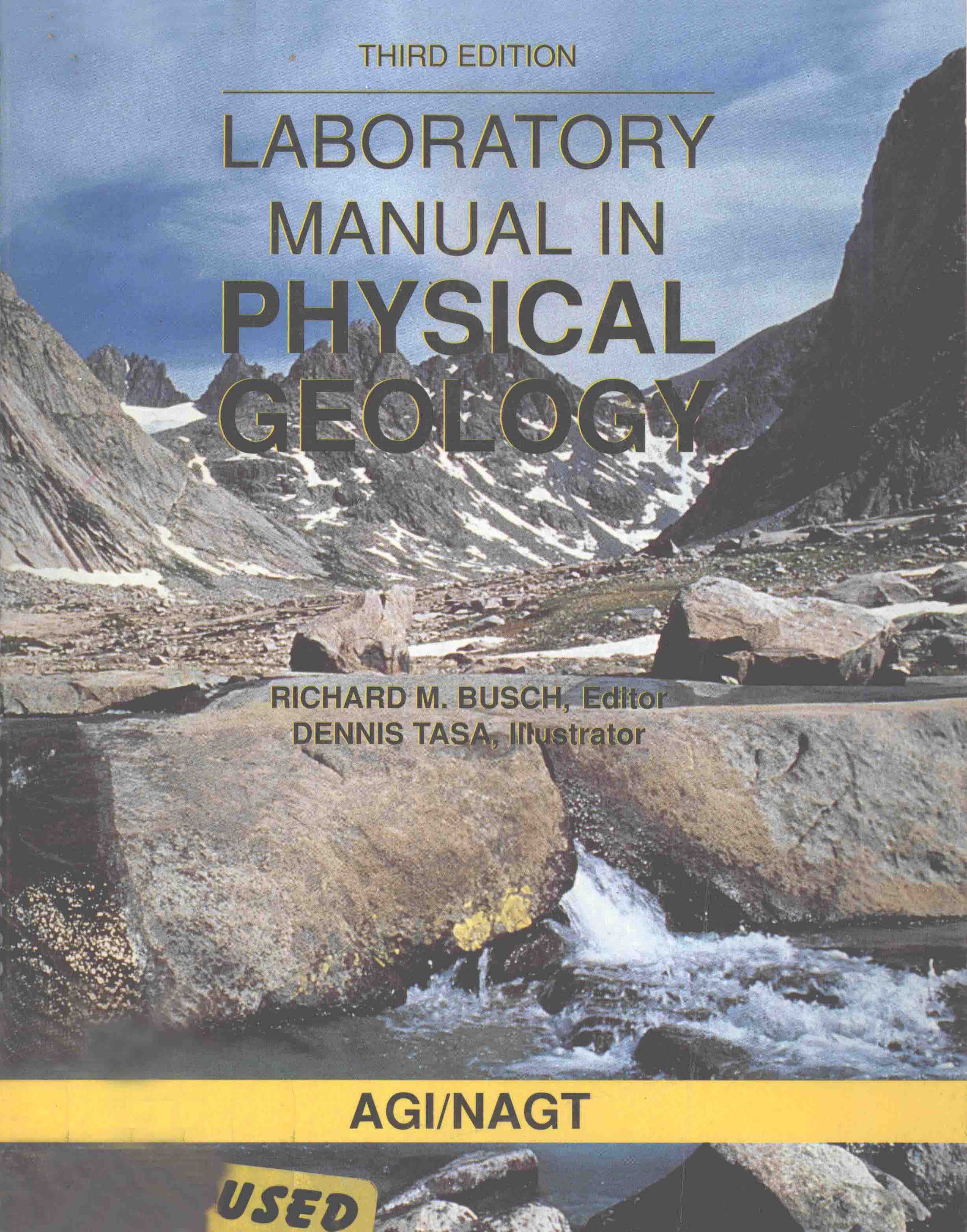
THIRD EDITION

LABORATORY MANUAL IN PHYSICAL GEOLOGY

RICHARD M. BUSCH, Editor
DENNIS TASA, Illustrator



AGI/NAGT

THIRD EDITION

LABORATORY MANUAL IN PHYSICAL GEOLOGY

Produced under the auspices of

AMERICAN GEOLOGICAL INSTITUTE

and

NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

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Tasa Graphic Arts, Inc.

Macmillan Publishing Company
New York

Maxwell Macmillan Canada
Toronto

Maxwell Macmillan International
New York Oxford Singapore Sydney

Editor: Robert A. McConnin
Production Editor: Rex Davidson
Art Coordinator: Peter A. Robison
Cover Designer: Robert Vega
Production Buyer: Pamela D. Bennett
Page Layout: Ellen Robison

This book was set in Palatino by York Graphic Services, Inc. and was printed and bound by R. R. Donnelley & Sons Company. The cover was printed by Phoenix Color Corp.

Printed in the United States of America

Macmillan Publishing Company
866 Third Avenue
New York, New York 10022

Macmillan Publishing Company is part of the Maxwell Communication Group of Companies.

