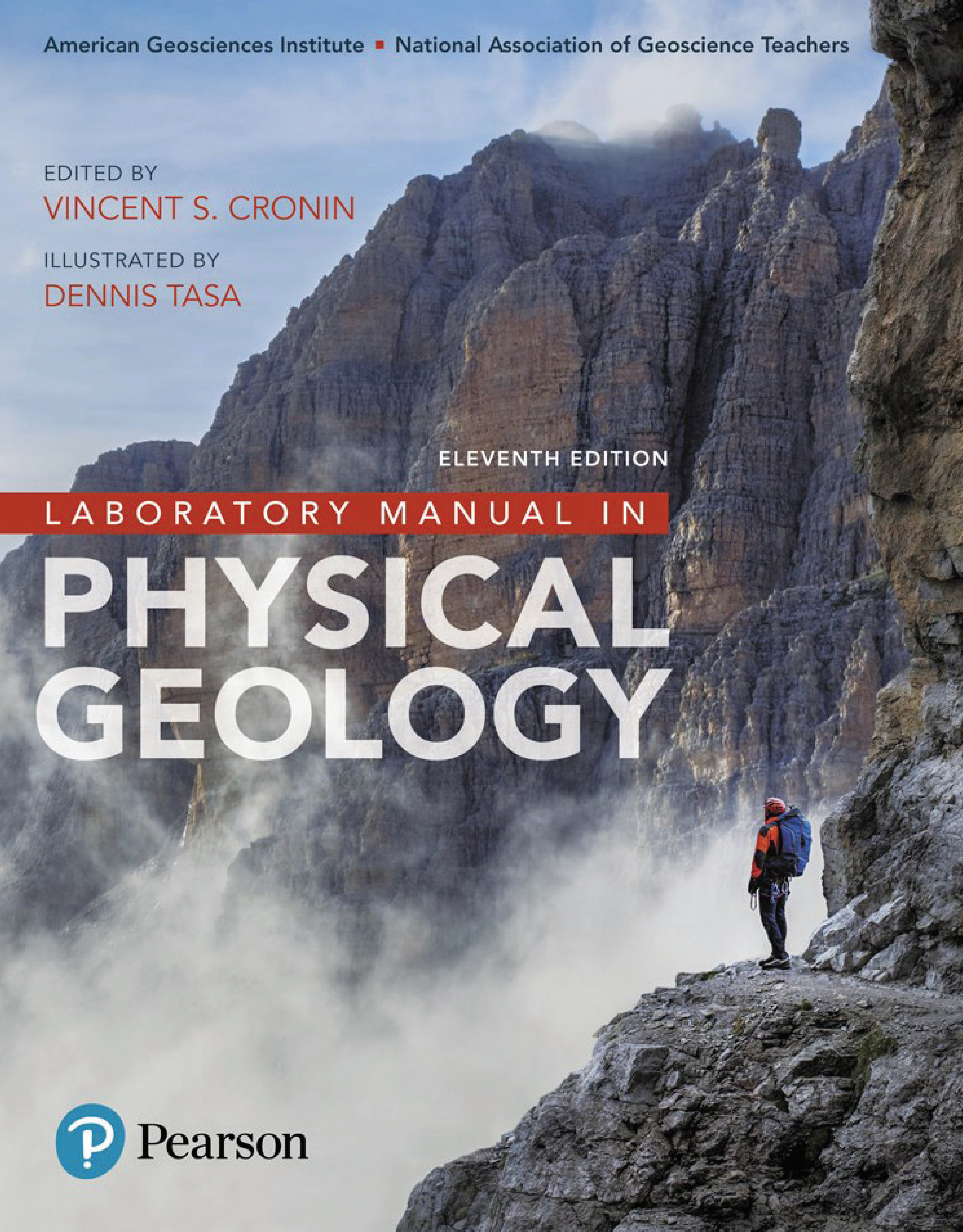

American Geosciences Institute ▪ National Association of Geoscience Teachers


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VINCENT S. CRONIN
ILLUSTRATED BY
DENNIS TASA


ELEVENTH EDITION

# LABORATORY MANUAL IN PHYSICAL GEOLOGY

Pearson

ELEVENTH EDITION

# Laboratory Manual in PHYSICAL GEOLOGY

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ELEVENTH EDITION

# Laboratory Manual in PHYSICAL GEOLOGY

PRODUCED UNDER THE AUSPICES OF THE

**American Geosciences Institute**

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# 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 11$^{th}$ edition is more user-friendly than ever, with an effective pedagogical format and many more teaching and learning options. It is supported by MasteringGeology—the most effective and widely used online homework, tutorial, and assessment platform in the Geosciences, including an eText version of the lab manual—as well as by GeoTools (ruler, protractor, UTM grids, sediment grain size scale, etc.), an *Instructor Resource Manual*, and many other online resources.

The idea for this jointly sponsored laboratory manual originated with Robert W. Ridky (past president of NAGT and 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 edition represents the cumulative ideas of more than 225 contributing authors, 31 years of evolution in geoscience and geoscience education, the comments of faculty peer reviewers and geoscience professionals, and important input from students and instructors who have used past editions.

## About the 11$^{th}$ Edition

Why did AGI and NAGT develop an 11$^{th}$ edition of the *Laboratory Manual in Physical Geology*? We are in a time of dramatic change within the geosciences, in society, and in the environment of our planetary home—Earth. New technologies, new data, and new hypotheses are flooding into the geosciences, as geoscientists strive to apply new knowledge to provide expertise to a society trying to cope with challenges related to water, energy, mineral resources, natural and human-induced environmental hazards, and global change. An ever-changing *Laboratory Manual in Physical Geology* is essential for AGI and NAGT to fulfill their missions in helping to educate and inform the public and to facilitate the development of the next generation of geoscientists.

Through a nationwide search conducted collaboratively by AGI and NAGT, Professor Vincent S. Cronin was selected as editor of the 11$^{th}$ edition. Dr. Cronin brings a mix of practical instructional knowledge and expert geological background. He has been a geoscientist and university-level geoscience educator for about three decades, and has experience teaching with the *Laboratory Manual in Physical Geology*. His research includes topics in engineering geology, structural geology, and tectonics. He is also Co-Chair of the U.S. Section of the International Association for Promoting Geoethics.

The team that developed the new edition of this classic laboratory manual sought to preserve features that are familiar and valued by the geoscience education community, while making revisions that were requested by users or deemed necessary to better reflect current developments in specific areas of the geosciences. We have also developed new online resources for students, such as a glossary to facilitate the learning process of students using this textbook, as well as enhancing access to images and videos. In this edition, we have embarked on a process that will ultimately make all of our illustrations more accessible to people with color blindness or other vision-related issues. We are committed to a geoscience community that is diverse, inclusive, and welcoming to all. And we recognize that there is an essential ethical dimension to our work in geoscience, which we explore in many ways throughout the text.

### Supporting Text

The text that appears before the Activity section of each chapter serves two goals. One is the practical goal to provide essential information to students working on the Activities. The second is to provide students with a coherent body of information that will remain after the Activities are completed, and after the Activity pages are torn from the book.

Most of the supporting text in the 11$^{th}$ edition is new or has been revised. These changes have been made on the basis of reviews by faculty and students, and based on current trends in the geosciences. Great care has been taken to compose supporting text that is scientifically correct, uses the appropriate geoscience terms correctly, is comprehensible by undergraduate college students, and is well supported with illustrations. Whereas the target audience for this Laboratory Manual is a diverse population of students who will ultimately pursue knowledge and careers in other fields, we also want this edition to provide a sound foundation for those who pursue additional study in geoscience.

### Vocabulary and Geoscience Terminology

We have continued the tradition of using vocabulary appropriate to undergraduate students in the 11$^{th}$ edition, and have sought to keep geoscience jargon to a necessary minimum. Rock and mineral terms are used in a way that is consistent with the published standards of the International Mineralogical Association and the International Union of Geological Sciences, as well as with the latest edition of the American Geoscience Institute (AGI) *Glossary of Geology*. The complete AGI *Glossary of Geology* is available in print, as an E-book for Kindle and Nook, as an app for mobile devices (available at the Apple Store and at Google Play), and online for universities and companies (but not for individuals; www.americangeosciences.org/pubs/glossary). An abbreviated glossary developed for the *Laboratory Manual in Physical Geology* is also available online.

## Art

Dennis Tasa's brilliant artwork reinforces the visual aspect of geology and enhances student learning. Many figures have been revised for the 11th edition, and all of the figures in both the text and in the activities are numbered to help students navigate to the resources they need efficiently. For example, labels and overlays have been added to photographs and other images to facilitate students' understanding.

- **Photographs.** There are almost two hundred new photographs or satellite images in the 11th edition. Some of the new photographs of rock and mineral specimens are the result of very high resolution macro photography enhanced by focus-stacking technology.
- **Maps.** There are about three dozen new maps in this edition. New topographic maps are based on the most current U.S. topographic map product published digitally by the USGS. Many of the maps have been simplified to reduce irrelevant elements and improve clarity.
- **Illustrations.** Many of the graphics retained from previous editions are revised, and there are dozens of entirely new illustrations and tables.

## Activities

Of the 96 activities spread across 16 chapters, 10 are new and many of the rest are revised to improve content and clarity. Having access to such a large number of activities allows an instructor to select and adapt activities according 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, homework, or recitation topics.

## Math

Geoscience in the 21st Century relies largely on quantitative information, although many definitions and descriptions of geological materials involve qualitative information, too. Nearly four hundred years ago, Galileo wrote that the book of Nature is written in the language of mathematics. While it is true that essential insights are gained through descriptive or qualitative observations, we cannot progress far in geoscience without quantitative measurements, mathematical expressions that link quantitative observations together, and statistical analysis. We assume that students have an average understanding of basic high-school mathematics, and develop useful math skills as they are needed to understand the material or to complete an activity.

# Outstanding Features

This edition contains the tried-and-tested strengths of ten past editions of this lab manual that have been used by faculty and teachers over more than three decades, with updates to maintain its position as a reflection of current geoscience thinking. The outstanding features listed below remain a core part of this manual.

## 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™, 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*. Presentation graphics (PowerPoint) and video clips appeal to *auditory/aural learners*. Numerical data, mathematics, models, graphs, systems, and opportunities for discourse appeal to *logical/abstract learners*.

## Pre-Lab Videos

Pre-Lab videos are found on the chapter-opening spreads of each lab, and are accessed via a Quick Response (QR) code or direct web-link. These videos allow students to come to lab better prepared and ready to immediately benefit from their engagement with lab exercise. No longer do instructors have to spend the first portion of hands-on lab time lecturing. The videos can be viewed during the students' own preparatory time, and review key concepts relevant to the lab activities. The videos, created by Callan Bentley (Northern Virginia Community College), 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. Students can download free QR reader apps from the Apple App Store or Google Play.

## Format and Pedagogical Framework

- **Big Ideas and Engaging Chapter Openers.** Every laboratory opens with an engaging image and a statement of *Big Ideas*, which establish the overall conceptual themes upon which the laboratory is based. *Big Ideas* are concise statements that help students understand and focus on the lab topic.
- **Think About It—Key Questions.** Every activity is based on a key question that is linked to the *Big Ideas*. *Think About It* questions function as the conceptual "lenses" that frame student inquiry and promote critical thinking and discourse.
- **Guided and Structured Inquiry Activities.** Many of the laboratories begin with a guided inquiry activity. These inquiries are designed to be engaging and to help students activate cognitive schemata that relate to the upcoming investigations. These can be used for individualized or cooperative learning. The guided inquiry activity is followed by activities that are more structured, so students can develop their understanding of specific geoscience concepts and principles.
- **Reflect & Discuss Questions.** Every activity concludes with a *Reflect & 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.

- **Continuous Assessment Options.** The 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 & Discuss* questions. When students tear out and submit 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 distribute worksheets to supplement the manual.

## Enhanced Learning Options

- **Transferable Skill Development and Real-World Connections.** Many activities have been designed or revised for students to develop transferrable skills and make connections that are relevant 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 learn to use resources provided by the U.S. Geological Survey, JPL-NASA, NOAA, Google Earth™, and other online sources of reliable data and analysis about Earth's resources, hazards, changes, and management.

- **The Math You Need (TMYN) Options.** Throughout the laboratories, students are referred 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).

- **Mobile-Enabled Media and Web Resources.** Quick Response (QR) codes give students with smartphones or other mobile devices instant access to supporting online media content and websites.

- **Enhanced Instructor Support.** Instructor materials are available online in the Instructor Resource Center (IRC) at www.pearsonhighered.com/irc. Resources include the enhanced *Instructor Resource Manual* (answer key and teaching tips), files of all figures in the manual, PowerPoint presentations for each laboratory manual in JPEG and PowerPoint formats, the Pearson Geoscience Animation Library (over 120 animations illuminating the most difficult-to-visualize geological concepts and phenomena), and MasteringGeology options.

## 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 make course material accessible and to help them develop their understanding of 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.

- **Pre-lab video quizzes** help students come to lab better prepared and ready to immediately get started with the lab exercise.
- **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 areas in which adjustments to instruction will be helpful to students.
- 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. To learn more, go to www.learningcatalytics.com.

## Materials

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

## GeoTools, GPS, and UTM

Rulers, protractors, a sediment grain size scale, UTM grids, and other laboratory tools are available 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.

## New & Updated in the 11th Edition

**1.1: A View of Earth from Above** (new)
New—coordinate systems and Google Earth used to locate places and geologic features.
**A1.1.1, A1.1.2, A1.1.3, A1.1.4:** new tables for data and student answers

**1.2: Latitude and Longitude or UTM Coordinates of a Point** (new)
New—map scales, measure on map, and calculate representative fraction.
**A1.2.1:** new diagram; **A1.2.2:** new map with UTM coordinates

**1.3: Plotting a Point on a Map Using UTM Coordinates** (new)
New—practice in plotting points precisely using UTM coordinates and Google Earth.
**A1.3.1:** map with UTM coordinates

**1.4: Floating Blocks and Icebergs** (new)
New—measure volume and mass, calculate density, apply Archimedes principle.
**A1.4.1:** new art relating volume, mass, and density; **A1.4.2:** new art showing buoyancy

**1.5: Summarizing Data and Imagining Crustbergs Floating on the Mantle** (10e: 1.6)
Revised to clarify concept of isostasy; calculate standard deviations of rock-sample densities
**A1.5.1, A1.5.2:** revised data tables for densities mode and standard deviation

**1.6: Unit Conversions, Notation, Rates, and Interpretations** (10e: 1.4)
Revised to focus on rates of change (erosion, geothermal gradient, and changing atmospheric $CO_2$ levels).
**A1.6.1, A1.6.2, A1.6.3:** revised data and graphs with updated atmospheric $CO_2$ data

**1.7: Scaling, Density, and Earth's Deep Interior** (new)
New—draw Earth's interior structure to scale based on graph of density changes beneath surface.
**A1.7.1:** new table; **A1.7.2:** new diagram and graph of Earth's interior structure

**2.1: Reference Frames and Motion Vectors** (new)
New—uses concepts of reference frames and vectors to explore plate motions.
**A2.1.1:** new map of Juan de Fuca plate; **A2.1.2:** new graphic (template) for drawing vectors

**2.2: Measuring Plate Motion Using GPS Time Series** (10e: 2.1)
Revised to walk students step-by-step through activity; **Part D:** New *Reflect & Discuss* question; use of UNAVCO online calculator.
**A2.2.2:** revised map

**2.3: Hotspots and Plate Motions** (10e: 2.8)
**Part A:** Question #4 added; Question #5 revised; **Part B:** added questions and steps; use of Pythagorean theorem to determine speed of plate motion.

