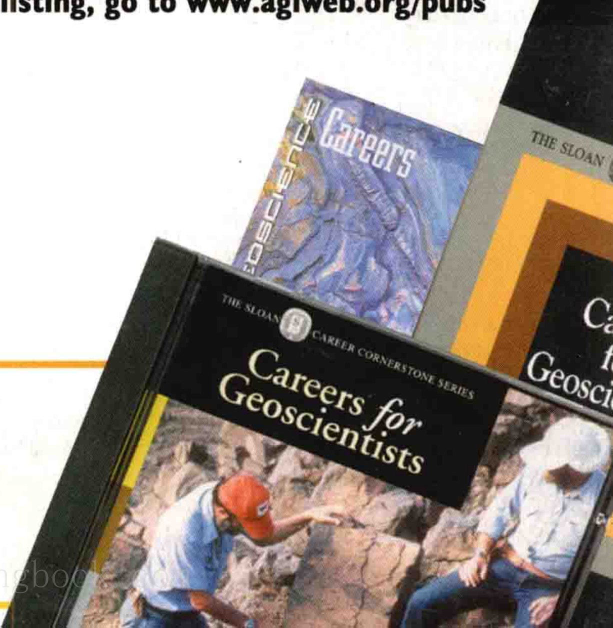

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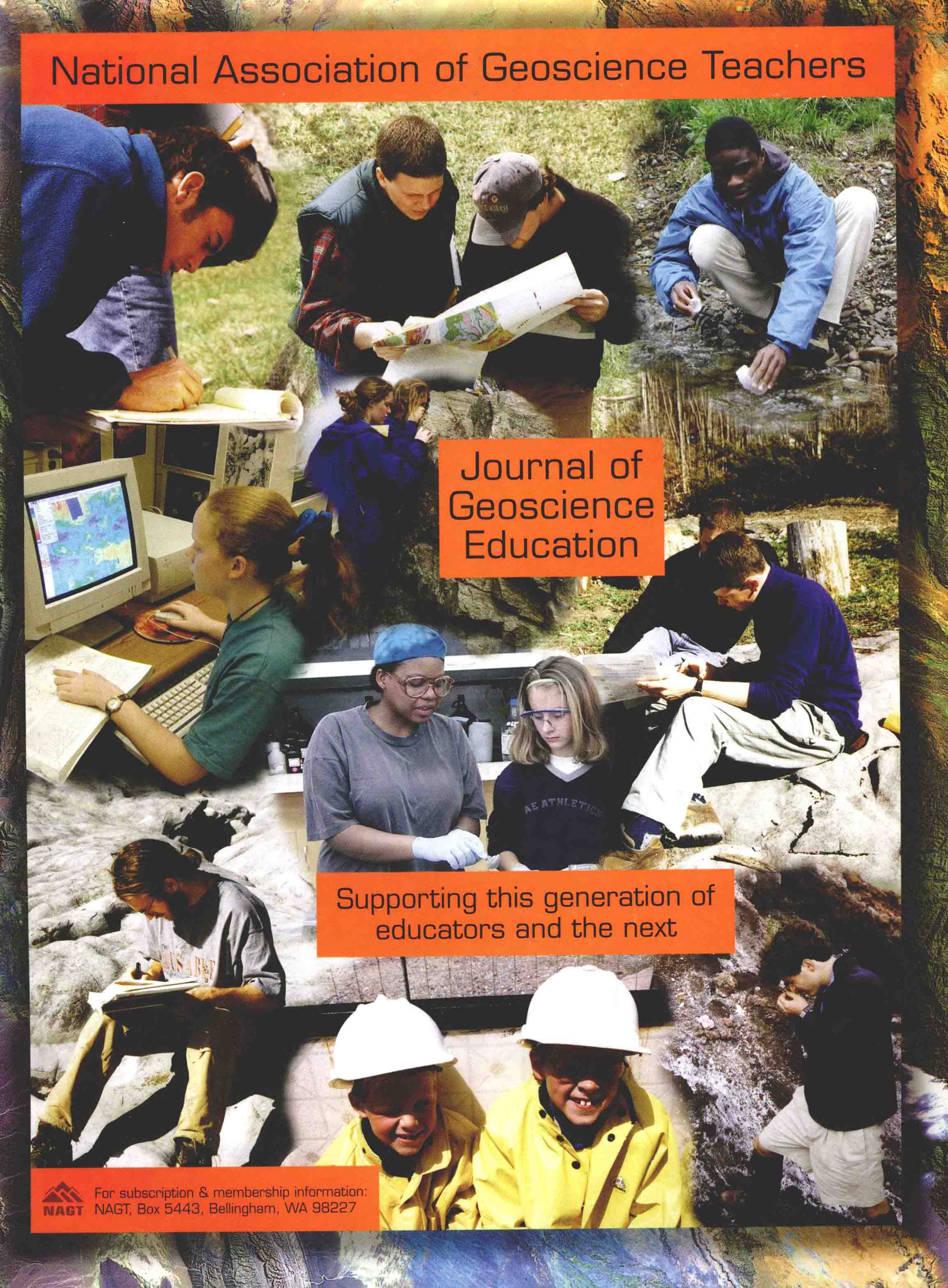
National Association of Geoscience Teachers
Journal of Geoscience Education
Supporting this generation of educators and the next
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THE GEOLOGIC TIME SCALE