Maxwell Macmillan Canada, Inc.
1200 Eglinton Avenue East, Suite 200
Don Mills, Ontario M3C 3N1

Printing: 1 2 3 4 5 6 7 8 9 Year: 3 4 5 6 7

PREFACE

This laboratory manual was designed for use in a course on Introductory Geology or Physical Geology. It was produced under the auspices of the American Geological Institute and the National Association of Geology Teachers. The idea of 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 third edition of the manual consists of nineteen exercises developed primarily with input from thirty-six contributing authors. The authors are nationally prominent Earth science educators and/or specialists in the geologic subject areas of their contributions.

The first edition of this laboratory manual was planned in 1984, when Merrill Publishing Company became interested in the Ridky concept. AGI initiated negotiations with a proposal developed by AGI Education Director, Andrew J. Verdon, Jr., and Ridky. Verdon directed the project and chaired a Laboratory Manual Project Steering Committee. The Committee was charged to design the manual, select exercises, and choose an editor. The Committee included Brewster Baldwin, Robert L. Bates, William E. Bonini, Jeffrey G. Callister, Marvin E. Kauffman, Julia A. Jackson, William H. Matthews III, Robert W. Ridky, and A. G. Unklesbay. Robert L. Bates was named Editor, and the "best exercises" were acquired by sending notices to NAGT members and to geology departments in the United States and Canada. The exercises were screened by Robert L. Bates, Marvin E. Kauffman, Constantine Manos, Kenneth J. Van Dellen, and Andrew J. Verdon, Jr.

In 1985, AGI signed the publishing agreement with Merrill and the jointly-shared royalty agreement with NAGT. Royalties support the education programs of both organizations. Special thanks are due to Marvin E. Kauffman (NAGT President 1984–1985, AGI Executive Director 1985–1990), Kathy Nee (then of Merrill), and the many reviewers for ensuring the success of the innovative first edition, published in 1986.

Preparation for a second edition began in 1987, when Richard M. Busch (then of Kansas State University) was named Editor. For the second edition, nearly all of the exercises were reorganized and rewritten according to a standardized style and format, and five new exercises were added. Both metric and English systems of measurement were used (as in this latest edition), because Earth scientists generally use both systems on a daily basis. The second edition manuscript was subjected to rigorous peer review and was field tested at West Chester University (Department of Geology and Astronomy) and the University of Delaware (Department of Educational Development). The second edition was published in 1990.

Macmillan Publishing Company acquired Merrill in 1989 and initiated the planning process for this third edition. AGI Executive Director, Chip Groat, AGI Education Director, Andrew J. Verdon Jr., and the Editor, Richard M. Busch, met at AGI headquarters in July 1991 to develop a revision plan. A limited survey was also developed and conducted of Earth science educators who helped develop the first and/or second editions of the manual. This meeting and survey made possible the development of a specific revision plan for this edition. Dennis Tasa and William Fox Munroe added valuable input on issues pertaining to revision of figures and manual layout.

NEW FEATURES

The third edition reflects the strengths and features of previous editions: consistent exercise format, concise background information, full-color photographs, Dennis Tasa art pieces and charts, and the six tear-out structural models at the end of the book. The following features make this new edition an even more effective teaching tool:

- Several short, related exercises are now combined.
- Greater emphasis is placed on student understanding of the Earth as a complex, evolving system having interacting processes and cycles of change.
- Concept emphasis has been modified based on the results of a four-year nationwide study of Earth science educational goals for the 21st century by AGI.
- New Exercise One introduces the science of geology from a planetary perspective. Students briefly explore the evolution of Earth's dynamic system as it relates to the other terrestrial planets. They also explore the practicality of the global Plate Tectonics Model relative to determinations of plate motions, news reports of geologic phenomena, and mineral resource exploration.
- New Exercise Three introduces rocks and the rock cycle.
- Better examples, better directives, and more supporting information make this edition more user-friendly than ever before.
- There are more full-color figures than previous editions; including more Dennis Tasa art pieces and charts, maps, stereograms, sample photographs, outcrop photographs, computer-enhanced images, and photomicrographs.
- There are more process-oriented, inquiry-type questions and fewer questions emphasizing recall of terms and information.
- The Instructor's Resource Guide has been enhanced and expanded by Timothy Lutz, LeeAnn Srogi, and the Editor.
- A slide set is available to instructors using the manual.

We sincerely appreciate the assistance and contributions made by those individuals and institutions who have helped in the preparation of this edition. Lauret E. Savoy (Mount Holyoke College) provided the front-cover photograph. Other new photographs were supplied by Mary Dale-Bannister (Washington University in St. Louis), Jody Swann (U.S. Geological Survey, Branch of Astrogeology), Michael F. Hochella, Jr. and C. M. Eggleston (Stanford University), and J. van der Woude (Jet Propulsion Laboratory, California Institute of Technology). Thomas R. Watters and Rose Steinet (Smithsonian Institution, Center for Earth and Planetary Science) provided data and assisted with photographic research.