**2.4: How Earth Materials Deform** (10e: 2.3)
Added steps and questions help students grasp how activities model Earth processes.

**2.5: Paleomagnetic Stripes and Seafloor Spreading** (10e: 2.4)
**A2.5.1:** revised map of Juan de Fuca plate

**2.6: Atlantic Seafloor Spreading** (10e: 2.5)
Heavily revised: Concept of isochrons on map of Atlantic seafloor added; new questions lead students through an in-depth exploration.
**A2.6.1:** new basemap of seafloor spreading

**2.7: Using Earthquakes to Identify Plate Boundaries** (10e: 2.6)
Questions and procedures edited to clarify and add background info.

**3.1: Mineral and Rock Inquiry** (10e: 3.1)
Questions edited for clarity; **Part C:** New *Reflect & Discuss* question based on students' observations.

**3.2: Mineral Properties** (10e: 3.2)
**Part I:** New *Reflect & Discuss* questions on distinguishing crystal systems, forms, and habits.

**3.5: Mineral Dependency Crisis** (10e: 3.5)
**Part C:** New *Reflect & Discuss* question on foreign vs. domestic sources of essential minerals.

**4.1: Rock Inquiry** (10e: 4.1)
**Part C:** New *Reflect & Discuss* question on how rocks form.
**A4.1.3:** new photo of gneiss to go with new question

**4.2: What Are Rocks Made Of?** (10e: 4.2)
**A4.2.1:** new improved photo #5 of gabbro

**4.3: Rock-Forming Minerals** (10e: 4.3)
**A4.3.1:** 8 new photos of rock-forming minerals

**4.4: What Is Rock Texture?** (10e: 4.4)
**A4.4.1:** new photos of labradorite gabbro

**4.5: Rock and the Rock Cycle** (10e: 4.5)
**A4.5.2:** table revised (because obsidian is not considered a rock)

**5.5: Estimate Percentage of Mafic Minerals** (new)
New—describe igneous rock samples and estimate mafic-mineral content.
**A5.5.1:** new scale of percent mafic minerals; **A5.5.2:** new photos of igneous rock samples for analysis

**5.6: Estimate Composition of a Phaneritic Rock by Point Counting** (new)
New—point-counting to estimate mineral composition; calculate averages and standard deviations for point-count data.
**A5.6.1:** new photo of granite sample and art of its mineral composition; **A5.6.2:** new grids used in point counting exercise

**6.2: Sediment from Source to Sink** (new)
New example walks students step-by-step through analysis of how sediment changes.
**A6.2.1:** new sequence of photos by author showing changes in sediment along river

**6.3: Clastic Sediment** (10e: 6.3)
Questions edited to clarify and add background information.

**6.4: Bioclastic Sediment and Coal** (10e: 6.4)
Revised to use preferred terms *bioclastic* and *siliciclastic*. Questions edited to clarify; **Part C:** New *Reflect & Discuss* question on classifying types of coal.

**6.7: Grand Canyon Outcrop Analysis and Interpretation** (10e: 6.7)
Questions edited to clarify.
**A6.7.1:** labels and lines added to photo of sedimentary strata

**7.2: Minerals in Metamorphic Rock** (new)
New exercise in mineral identification.
**A7.2.1:** set of 6 minerals that students identify based on descriptions in the text

**7.3: Metamorphic Rock Analysis and Interpretation** (10e: 7.2)
Questions edited to clarify and add background information.

**7.5: Metamorphic Grades and Facies** (10e: 7.4)
Questions edited to clarify and add background information; **Part C:** New *Reflect & Discuss* question on interpreting A7.5.4.
**A7.5.4:** new PT diagram of Barrow's metamorphic zones; **A7.5.5:** revised block diagram with improved legibility and detail

**8.1: Geologic Inquiry for Relative Dating** (10e: 8.1)
**A8.1.2, A8.1.3:** adds grayscale duplicates to photos so that students can trace the contacts

**8.3: Use of Index Fossils to Date Rocks and Events** (10e: 8.3)
Terms added to enable more precise relative dating of index fossils.

**8.4: Numerical Dating of Rocks and Fossils** (10e: 8.4)
**Part C** Revised to clarify and add background information.

**8.5: Infer Geologic History from a New Mexico Outcrop** (10e: 8.5)
**A8.5.1:** adds labels to photo to clarify the geology of the strata

**8.6: Investigating a Natural Cross Section in the Grand Canyon** (10e: 8.6)
**Part A** Revised to clarify *Reflect & Discuss.*
**A8.6.1, A8.6.2:** adds grayscale duplicates to photos so that students can trace the contacts

**9.2: Map Locations, Distances, Directions, and Symbols** (10e: 9.2)
**Parts D, F, G:** Revised to clarify and add background information; new questions about magnetic declination, grid north and true north.
**A9.2.1:** adjust map scale for accuracy, add UTM coordinates and improve legibility

**9.3: Topographic Map Construction** (10e: 9.3)
Background information added to questions about contour lines and hachures.

**9.4: Topographic Map and Orthoimage Interpretation** (10e: 9.4)
**A9.4.1:** improve legibility of streams, contour lines, and labels; **A9.4.2:** topo map with improved legibility

**9.5: Relief and Gradient (Slope) Analysis** (new—although based on 10e, 9.5)
Uses real-world example; new questions on using map scale and measurements to calculate gradient and interpret slopes.
**A9.5.1:** uses part of a real USGS topo map of Yosemite N.P.

**9.6: Topographic Profile Construction** (10e: 9.6)
**A9.6.1:** replaces graph paper with more student friendly template for drawing topographic profile

**10.1: Map Contacts and Formations** (10e: 10.3)
Revised activity now focuses on Grand Canyon example, and provides more guidance for students in tracing the contacts.
**A10.1.2:** replaces the Grand Canyon topo map with adapted version of more legible map by the geologist Billingsley

**10.2: Geologic Structures Inquiry** (10e: 10.1)
**Part C:** New *Reflect & Discuss* question involves determining strike and dip of inclined strata.
**A10.2.1:** new, clearer photo of Grand Canyon (upper left); **A10.2.2:** new photo of inclined strata; includes a grayscale duplicate so that students can draw dip vector and label photo

**10.3: Fault Analysis Using Orthoimages** (10e: 10.7)
**Part C:** New *Reflect & Discuss* question about vertical as well as horizontal components of fault slip.
**A10.3.1, A1.3.2:** scale and north arrow added to orthoimages

**10.4: Appalachian Mountains Geologic Map** (10e: 10.8)
**A10.4.1:** geologic cross section revised to clarify.

**10.5: Cardboard Model Analysis and Interpretation** (10e: 10.5)
Lightly edited to clarify questions and use correct terminology.

**10.6: Block Diagram Analysis and Interpretation** (10e: 10.6)
**A10.6.1:** Edits to captions on the block diagrams to clarify the questions.

**11.1: Streamer Inquiry** (10e: 11.1)
Lightly edited to make instructions more precise; **Part C:** New questions on a stream's discharge, channel width and volume.

**11.2: Drainage Basins, Patterns, Gradients, and Sinuosity** (10e: 11.2)
Revised to clarify and shorten; 10e **Parts D** and **E** used as the basis for Activity 11.3.
**A11.2.1:** map contour lines and labels revised to improve legibility; **A11.2.2:** improved legibility of basemap; **A11.2.3:** improved legibility of topo map

**11.3: Mountain Stream** (10e: 11.2)
Made up of **Parts D** and **E** of 11.2; focuses on analysis of specific streams in Ennis, MT quadrangle.
**A11.3.1:** improved labeling of topo map and profile box

**11.4: Escarpments and Stream Terraces** (10e: 11.3)
"Starter" points added to profile box to aid students in constructing profile; location coordinates added.
**A11.4.1:** improved legibility of basemap of Voltaire, ND

**11.6: Retreat of Niagara Falls** (10e: 11.5)
Background information on Niagara gorge added; **Part A:** Measure Niagara gorge on map; location coordinates added.

**A11.6.1:** cross section of Niagara Falls moved to point-of-use in Activity 11.6

**11.7: Flood Hazard Mapping, Assessment** (10e: 11.6)
Concepts of gage datum and gage height added; questions and procedures revised to clarify.
**A11.7.1:** improved legibility of labels; north arrow and scale added; **A11.7.2:** flood data table revised; **A11.7.4:** labels, north arrow, and scale added

**12.1: Groundwater Inquiry** (10e: 12.1)
**Part A:** New Experiment 2 compares rates of groundwater flow; **Part D:** New *Reflect & Discuss* question on Experiment 3 (former 2)
**A12.1.2:** art showing setup of tubes in Experiment 2; **A12.1.3:** revised data in table

**12.2: Where Is the Nasty Stuff Going?** (new)
New—construct a contour map of water table and trace pollutants' flow lines through the aquifer.
**A12.2.1:** art showing water table elevations used in constructing map of groundwater flow

**12.3: Using Data to Map the Flow of Groundwater** (new)
New—use piezometer data to determine total head values, map them, and infer flow lines.
**A12.3.1:** cross section showing total head values at different points within an aquifer

**12.6: Land Subsidence from Groundwater Withdrawal** (10e: 12.4)
**Part A:** New questions 8b–f on changes in water level based on hydrograph data (Fig. 12.6.X); **Part B:** New *Reflect & Discuss* question on effects of land use change on subsidence.
**A12.6.2:** graphs of land subsidence in Santa Clara Valley in relation to water table and groundwater use.

**13.1: The Cryosphere and Sea Ice** (10e: 13.1, 13.6)
**Part A:** Revised to clarify questions and shorten; **Parts B** and **C:** Based on 10e, Activity 13.6, with new *Reflect & Discuss* in which students compare climate change in Arctic and Antarctic.
**A13.1.1:** data table and graphs (where student's plot the data) on Arctic sea ice extent

**13.2: Mountain Glaciers and Glacial Landforms** (10e: 13.2)
Revised to focus on glaciation in Yosemite, with added background information.
**A13.2.1, A13.2.2:** new profile boxes for constructing profiles; **A13.2.3:** new topo map with transect line and profile box

**13.3: Nisqually Glacier Response to Climate Change** (10e: 13.5)
**Parts A** and **B:** Revised to clarify questions, with step-by-step directions on plotting data.
**A13.3.1:** revised data table, bar graph, and blank graph of changes in glacier

**13.4: Glacier National Park Investigation** (10e: 13.4)
**Part D:** Revised to explain Continental Divide; new question 3 on correlating glaciers with topography and slope orientation.

**13.5: Some Effects of Continental Glaciation** (10e: 13.3)
Revised to shorten: Focuses on Whitewater, WI topo map; new question 7 on identifying glacial features on map.

**14.1: Dry Land Inquiry** (10e: 14.1)
**Parts B** and **D:** Edited for clarity; **Part C:** Mostly new—use GoogleEarth to analyze a fault-bounded valley.

**14.2: Sand Seas of Nebraska and the Arabian Peninsula** (10e: 14.3)
**Parts A** and **B:** Edited to clarify questions and add background info; location coordinates added.
**A14.2.2:** new aerial photo and topo map of White Lake, NB quadrangle

**14.3: Dry-Land Lakes of Utah** (10e: 14.4)
**Part F:** Edited to clarify and remove references to 10e's use of a stereogram image.
**A14.3.1:** locator map and scale information added to map of Wah Wah Valley, UT

**14.4: Death Valley, California** (10e: 14.2)
**Part C:** New—identify and trace normal faults on map.: **Part D:** New—consider plate motions in relation to pull-apart basins.
**A14.4.1:** labels edited and added to map of Death Valley

**15.1: Coastline Inquiry** (10e: 15.1)
**Part A:** Question 1 revised to focus on geology of the coastal areas; **Part B:** *Reflect & Discuss* questions made more specific.

**15.2: Introduction to Coastlines** (10e: 15.2)
Edited to simplify terminology.

**15.3: Coastline Modification at Ocean City, Maryland** (10e: 15.3)
Edits to clarify historical changes; **Part F:** *Reflect & Discuss* on the future of Ocean City given its elevation and rate of local sea-level rise.

**15.4: The Threat of Rising Seas** (10e: 15.4)
Added background information on Hurricane Sandy's storm surge on Staten Island, NY.

**16.1: Earthquake Hazards Inquiry** (10e: 16.1)
**Part A:** Revised to clarify directions and rephrase *Reflect & Discuss*; **Parts B, C,** and **D:** Revised to clarify questions and add background information.

**16.2: How Seismic Waves Travel Through Earth** (10e: 16.2)
Edited to clarify terms and concepts relating to seismic waves.

**16.3: Locate the Epicenter of an Earthquake** (10e: 16.3)
**Part C:** Revised question 3 refers students to a USGS website with an interactive map of active faults.

**16.4: San Andreas Fault Analysis at Wallace Creek** (10e: 16.4)
**Part A:** Revised to facilitate tracing and interpreting the fault; **Part B:** New background info and steps for calculating displacement rate.
**A16.4.1:** improved shaded relief map of topography in Wallace Creek area; **A16.4.2:** new table for students answers

**16.5: New Madrid Seismic Zone** (10e: 16.5)
New background information on faults in the New Madrid Seismic Zone (NMSZ).
**A16.5.1:** revised map to show the primary fault in the NMSZ and identify the epicenter

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# 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 the decimal system of measurement adopted by most nations of the world, including the United States (http://www.bipm.org/en/publications/si-brochure/). Each SI unit can be divided or multiplied by 10 and its powers to form the smaller or larger units. Therefore, SI is a "base-10" or "decimal" 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- |
| $\mu$ | 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 (1 $\mu$m) = 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. In this edition, we use the abbreviation "yr" for years, preceded as necessary with the letters "k" (kyr) for thousand years, "M" (Myr) for million years, or G (Gyr) for 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 ($\mu$m) | 10,000 $\mu$m/cm | |
| millimeters (mm) | meters (m) | 0.001 m/mm | |
| | centimeters (cm) | 0.1 cm/mm | |
| | inches (in) | 0.03937 in/mm | |
| | micrometers ($\mu$m) | 1000 $\mu$m/mm | |
| | nanometers (nm) | 1,000,000 nm/mm | |
| micrometers* ($\mu$m) | millimeters (mm) | 0.001 mm/$\mu$m | |
| 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* ($\mu$m) | 25,400 $\mu$m/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 $mi^2$/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.
*Sometimes called microns ($\mu$).