Eon	Era	Period**	Epoch	Approximate Ages (In millions of years)
Phanerozoic: The Eon of Visible Life	Cenozoic: The Age of Mammals 	Quaternary (Q)	Recent Pleistocene	1.8
		Tertiary (T)	Pliocene Miocene	23
			Oligocene Eocene Paleocene	65
	Mesozoic: The Age of Reptiles 	Cretaceous (K)	Late Early	144
		Jurassic (J)	Late Middle Early	206
		Triassic (Ꞧ)	Late Middle Early	248
	Paleozoic: The Age of Trilobites 	Permian (P)	Late Early	290
		Carboniferous (C)*: Pennsylvanian (ℙ)	Late Middle Early	323
		Carboniferous (C)*: Mississippian (M)	Late Early	354
		Devonian (D)	Late Middle Early	417
		Silurian (S)	Late Middle Early	443
		Ordovician (O)	Late Middle Early	490
		Cambrian (Є)	Late Middle Early	540
	Precambrian (pЄ)	Locally divided into Early, Middle, and Late		4500+

*European name

**Symbols in parentheses are abbreviations commonly used to designate the age of rock units on geologic maps.

CONTENTS

LABORATORY ONE

Observing and Measuring Earth Materials and Processes

•CONTRIBUTING AUTHORS•

Cynthia Fisher • *West Chester University*

C Gil Wiswall • *West Chester University*

OBJECTIVES

A. Identify and describe Earth materials and processes of change using your skills of observation.

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

C. 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.

D. 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

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, 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 logical and methodological process of investigation that people use to answer questions and solve problems. The branch of science that deals with Earth is **geology.** Its name 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 more complex technologies to make accurate, precise, remote, and automated observations. These collective observations have provided geologists with a growing body of data (information) about Earth that can be used to:

- characterize and classify Earth materials
- identify relationships of cause (process) and effect (product)
- form **hypotheses** (ideas to be tested)

- devise **experiments** (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 thinking and evidence)

Therefore geologists collect, analyze, interpret, and evaluate data to form models and tentative inferences about Earth materials, processes, and changes on different scales of space and time. They share their data and inferences with other geologists who apply and test them to falsify (reject), verify (confirm), or modify them. Reasonable data and inferences are applied in new geological studies to form a growing body of knowledge and understanding about Earth and science.

PART 1A: OBSERVING EARTH MATERIALS AND PROCESSES OF CHANGE

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. 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.

When making geologic observations, think of yourself as a geologic detective. You should observe and record **qualitative information** by *describing* how materials look, feel, smell, sound, taste, or behave. You should also collect and record **quantitative information** by *measuring* materials, energy levels, and processes of change in time and space. This will require that you understand and use some scales and tools of measurement that geologists use in their work. You will also be expected to calculate relationships by comparing one set of measurements to another.

Scales of Earth Observation

Geologists study Earth materials from the scale of atoms (atomic scale) and to the scale of our entire planet (global scale). At each scale, they identify and characterize materials and relationships. Each scale is also related to the others. You should familiarize yourself with these **physical scales of observation** as they are summarized in Figure 1.1. A summary table of quantitative units of measurement, symbols, abbreviations, and conversions is also provided on pages x and xi at the front of this manual.

Geologists also think about **temporal scales of observation** from seconds to billions of years. You will learn more about how to tell geologic time in Laboratory 8, but you should now begin to familiarize yourself with the *geologic time scale* (page xiv). Notice that the geologic time scale consists of a sequence of named divisions of Earth history called Eons (the longest divisions), Eras, Periods, and Epochs. The ages of these divisions are given in millions of years. They have been named and dated on the basis of more than a century of cooperative work among Earth scientists of different nations, races, religions, genders, classes, and ethnic groups from throughout the world. What all of these Earth scientists have had in common is the ability to do science and an intense desire to decipher Earth's long and complex history.

Processes and Cycles of Change

Energy and processes of change occur at each physical and temporal scale of observation. Earth's surface is energized by geothermal energy (from inside the planet) and solar energy (from outside the planet). The energy flows from *sources* to *sinks* (objects that store or convert energy) and drives processes of change. For example, review the list of common physical and chemical processes of change described in Figure 1.2. Most of these processes involve inorganic and organic materials in solid, liquid, and gaseous states, or *phases*. Note that many of the processes have opposite effects depending on the flow of energy to or from a material: melting and freezing, evaporation and condensation, dissolution and chemical precipitation, photosynthesis (food energy storage) and respiration (food energy release or "burning" without flames). The process called *sublimation* also is reversible: a solid changing directly to a gas, or a gas changing directly to a solid (Figure 1.3). Such effects cause chemical materials to be endlessly cycled and recycled between two or more phases. One of these cycles is the *hydrologic cycle*, or "water cycle" (Figure 1.4).

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