# 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
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
Gulf of Alaska
Hudson Bay
Baffin Bay
Bering Strait
Prudhoe Bay
Greenland
Baffin Island
EURASIAN PLATE
NORTH AMERICAN PLATE
PACIFIC PLATE
JUAN DE FUCA PLATE
Arctic Circle
Brooks Range
Alaska Range
Anchorage
YUKON TERRITORY
Whitehorse
NORTHWEST TERRITORIES
NUNAVUT
Mackenzie R.
Great Slave Lake
Coast Mountains
BRITISH COLUMBIA
ALBERTA
MANITOBA
SASKATCHEWAN
ONTARIO
QUÉBEC
NEWFOUNDLAND AND LABRADOR
Newfoundland
Prince Edward Island
P.E.I.
NEW BRUNSWICK
NOVA SCOTIA
C A N A D A
Edmonton
Calgary
Saskatoon
Regina
Winnipeg
Lake Winnipeg
Vancouver Island
Vancouver
Puget Sound
Columbia R.
Seattle
Portland
Quebec City
Saint John
Halifax
Montréal
Ottawa
St. Lawrence R.
Toronto
Hamilton
L. Superior
L. Huron
L. Michigan
L. Ontario
L. Erie
Adirondack Mtns.
ROCKY MOUNTAINS
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Teton Range
Cascade Range
Coast Ranges
Central Valley
Sierra Nevada
Great Basin
Great Salt Lake
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Boise
Missouri R.
Platte R.
Arkansas R.
Red R.
Colorado R.
Rio Grande
Ohio R.
Mississippi R.
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Milwaukee
Detroit
Chicago
Buffalo
Cleveland
Pittsburgh
Columbus
Indianapolis
Cincinnati
Louisville
St. Louis
Kansas City
Denver
Sacramento
San Francisco
San Jose
Las Vegas
Grand Canyon
Colorado Plateau
Los Angeles
Riverside
San Diego
Salton Sea
Phoenix
Tucson
Albuquerque
El Paso
Oklahoma City
Dallas-Fort Worth
Austin
San Antonio
Houston
New Orleans
Ozark Mtns.
Ouachita Plateau
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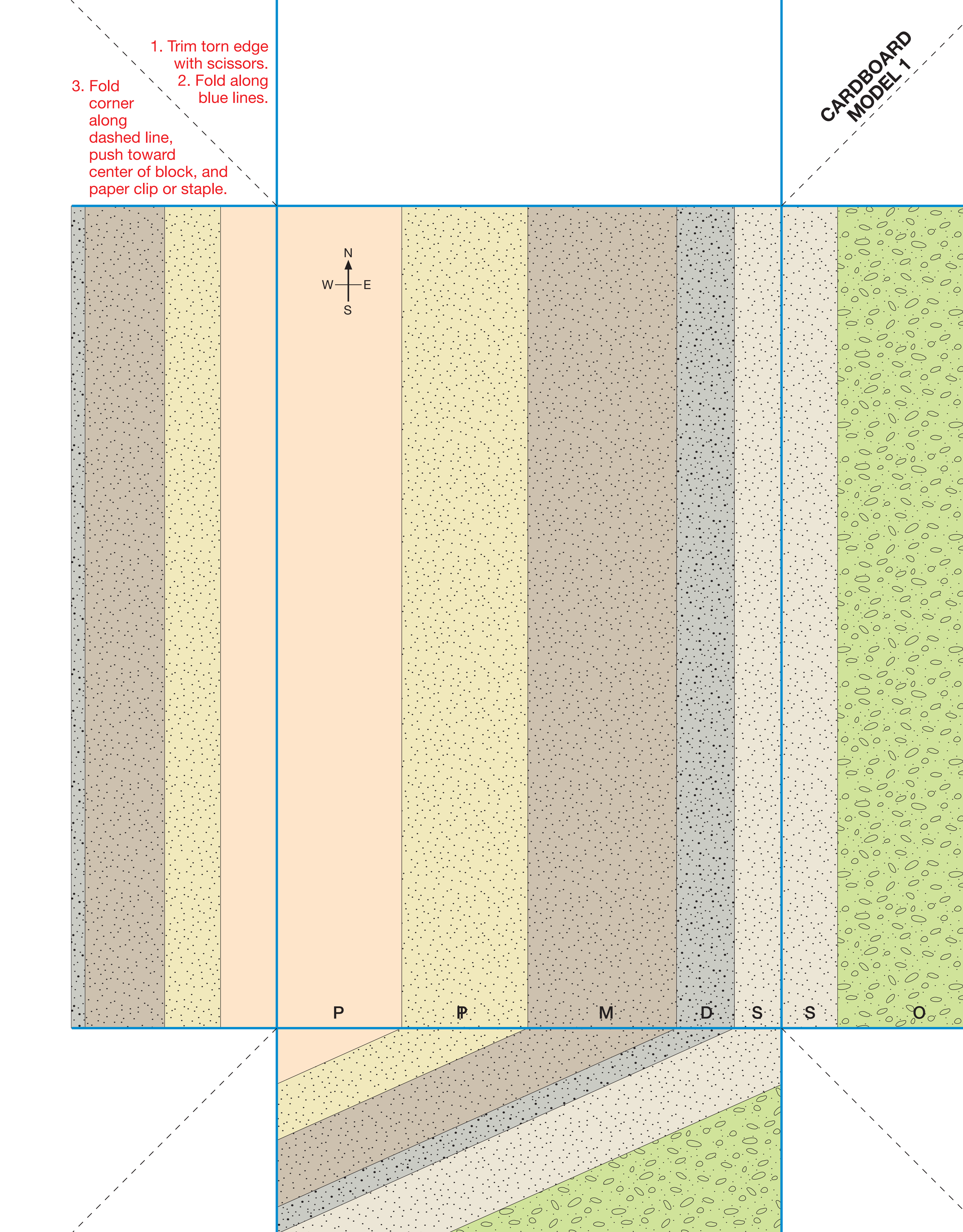
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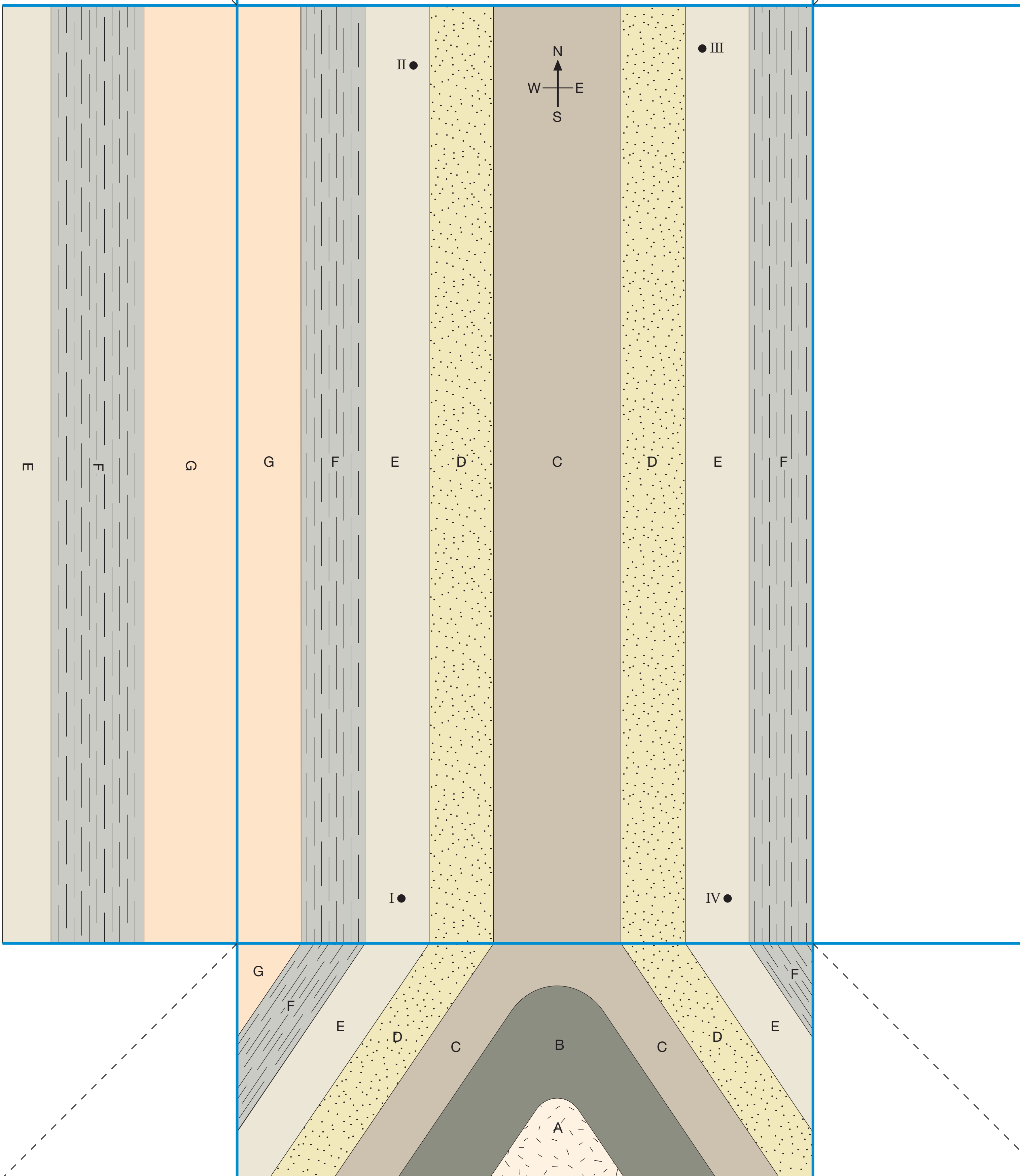

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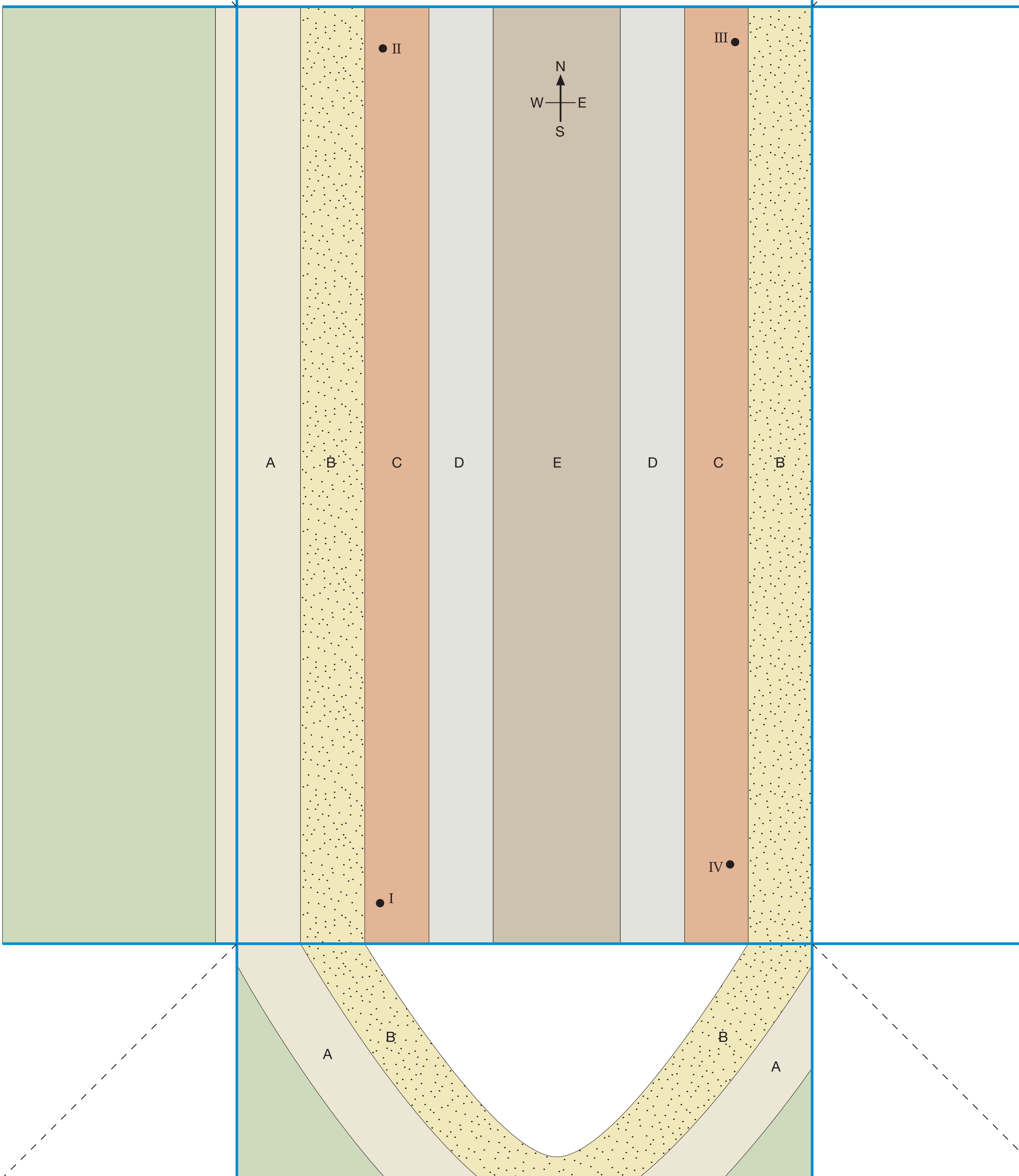

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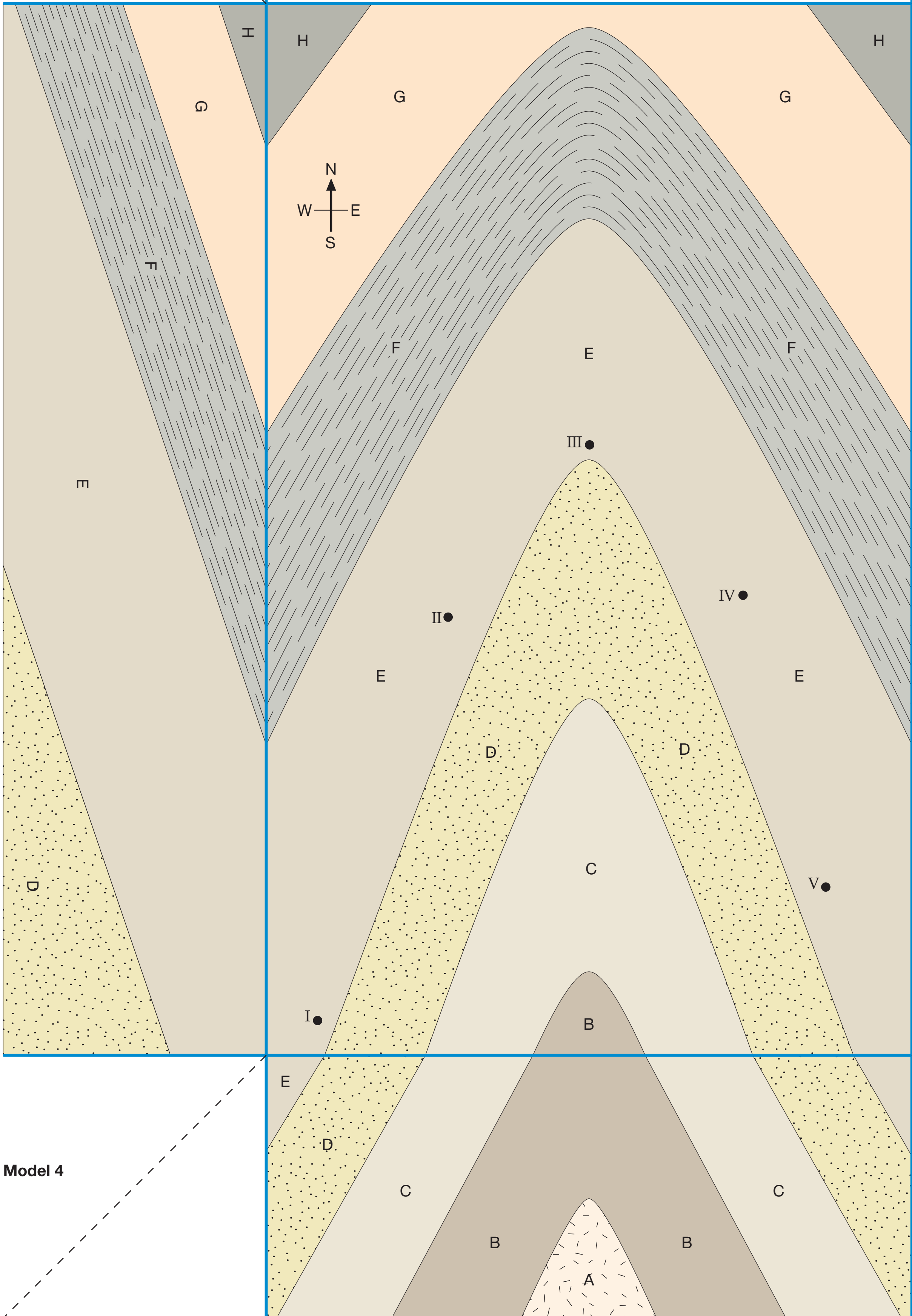


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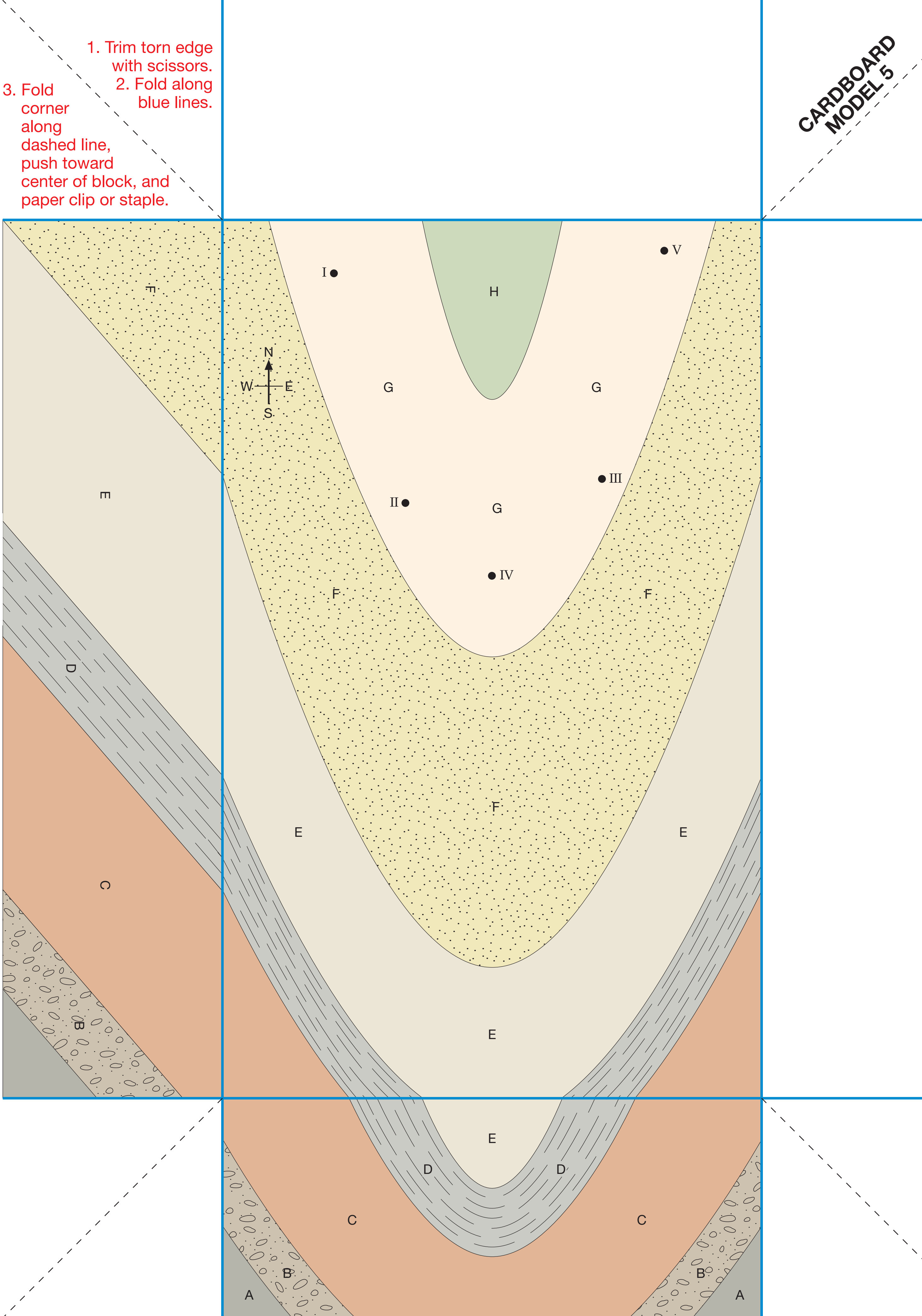

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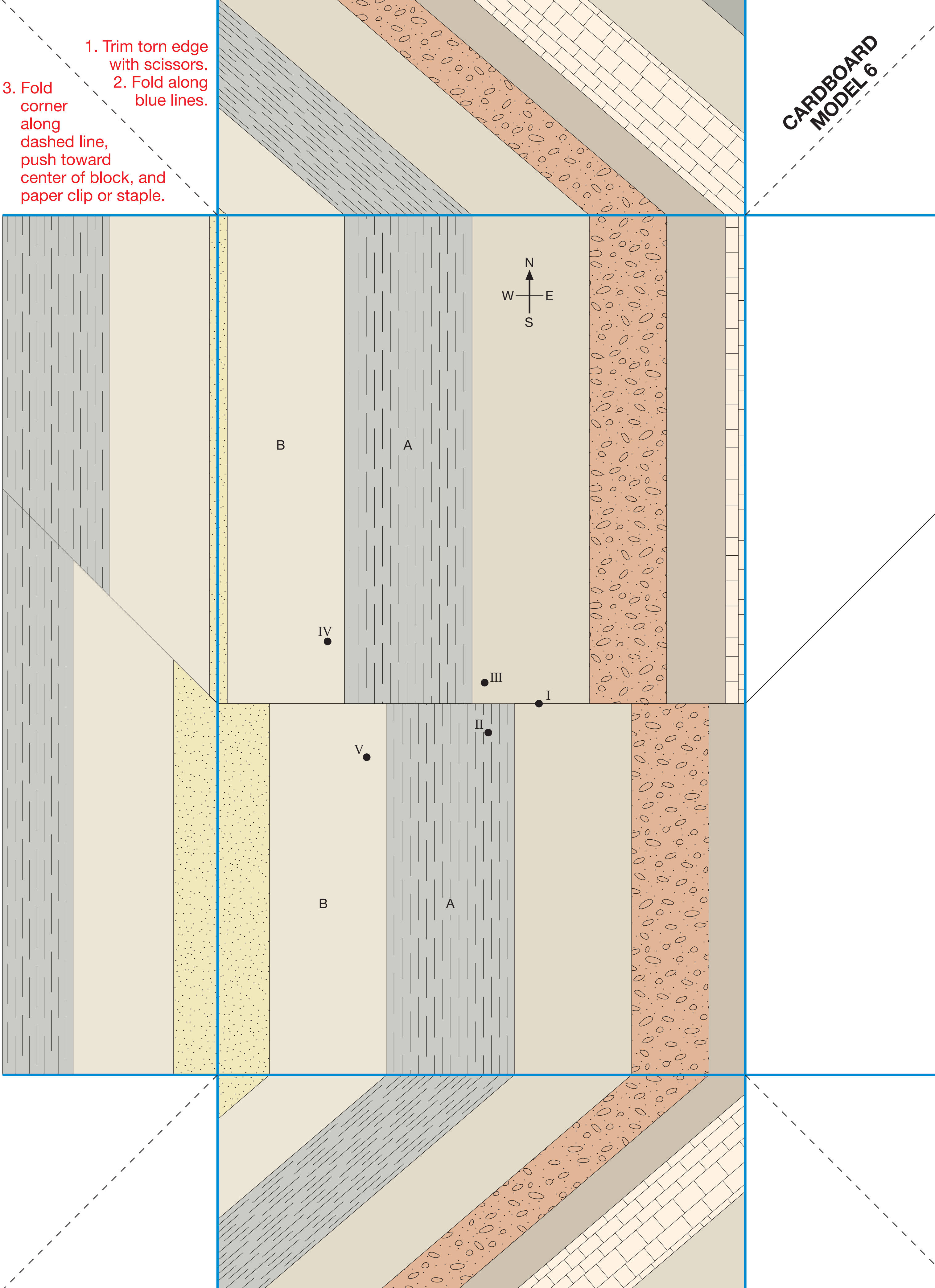
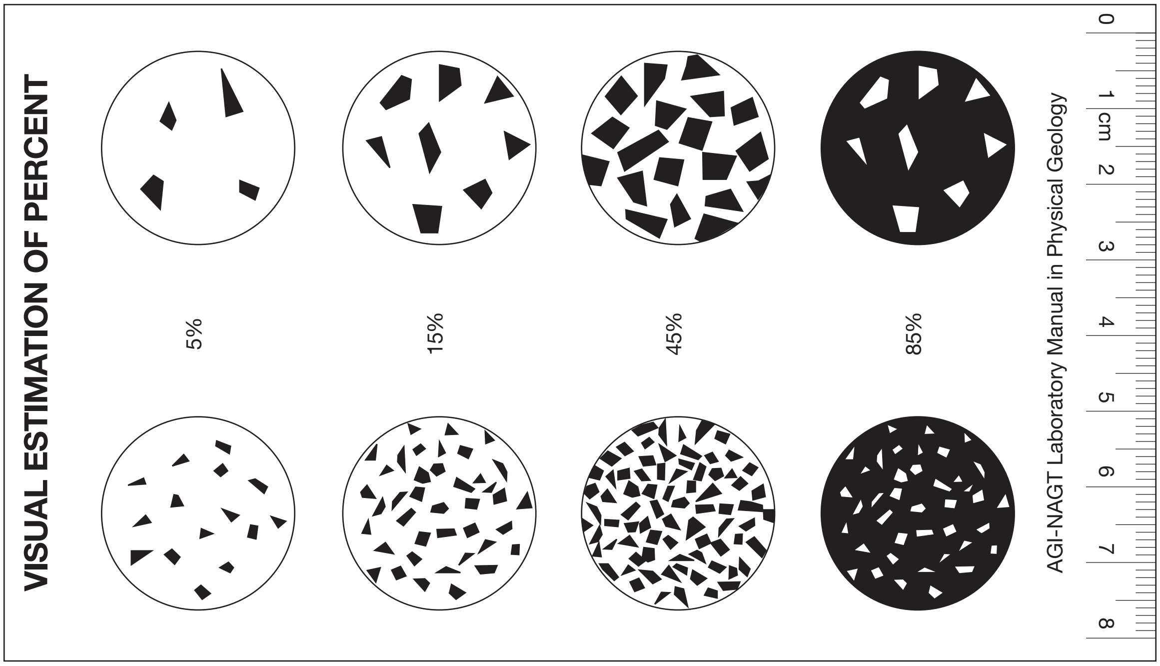
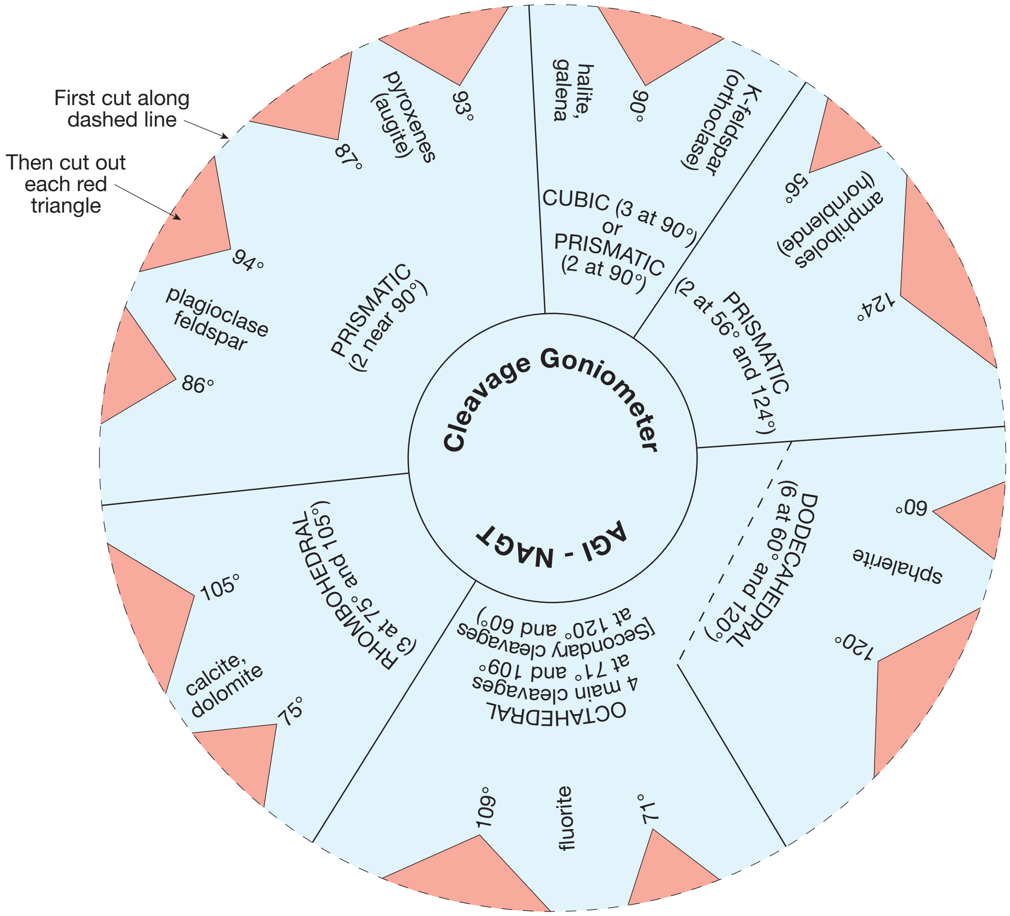
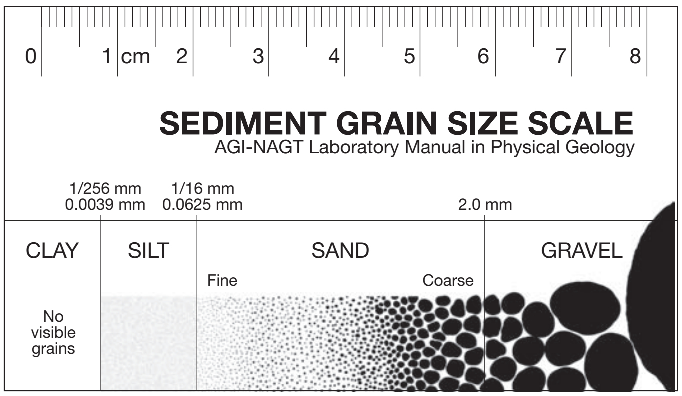


# GEOTOOLS SHEET 1




## GeoTools

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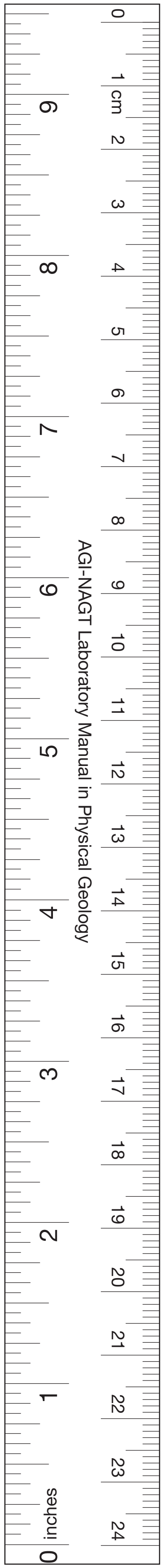

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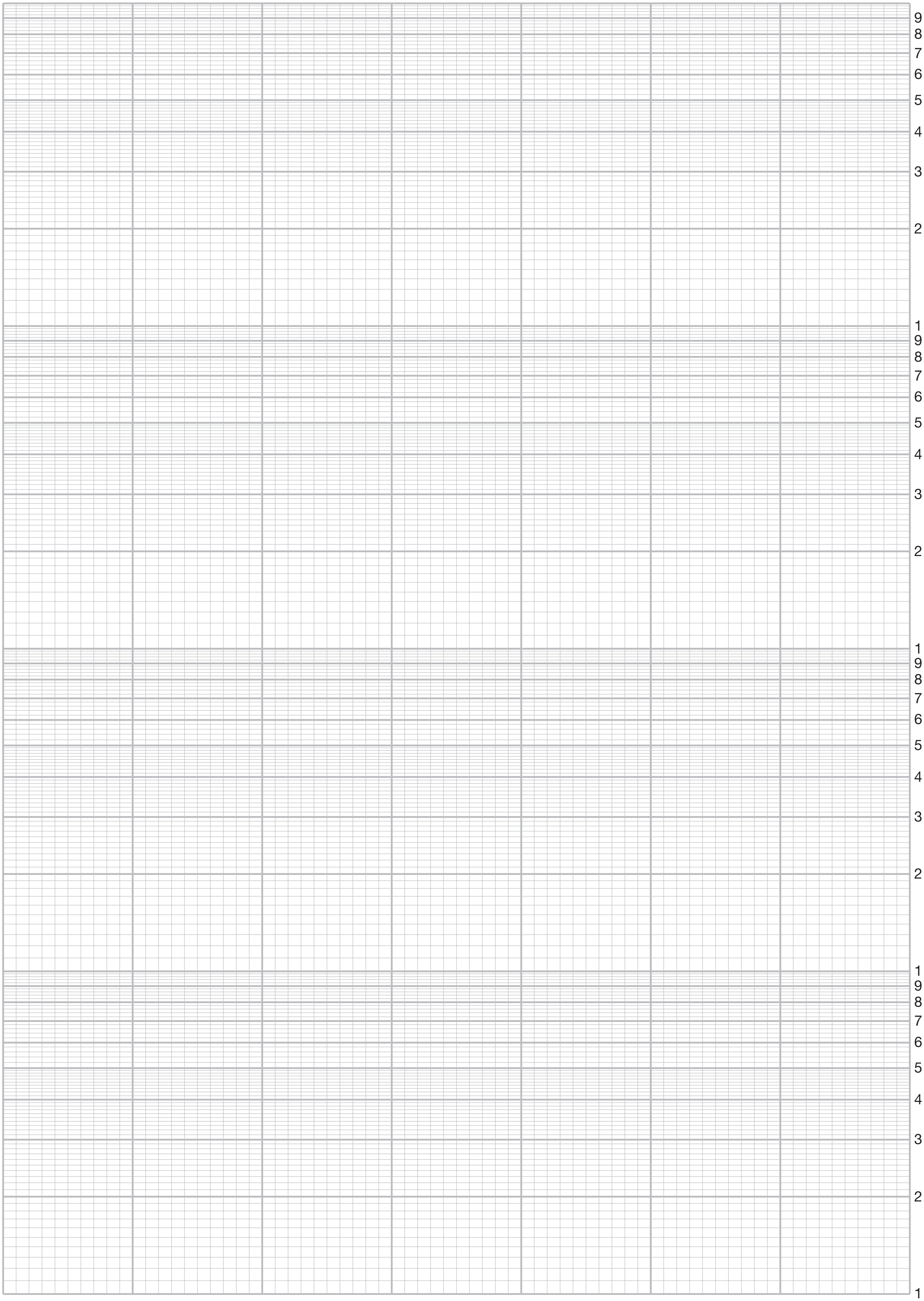
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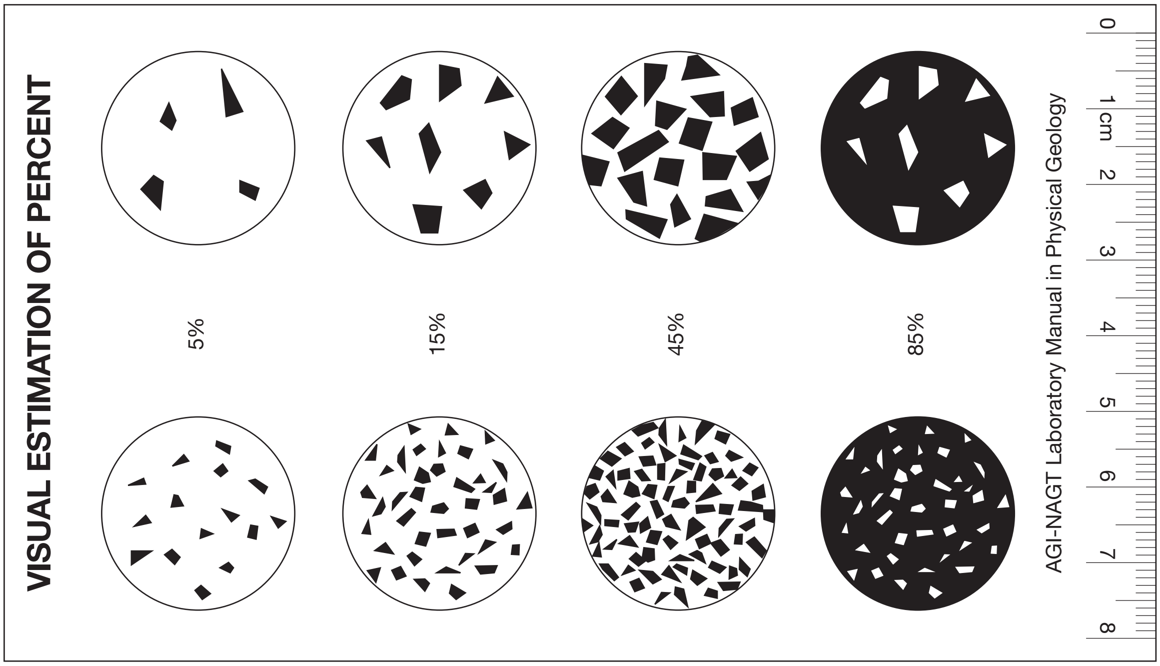


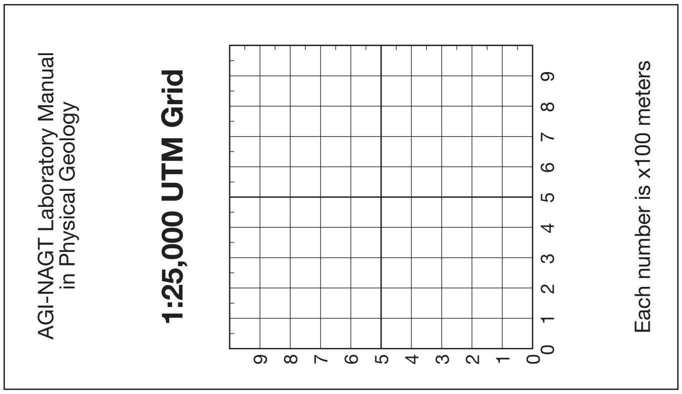


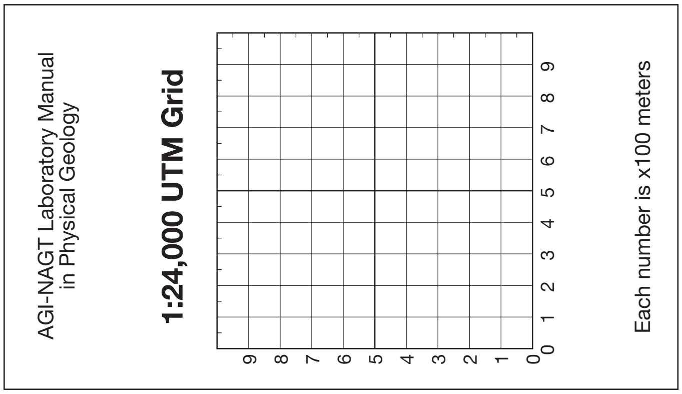


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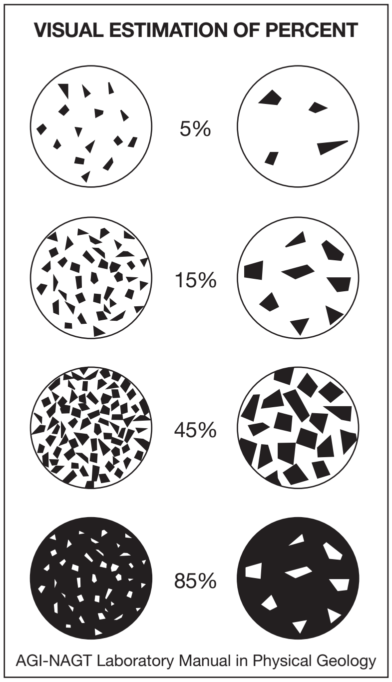


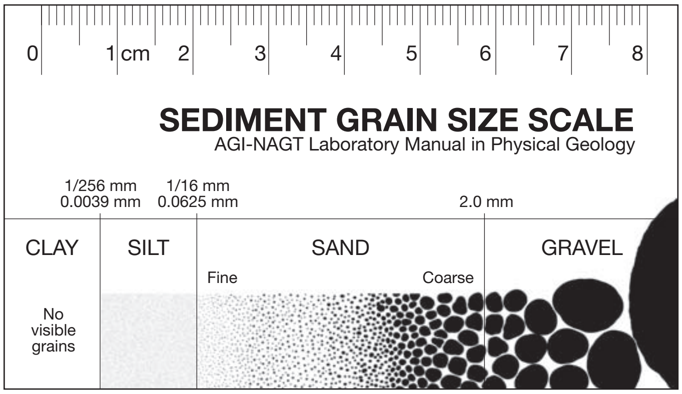


## GeoTools

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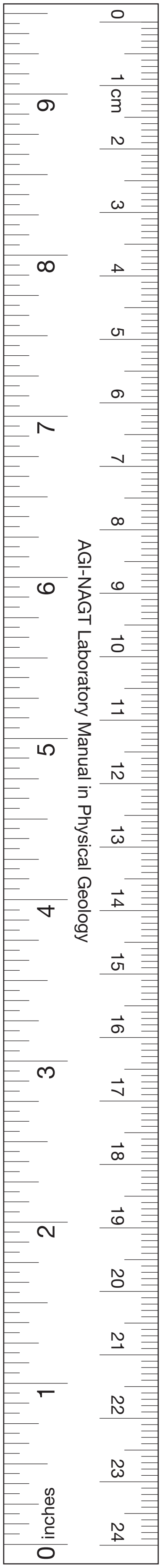

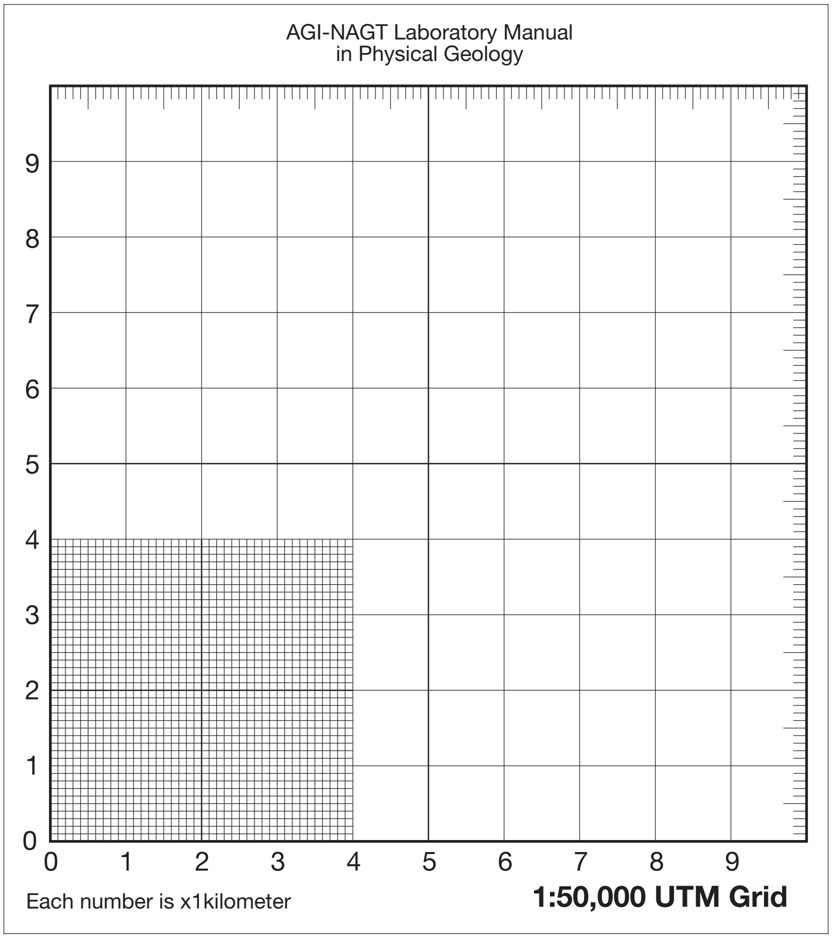


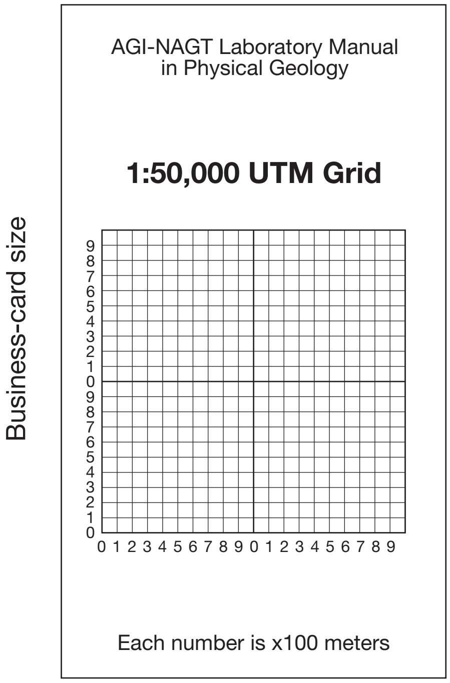


# GEOTOOLS

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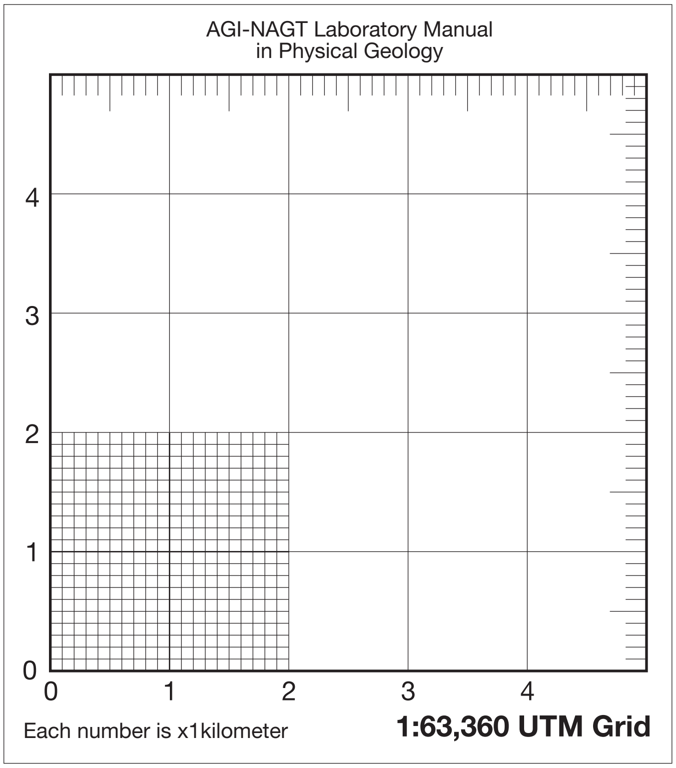


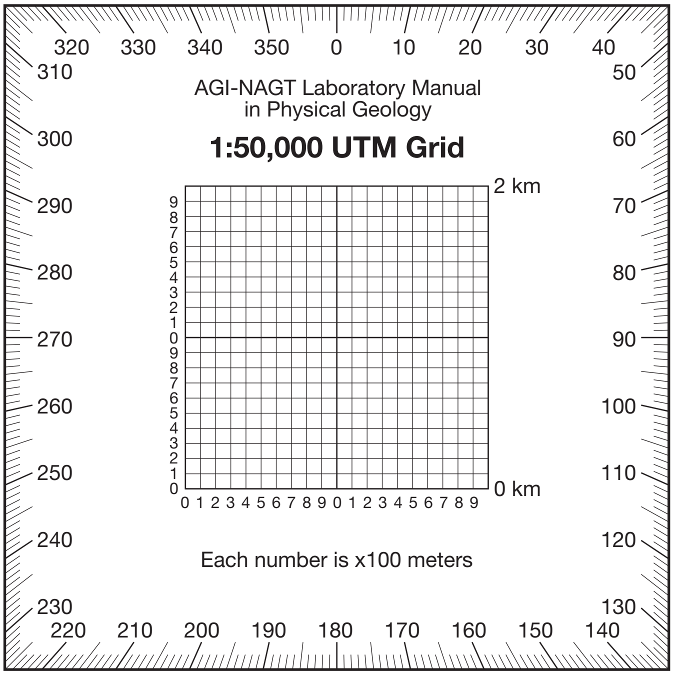

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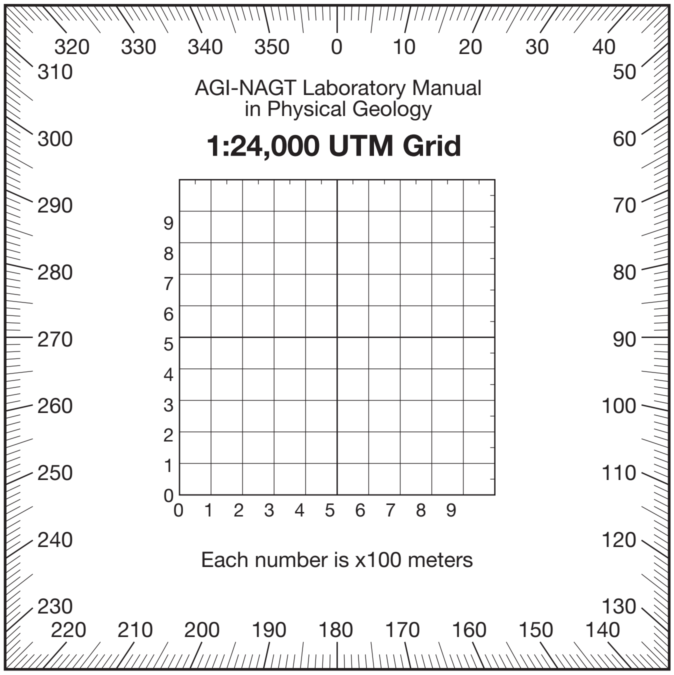


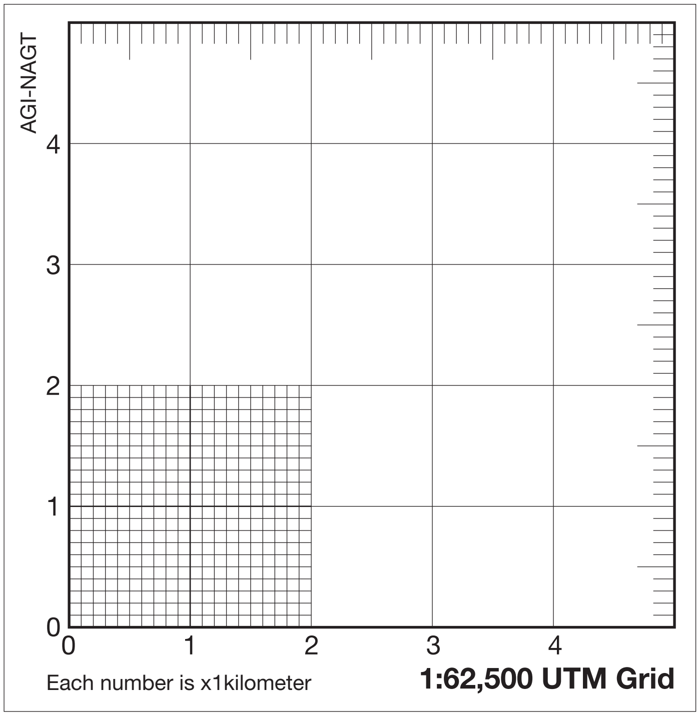


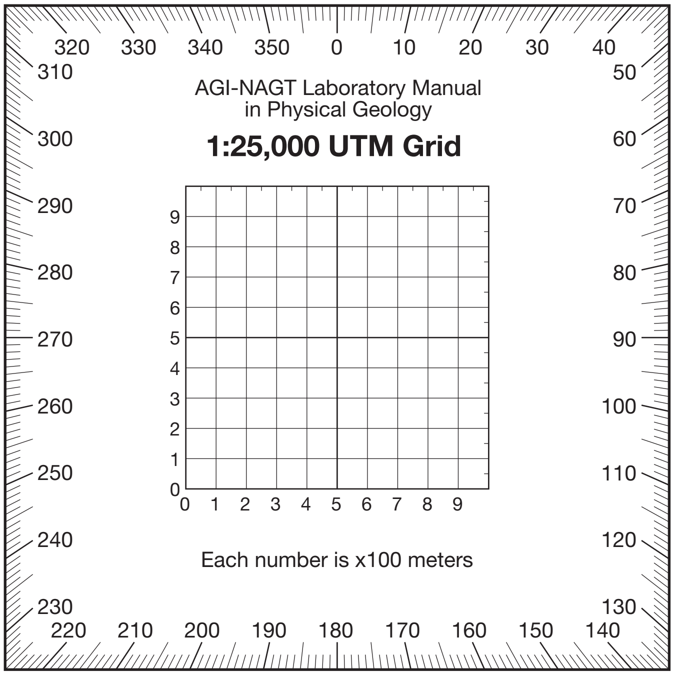


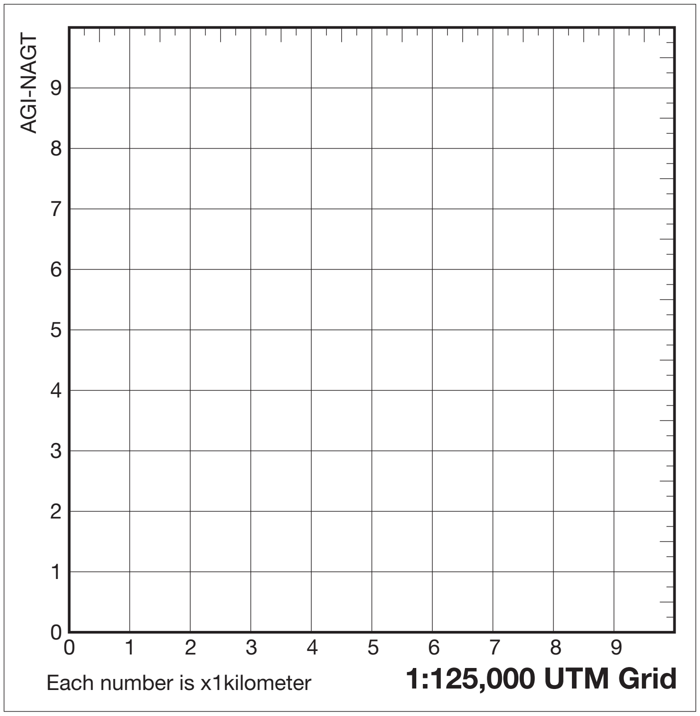


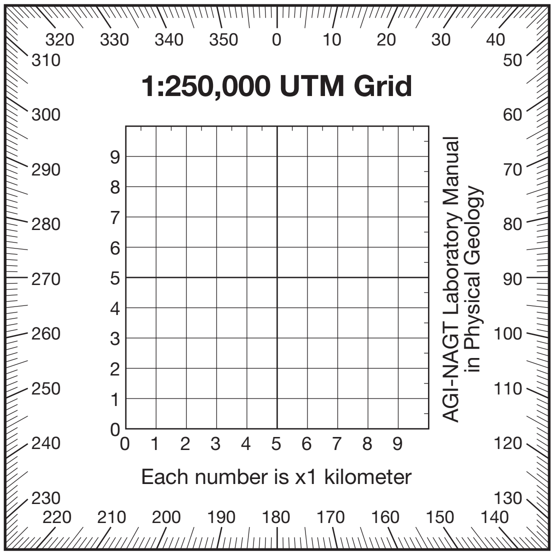


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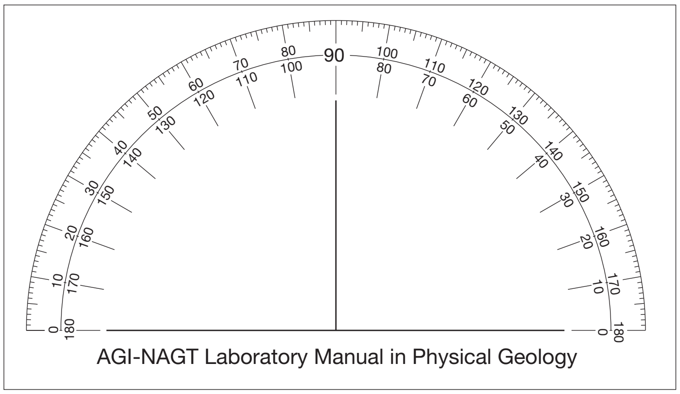


**GEOTOOLS:** Cut out these tools or make copies of them for your personal use.

# LABORATORY 1

Pre-Lab Video 1

https://goo.gl/c3zAzr

# Filling Your Geoscience Toolbox

Contributing Authors

Cynthia Fisher • *West Chester University of Pennsylvania*

C. Gil Wiswall • *West Chester University of Pennsylvania*

▲ Geoscience student documenting a small fault in the Raton Formation west of Trinidad, Colorado (37.12641°N, 104.76647°W).

## BIG IDEAS

*Geology is the science of Earth. Society needs reliable information about Earth as it confronts challenges related to resources, natural hazards, environmental health, and sustainable development. Geoscientists observe Earth using many technologies, from sophisticated airborne or orbital sensors to laboratory instruments and basic fieldwork. We map Earth's surface and describe locations using several coordinate systems. Mapping Earth helps us document change over time and identify where useful resources occur. Mathematics is an important language we use to communicate ideas in geoscience.*

## FOCUS YOUR INQUIRY

**Think About It** What do we see when we look at different parts of Earth?



**Think About It** How is the elevation of a solid block floating in a more dense fluid related to the relative densities of the two materials?



**Think About It** How can we convert many observations into useful summary data?



**Think About It** How can we represent data to help us interpret trends and implications?



**Think About It** How does a variation in density help us understand the broad structure of Earth?

## Introduction

On December 7, 1972, three astronauts in Apollo 17 looked back on Earth from a distance of ~29,000 km as they glided toward their rendezvous with the Moon. Either Jack Schmitt—an astronaut who is also a geologist—or astronaut Ron Evans took a photograph of our home in full sunlight (**Fig. 1.1**). Earth is a breathtakingly beautiful sight, cloaked in a swirling atmosphere that reveals the South Atlantic and Indian oceans, Africa, Arabia, Antarctica, and the island of Madagascar near the center of the image. It is a portrait of a dynamic planet. Below those slowly moving clouds are oceans of liquid water circulating much more slowly than the atmosphere. There are plates of solid lithosphere in which the continents are embedded and that extend below the ocean basins. The plates are also in motion, gliding over the top of a solid mantle that flows even more slowly. Below the rocky mantle and almost 3000 km below Earth's surface is the liquid iron core whose circulation is responsible for the magnetic field that protects Earth from many of the most dangerous effects of solar radiation. Even the solid inner core is interpreted to be in motion, rotating slightly faster than the outer part of the planet.

This dynamic Earth is the stage on which all of the acts of life are played. It is the source of all the resources we need to survive. As vast as Earth is from our perspective as individuals living out our lives on its surface, Earth is an oasis as viewed from space. It is worth the time for us to gain a basic understanding of our home.

**Figure 1.1 The blue marble.** Photograph of Earth taken by the crew of Apollo 17 on their way to the Moon in December 1972. Earth's restless, dynamic nature is well expressed in this image of our home.

In developing this laboratory manual, we provide you with the opportunity

- To see good examples of the materials that make up the surface of earth
- To work with maps and imagery and other forms of data used in the geosciences
- To experience using some simple mathematics to help us understand relationships within the physical world
- To learn about this planet that we share.

The labs in this course are for actively *doing* things. We want you to experience science and, in particular, to engage in geoscience.

You live during a remarkably productive time in the geosciences. Today, it is increasingly common for data to be shared soon after it is collected and for all types of raw data about Earth and its systems to be routinely collected in great quantities. This has been encouraged if not mandated by major funding agencies and has yielded tremendous benefits to science and society. In this set of lab chapters, we will tap into online sources of research-quality data collected by field-based geoscientists as well as by automated networks of seismographs and GPS receivers, Earth-observing satellites, and stream gages. Moderate to high-resolution imagery of Earth are now available online for free as are new digital topographic maps and archival maps for most of the United States. You won't just hear the stale factoid that Los Angeles and San Francisco are moving toward each other because they are located on different plates, but you will learn how to access the GPS velocity data and will acquire the knowledge needed to explore motion along that remarkable plate boundary yourself.

This lab book is a gateway to your exploration of Earth.

## How Is Each Laboratory Chapter Organized?

There are important features in this lab manual you might miss if they were not pointed out to you. Square black-and-white QR codes are printed throughout each chapter that can be scanned with a smartphone that has an app for reading QR codes. There are many such apps available on the web for little or no cost. Scanning the QR code links you to a web resource that will likely be helpful.

Each chapter begins with some general information, followed by an *Activity Box* that introduces you to the first of the lab activities. Each Activity Box alerts you to an upcoming activity, describes the objective of the activity, and makes you aware of any special data, tools, or resources you will need in order to complete the activity successfully. **The text that follows an Activity Box is closely related to the activity, so you should read the**

**relevant section of text before you begin the activity.** As you are working on an activity at the back of the chapter and need to find relevant information in the text, the corresponding Activity Box functions like a bookmark. Just find the corresponding Activity Box and start reading down from there.

Terms that are particularly important for you to know are printed in a **bold** type face. Those terms are usually defined in the text, but additional information about these special words is available in an online glossary prepared for use with this lab manual.

## Science as a Process for Learning Reliable Information

An essential goal of any introductory geoscience course is to help you deepen your understanding of science and of its importance to our lives. Of course, many books and essays have been written in an attempt to describe the nature of science from various viewpoints and worldviews. The geoscientists who have collaborated in developing this laboratory manual would like you to understand at least some of the essential characteristics of science:

- Science is a way of learning reliable information about the world.
- Reliable information is derived from reproducible observations.
- All scientific observations involve some degree of uncertainty, and the proper assessment and reporting of that uncertainty is a fundamental responsibility of scientists.
- We will refer to reproducible observations with their associated uncertainties as **scientific facts**. Scientific facts are always subject to refinement.
- Scientific explanations of the relationships between scientific facts—**hypotheses**—must be testable.
- Many or most preliminary hypotheses are eventually found to be incomplete or simply wrong. Hypotheses in science generally have a short life span because they are replaced by better, more complete hypotheses. Science is a winnowing process that helps us identify the false leads and dead ends so that we can focus on potentially fruitful areas of inquiry.
- Scientific reports are critically reviewed by appropriate scientific experts prior to publication in the peer-reviewed journals that form the communication backbone of science.
- Science involves the work of individual scientists and teams of scientists in the context of a worldwide community of scientists involved in the process of reproducing data, assessing uncertainty, testing hypotheses, reviewing scientific reports made by other scientists, and adding reliable information to our models of how the world works.
- Mathematics is a fundamental language in science because of the clarity and efficiency with which it describes the relationships among scientific facts.

## Geoscience and Geoethics

**Geoscience** is the branch of science that is primarily concerned with the natural history, materials, and processes of Earth and, by extension, of other planetary and subplanetary bodies within our observational reach. Geoscientists study Earth through many different types of inquiry. We go out into the natural world, collect specimens, observe processes, take measurements, and record descriptions. We conduct chemical and physical tests on geological materials in a laboratory setting, making use of all the analytical tools of a chemist or physicist. Geologists engage in theoretical modeling to define the mathematical relationships that govern the behavior of geological materials and processes. In each of these areas of inquiry, the geoscientist's work must be reproducible or else it is not scientifically valid or useful.

Some envision science as a search for truth, although that begs the classic philosophical question, "What is truth?" Most scientists are content to leave notions of truth to philosophers to debate while we work daily to enhance our store of reliable information acquired through the methods of science. Scientific knowledge can be very reliable, but it never fully escapes its provisional nature. We are always improving our knowledge by testing our hypotheses with new data.

Albert Einstein wrote, "Truth is what stands the test of experience" in an essay on ethics. Ethics plays a fundamental role in science in several ways, including the practice of science, the application of science, and the motivation behind the work of scientists. Virtually all of the major professional organizations in science and in geoscience have developed codes of ethics (**http://www.americangeosciences.org/community/agi-guidelines-ethical-professional-conduct**). **Geoethics** is an expanding field of inquiry and thought.

Geoscientists have important responsibilities toward society because of our unique knowledge of Earth (Fig. 1.2). Geoscientists must act ethically to provide society with the reliable information needed to make good choices related to energy, mineral resources, water management, environmental health, natural hazards, climate change, and many other issues of public policy. Only reliable information is useful as we confront our many challenges. In addition to our responsibilities toward society, geoscientists are also responsible for acting as caretakers of the only habitable planet that we have useful access to—our home, Earth.

The fact that you are privileged to have access to a college course in physical geology imparts ethical responsibilities to you. Take full advantage of your opportunity

Figure 1.2 **Society needs the input of geoscientists.** A landslide destroyed this important access road in southern California that cost many millions of dollars to repair. Geoscientists provide society with the expertise needed to effectively address challenges related to energy, supply of industrial minerals, fresh water, climate change, and natural hazards ranging from landslides and floods to earthquakes and volcanic eruptions.

to think, to question, and to learn about Earth. To paraphrase James Blaisdell of Pomona College, you bear your added riches in trust for all of humanity.

## Learning to Think Like a Geoscientist

As you complete exercises in this laboratory manual, think and act like a geoscientist. Focus on questions about 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. As you make observations, record the data you develop. 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 geoscience work 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 about it. Those initial impressions need to be expanded and formalized into testable hypotheses, and that process of developing hypotheses often inspires the collection of new data. Your tentative ideas are likely to change as you acquire additional information.

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 understand and use it.

Your instructor will not accept simple yes or no answers to questions. He or she will expect your answers to be complete statements justified with data, sometimes accompanied by an explanation of your critical thinking. Show your work whenever you use mathematics to solve a problem so your method of thinking is obvious.

**ACTIVITY 1.1**

### A View of Earth from Above, (p. 19)

**Think About It** What do we see when we look at different parts of Earth?

**Objective** Learn how to use Google Earth to view Earth from above, and then use that skill to investigate our planet.

**Before You Begin** Read the following section: Getting to Know Your Planet.

**Plan Ahead** This activity requires that you use Google Earth to find several features on Earth's surface given their map coordinates. You will need to have access to the web and to Google Earth during the lab period, or this activity will have to be completed outside of lab time. Google Earth is a free application, and current information about how to access and use Google Earth is available online at **earth.google.com**.

**ACTIVITY 1.2**

### Finding Latitude and Longitude or UTM Coordinates of a Point, (p. 21)

**Objective** Learn how to determine the coordinates of a point on a map using geographic coordinates (latitude and longitude) and Universal Transverse Mercator (UTM) coordinates.

**Before You Begin** Read the following sections: Geographic Coordinates (Latitude and Longitude); Universal Transverse Mercator (UTM) Coordinates; and Scaling, Proportions, and Using Maps.

**Plan Ahead** You will need a metric ruler and a basic calculator for this activity.

**ACTIVITY 1.3**

### Plotting a Point on a Map Using UTM Coordinates, (p. 24)

**Objective** Learn how to use UTM coordinates to find a point on a map.

**Before You Begin** Read the following sections: Geographic Coordinates (Latitude and Longitude); Universal Transverse Mercator (UTM) Coordinates; and Scaling, Proportions, and Using Maps.

**Plan Ahead** You will need a metric ruler and a basic calculator for this activity.

## Getting to Know Your Planet

We gained the ability to rise a significant distance above Earth's surface when the Montgolfier brothers in France developed hot-air balloons large enough to carry us aloft in 1783. Alfred and Kurt Wegener were avid balloonists in Germany and set the world endurance record in 1906, less than three years after the Wright brothers' first flight in a powered airplane at Kitty Hawk, North Carolina. (Alfred Wegener would later propose the idea of continental drift that evolved into our current understanding of plate tectonics.) As anyone who has had a window seat on an aircraft on a clear day will tell you, Earth's surface is endlessly fascinating (Fig. 1.3). We are privileged to live at a time when there are many technologies available to help us study Earth's surface from above.

Throughout this course, you will encounter opportunities to look at Earth's surface using Google Earth, which is a free web application that you can access through **earth.google.com**. The first task you will need to be able to perform using Google Earth is to find a particular place on Earth's surface once given the coordinates of that point. That involves entering the map coordinates of the point into the Search box in Google Earth and clicking the "Search" button. You will also need to learn how to activate different features (e.g., Places, Borders, Photos), to zoom in and out of the image, to determine the height above Earth that is depicted in the image, and generally how to move from place to place across the surface. Different versions of Google Earth operate differently. The Help resource on your particular version of Google Earth will guide you in learning how to use its various functions to study the surface of Earth.

First, we need to learn about two ways we have developed to specify the location of a given point on Earth, using map coordinates. The two general methods are the geographic coordinates of latitude and longitude, and the UTM coordinates.

### Geographic Coordinates (Latitude and Longitude)

The location of a point on Earth can be specified using its latitude and longitude (Fig. 1.4). **Latitude** is measured relative to the **equator**, which is the circle around Earth located in the tropics exactly halfway between the north and south poles. The latitude is 0° at the equator, 90° at the north pole, and −90° at the south pole. The poles are the places where Earth's spin axis intersects the ground surface to the north (**north pole**) and south (**south pole**). Semicircles that wrap around Earth from the north pole to the south pole are called **meridians**. We measure the latitude of a given point along the meridian that passes through that point. The latitude is the angle from the point where that particular meridian crosses the equator to the center of Earth and back out to the given point.

**Longitude** is measured relative to a particular meridian that passes through a specific point on the grounds of the Royal Observatory at Greenwich, England. A group called the *Earth Rotation and Reference Systems Service* keeps track of the practical definition of the international reference meridian (the **prime meridian**) for us so we don't have to worry about it. The angle between the prime meridian and the meridian that passes through a given point is that point's longitude. Longitudes measured to the east of the prime meridian (east longitudes) are considered *positive* longitudes, and longitudes measured to the west of the prime meridian (west longitudes) are considered *negative* longitudes. So longitudes range from 180° (180°E) to 0° along the prime meridian to −180° (180°W). With the exception of several of the western Aleutian Islands in Alaska, all of the states in the United States have west, or negative, longitudes.

If you are moving either due north or due south, a change of one degree in latitude (at the same longitude) is a difference of ~111.2 km across Earth's surface.

**Figure 1.3 Grand Prismatic Spring.** This beautiful pool at Yellowstone National Park is one of the largest hot springs on Earth and is home to bacteria capable of living under extremely harsh conditions. The solid Earth, liquid water, water vapor, a hint of Earth's hot interior, and evidence of life are all visible in this image, illustrating the interconnectedness of Earth's systems. (Photo by Jim Peaco of the National Park Service.)

(The symbol "~" is used here to indicate an approximate number.) One degree of latitude is 1/360th of the distance around Earth whose average radius is ~6,371 km and whose circumference is ~40,030 km. The meridians that mark different longitudes all converge at the north and south poles and are spaced their maximum distance of ~111.2 km per degree of longitude

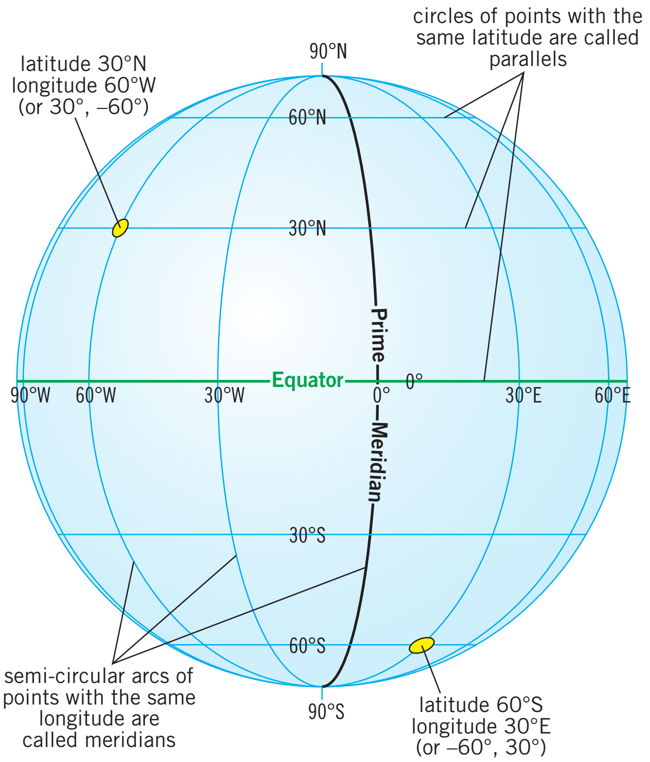


**Figure 1.4 Geographic coordinate system of latitude and longitude.** Explanation of the major elements of the geographic coordinate system.

where they cross the equator. So it would take a commercial jetliner over 7 minutes to fly across 1 degree of longitude at the equator (~111.2 km), but it would take a motivated sugar ant about a quarter of a second to walk 1 degree of longitude (~1.7 centimeters [cm]) if the ant was just a meter away from the north or south pole.

Geoscientists frequently use **decimal degrees** to indicate position when we use the geographic coordinate system of latitudes and longitudes. For example, the great obelisk of the Washington Monument in Washington, D.C., is located at latitude 38.889469°N, longitude 77.035258°W. When it is made clear that the number pair refers to latitude and longitude, we can simply write 38.889469, −77.035258 without the degree symbol or the letters N and W because positive-signed latitude is understood to be north latitude and negative-signed longitude is understood to be west longitude. You can find the Washington Monument in Google Earth by entering 38.889469, −77.035258 in the Search box. You can also find it by entering 38.889469°, −77.035258° or 38.889469°N, 77.035258°W, but then you would need to remember how to insert the degree (°) symbol using your web-enabled device.

An alternative to decimal degrees that has persisted for a very long time is the **degrees-minutes-seconds** system that subdivides each degree into 60 minutes of arc and then each minute of arc into 60 seconds of arc. Our use of degrees, minutes, and seconds for angles and our use of 24 hours of 60 minutes and 60 seconds for daily time have ancient roots. The "60" originated approximately 5000 years ago in the ancient Sumerian system of counting, which was a base-60 system. Not being ancient Sumerians, we generally use a base-10 system today, but old habits are difficult to break. Maps produced by the U.S. Geological Survey (USGS) are based on the degree-minute-second way of expressing latitude and longitude.

It is useful to know how to convert from the degrees-minutes-seconds system to decimal degrees. Let's say we have an angle of $a$ degrees, $b$ minutes, and $c$ seconds, which is commonly written as $a° \ b' \ c''$. The decimal-degree equivalent is $[a + (b/60) + (c/3600)]$ degrees, noting that $60 \times 60 = 3600$. Here's an example.

$$14° \ 38' \ 52'' \text{ is the same as } [14 + (38/60) + (52/3600)]° \cong 14.647778°$$

Google Earth can locate points expressed in the degree-minute-second, degree-decimal minute, and decimal degree systems of expressing longitude and latitude.

## Universal Transverse Mercator (UTM) Coordinates

Most handheld GPS receivers can provide us with locations in either a latitude–longitude format or a UTM format. Latitude–longitude is a bit easier to explain, but UTM has some practical advantages. UTM coordinates are based on a projection of Earth's surface onto a plane that has a coordinate grid in meters that is aligned (approximately) north–south, east–west. It is more useful to people trying to navigate from point A to point B to know how many meters they need to go in a given direction than to know how many degrees of longitude or latitude.

Although variations exist, the UTM coordinates of a given point usually have four components listed in the following order: **zone number**, **latitude band**, **easting**, and **northing** (**Fig. 1.5**). An example that can be directly interpreted by Google Earth's Search function is 12T 370730 4608526. Try it out and see where it leads you.

**UTM Zones.** Earth is divided into 60 zones starting at longitude 180°—the **international dateline** halfway around Earth from the prime meridian—and proceeding to the east. Each zone is 6° of longitude wide and extends from 80°S to 84°N latitudes. Zone 1 is from 180°W to 174°W followed by zone 2 from 174°W to 168°W. The continental United States extends from UTM zone 10 in the west to 19 in the east. Each zone has a **central meridian**, which is halfway between the two zone boundaries (**Fig. 1.5**). For example, the central meridian of zone 2 is longitude 171°W.

**UTM Bands.** Each zone is divided into 20 latitude bands that are 8° of latitude tall. The bands are lettered from C (between 80° and 72°S latitude) to X (between 72°N and 84°N latitude). Zone X is the only zone that is larger than 8° high; it was extended to 12° high to cover all of the major continental areas above sea level. The bands from N to X are in the northern hemisphere (**Fig. 1.5**). The continental United States is in bands R, S, T, and U.

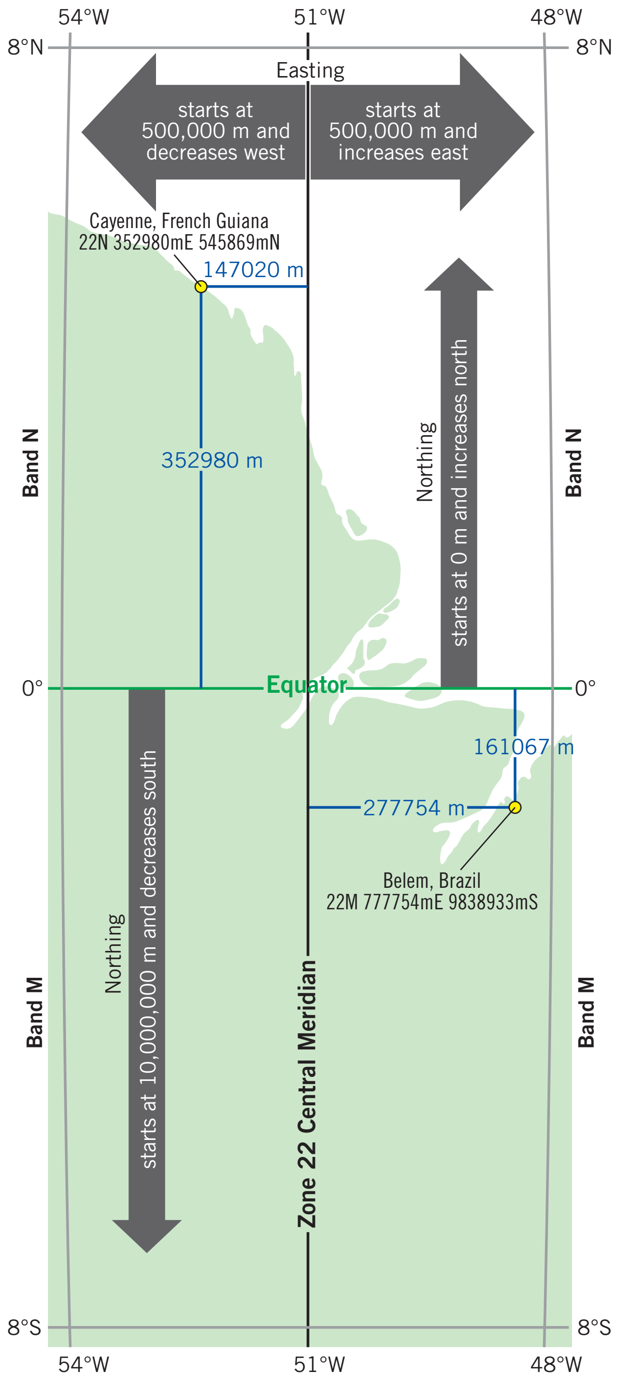


**Figure 1.5 Universal Transverse Mercator (UTM) coordinate system.** UTM zone 22, latitude bands M and N along the equator near the mouth of the Amazon River, northeastern South America. UTM coordinates of two cities are shown as examples.

**UTM Easting.** The easting within a given zone is measured in meters perpendicular to the zone's central meridian whose easting is defined as 500,000 meters, or 500,00 mE (**Fig. 1.5**). (The abbreviation *mE* is expressed in words as "meters east" or "easting.") It seems odd to express position in this way because we normally define position relative to some point whose coordinate is defined as 0, but the originators of UTM coordinates did not want to have any negative numbers in their system. Zones are a maximum of ~668,000 meters (m) wide, so giving all points along a central meridian the same easting of 500,000 mE ensures that no east–west coordinate in the zone has a negative value. A point that is 1500 m to the *west* of the central meridian has an easting of 500,000 − 1500 = 498,500 mE, whereas a point that is 24,000 m east of the central meridian has an easting of 500,000 + 24,000 = 524,000 mE.

**UTM Northing.** The northing of a given point in the northern hemisphere is its distances in meters from the equator measured along the meridian—the north–south line—that passes through the point. UTM northings in the northern hemisphere start at the equator (0 mN) and increase northward to ~9,300,000 mN at the top of the UTM projection at 84°N latitude (**Fig. 1.5**). In contrast, UTM northings in the southern hemisphere start at the equator (10,000,000 mS) and decrease southward to ~1,100,000 mS at the bottom of the UTM projection at 80°S latitude.

**Expressing UTM Coordinates.** Google Earth is able to interpret UTM coordinates (zone, band, easting, northing) typed into its Search box. For example, typing 18S 323482 4306480 and pressing the "Search" button will send you to the Washington Monument in Washington, D.C. Typing 13T 623805.6 4859546.9 and pressing the "Search" button will get you to George Washington's sculpted nose at Mount Rushmore, South Dakota. Fully written out in a conventional way, as you would in a geoscientific report, the UTM coordinates of his nose would be 13T 623805.6 mE 4859546.9 mN

## Scaling, Proportion, and Using Maps

The ability to work with proportions is an essential skill when working with maps, which are an important tool used by geoscientists. Imagine a map of your hand at ½ scale, so the image of your hand is just 50% the size of your actual hand. With that scale, a finger that is 2 cm wide on your hand would be 1 cm wide on the map image. Your thumb, at 2.5 cm wide, would be 1.25 cm wide on the map. Your little finger is 7 cm long but just 3.5 cm long on the map. Your middle finger is 9 cm long, but the image of that finger is 4.5 cm long on the map. The ratio of the length of the feature on the map to the length of the corresponding feature on your hand is always 1 to 2.

$$\frac{1}{2} = \frac{1.25}{2.5} = \frac{3.5}{7} = \frac{4.5}{9}$$

**Representative Fraction Scale.** Printed on some maps is a **representative fraction scale** (or simply a **fractional scale**) which is fundamentally a ratio. Examples of the two most common styles of fractional scales are 1/24,000 and 1:24,000. These scales are identical to each other—they represent two styles of presenting the same information. The meaning of "1:24,000" is that one unit of some sort (centimeters, for example) on the map is equal to 24,000 of that same unit (cm) on the ground in the mapped area. The problem with representative fractional scales is that they are of no use if the map is enlarged or reduced in size during reproduction. The "1:24,000" will still be printed on the map even if the map is reproduced to the size of a postage stamp or billboard.

**Bar Scale.** Many maps contain some form of a thin rectangle called a **bar scale** that represents a specific length on the map. An example of the style of bar scale used by the USGS is shown in **Fig. 1.6**. Bar scales are used extensively in this book and throughout the geosciences in part because the printed bar expands and contracts along with the map, so the map scale can always be interpreted. Let's work an example. Imagine that you have a map with a bar scale that represents a length of 2000 m (2 kilometers [km]) on the ground in the mapped area. You measure the bar with a rule, and find that 2 km on the ground is the same as 4 cm on the map because the distance from 0 to 2 km on the map's bar scale is 4 cm long. You want to take a 5 km stroll, 2.5 km down the road and 2.5 km back. What is the length of a line on the map that represents 2.5 km along the road?

We can frame this problem as a proportion or ratio problem: 4 cm is to 2 km as $c$ (the unknown map distance) is to 2.5 km. This is a type of problem we would like to be able to solve every time we encounter it regardless of the specific numbers involved. So rather than use numbers, let's use a unique letter to represent each of the numbers in our problem, rather than just the unknown map distance ($c$), and restate the problem: $a$

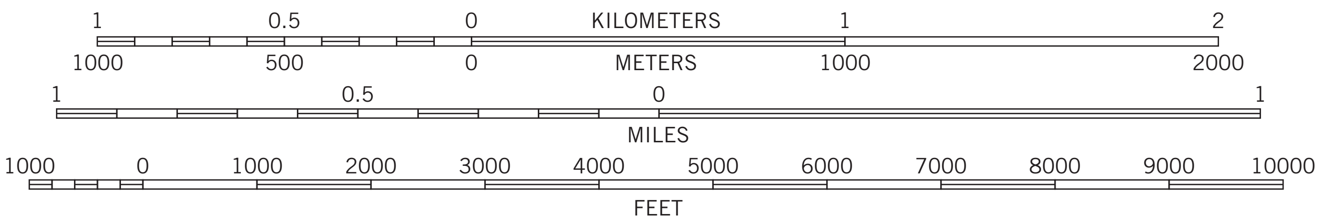


**Figure 1.6 Typical bar scale used by the USGS.** This bar scale was copied from a USGS topographic map published in 2015. It shows a metric bar scale in kilometers and two types of scales that use the English units miles and feet.

is to $b$ as $c$ is to $d$. In other words, the ratio of $a$ to $b$ is the same as the ratio of $c$ to $d$, or

$$\left(\frac{a}{b}\right) = \left(\frac{c}{d}\right)$$

This equation can be rearranged as $(a \times d) = (b \times c)$. In our original problem, the value of variable $c$ was unknown. We can rearrange the equation again so that variable $c$ is isolated by itself on one side of the equation.

$$c = \frac{(a \times d)}{b}$$

Now, let's insert the numbers from our problem.

$$c = \frac{(a \times d)}{b} = \frac{(4 \times 2.5)}{2}, \text{ so } c = 5$$

You would look on your map, mark a point 5 cm down the road on your map, find a recognizable landmark like a street corner near your mark, and start walking there and back for your stroll.

What if you saw something interesting on the same map (like an all-night ice cream store) and measured a map distance of 7 cm from your current location to that point. How far would you have to walk to get there? This is just another form of the same problem except that this time variable $c$ is known but $d$ is unknown. Recall that $(a \times d) = (b \times c)$, so we can rearrange this equation to isolate $d$ on one side of the equation and then replace the variables with the actual numbers from our problem.

$$d = \frac{(b \times c)}{a} = \frac{(2 \times 7)}{4}, \text{ so } d = 3.5$$

You would need to walk 3.5 km there and another 3.5 km back. The ability to manipulate these simple equations and solve proportion problems is a very useful skill.

**About Mathematics in Geoscience.** Geoscience is a branch of science that integrates certain aspects of physics, chemistry, biology, computer science, and related technologies in developing our understanding of Earth. Science is a quantitative enterprise. To paraphrase Galileo, mathematics is the language of science. You might think that mathematics seems like a large unfriendly animal with teeth and claws that you encounter along your path to learning about science. But math doesn't bite and is more like a set of tools. Some tools, like a hammer, are easier to use than others. Regardless of the work you will pursue in your life, it will take some time and effort to learn how to use the math tools you will need for your work.

It would be a disservice to college students to introduce you to the geosciences in a way that completely avoids quantitative ideas. The geoscientists who developed this laboratory manual thought it reasonable to use simple math at an average high school level in some of the text and activities. Much of the time, we will just use arithmetic. If you need additional help beyond that provided in this laboratory manual, ask your teacher. Help for some topics is available online through a resource called The Math You Need, When You Need It (**http://serc.carleton.edu/mathyouneed/index.html**), from the Khan Academy (**https://www.khanacademy.org**), and from other similar resources.

https://goo.gl/r1Kwfe

## Rearranging Equations—The Math You Need

You can learn more about how to rearrange equations to solve for a given variable (including practice problems) at **http://serc.carleton.edu/mathyouneed/equations/index.html** featuring The Math You Need, When You Need It tutorials for students in introductory geoscience courses.

https://goo.gl/eaVJq7

**ACTIVITY 1.4**

### Floating Blocks and Icebergs, (p. 26)

**Think About It** How is the elevation of a solid block floating in a more dense fluid related to the relative densities of the two materials?

**Objective** Practice working with lengths, volumes, and density while learning more about buoyancy and Archimedes' Principle.

**Before You Begin** Read the following sections: Measuring Earth Materials and Archimedes' Principle.

**Plan Ahead** It is best if you have an opportunity to actually observe and measure a rectangular wooden block floating in water to work out its density. Ask your teacher about setting up that experiment if it is not already available to you.

# Measuring Earth Materials

Observation and measurement are fundamental parts of the scientific process. Here, we review a few basics of measurement that will be needed throughout this laboratory course.

## SI Units of Length Measurement

The International System of Units (SI) is based on seven basic units of measure from which other units are derived. The SI system is used throughout science with few exceptions. The standard of length measurement is the **meter** (m), and useful units derived from that base unit include the **kilometer** (km; 1 km = 1000 m), **centimeter** (cm; 100 cm = 1 m), **millimeter** (mm; 1000 mm = 1 m), **micrometer** or **micron** ($\mu$m; 1,000,000 $\mu$m = 1 m). Since 1983, the official SI definition of a meter "is the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second." Practically speaking, we use a manufactured secondary standard such as a ruler