Joyce Young cheerfully typed the manuscript, and Fred C. Schroyer again provided outstanding copy editing. Revision comments were volunteered by Sally V. Beaty (on behalf of the Southern California Consortium, Pasadena), Deborah Casey (Lamar University), Ronald Corey (Baldwin Wallace College), Cydney Faul-Halsor and Sid P. Halsor (Wilkes University), Lawrence B. Gillett (State University of New York, Plattsburgh), Pamela J. W. Gore (Dekalb College), Gary Houlette (Oklahoma City College), Donal M. Ragan (Arizona State University), Stephen Simpson (Highland Community College), Richard C. Stenstrom (Beloit College), Gene C. Ulmer (Temple University), and Kenneth J. Van Dellen (Macomb Community College).

We thank the North Museum of Franklin and Marshall College, Omni Resources (formerly Geoscience Resources, Inc.), West Chester University (Department of Geology and Astronomy, Mineral Museum), and David B. Saja for providing many of the mineral and rock samples that appear as photographs in the manual. Photographs and data related to St. Catherines Island, Georgia, were made possible by grants to the Editor from the St. Catherines Island Research Program of the American Museum of Natural History, supported by the Edward J. Noble Foundation.

For maps, map data, and aerial photographs we thank the U.S. Geological Survey's EROS Data Center; National Aeronautics and Space Administration; National Space Science Data Center; U.S. Department of Agriculture; Mitchell Beazley Publishers, London; Department of Energy, Mines, and Resources, Ottawa; Bureau of Topographic and Geologic Survey of Pennsylvania; Surveys and Resource Mapping Branch, Ministry of Environment, Government of British Columbia; Grand Canyon Natural History Association; and Washington State Department of Natural Resources, Division of Geology and Earth Resources. Additional input to text and figures was provided by Cambridge University Press, Princeton University Press, *Scientific American*, *Paleobiology*, *Journal of Geological Education*, and the American Association of Petroleum Geologists.

The efforts of many persons at Macmillan Publishing Company are also appreciated. We thank Rex Davidson, Chuck Healy, Robert Vega, and Sue Bonito. Special thanks are also extended to Robert McConnin, whose extraordinarily effective and unique direction as Senior Editor made a complex revision process easy and wonderfully successful.

The continued success of this laboratory manual depends most on comments from colleagues. Therefore, we would welcome any and all comments regarding this edition and suggestions regarding a future edition. Please submit comments and suggestions directly to the Editor: Richard M. Busch, Department of Geology and Astronomy, West Chester University, West Chester, PA 19383.

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ITEMS REQUIRED TO COMPLETE EXERCISES IN THIS MANUAL

1. Sharp #2 or #3 pencils, with eraser
2. Graph paper: 10 divisions to the inch
3. Colored pencils
4. Hand lens
5. Ruler calibrated in metric and English units
6. Pocket stereoscope
7. Drafting compass
8. Protractor
9. Steel knife or masonry nail (provided by instructor)
10. Streak plate (provided by instructor)
11. Copper penny
12. Small magnet
13. Dilute hydrochloric acid (HCl) in dropper bottle (provided by instructor)
14. Calculator

QUANTITATIVE CONVERSIONS, UNIT SYMBOLS, AND ABBREVIATIONS

1 kilometer (km)	= 1000 meters (m)	= 0.621 mile (mi)
1 meter (m)	= 100 centimeters (cm)	= 3.28 feet (ft)
1 centimeter (cm)	= 0.01 meter (m)	= 0.394 inch (in.)
1 mile (mi)	= 1.6 kilometers (km)	= 5280 feet (ft)
1 foot (ft)	= 30.48 centimeters (cm)	= 0.305 meters (m)
1 inch (in.)	= 2.54 centimeters (cm)	= 25.4 millimeters (mm)

360 degrees (°)	= a complete circle
1 degree (°)	= 60 minutes (′)
1 minute (′)	= 60 seconds (″)

CONTENTS

EXERCISE ONE

Earth—A Planetary Perspective

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PURPOSE

This exercise introduces the science of geology from a *planetary perspective*. The first part helps you see Earth as a unique planetary system compared to other planets in our solar system. We will ask you to consider how Earth is evolving, both as a result of its position in the Solar System and because of its processes of change. In the second part, we introduce you to the Plate Tectonics Model. We will ask you to examine the practicality of this model relative to limited investigations of lithospheric plate motions, 1991 news reports of volcanic activity and earthquakes, and mineral resource exploration.

MATERIALS

Pencil, eraser, metric ruler, 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 Earth scientists. They work in field settings, laboratories, aircraft, spacecraft, and submersibles in the ocean. They make careful observations and collect data (information) about Earth materials, events, and processes of change.

These careful observations have provided geologists with a fast-growing body of knowledge and understanding of Earth. This knowledge and understanding is used:

- to form new **hypotheses** (ideas to be tested and evaluated)
- to devise **experiments** to test the hypotheses
- to make **inferences** (conclusions based on evidence)
- to design **models** (tentative concepts of cause-and-effect relationships or how observations and processes are related).

Therefore, geologists are uniquely qualified to explain Earth's origin and geologic history in reasonable and qualified terms, to locate Earth resources used by people, to evaluate the impact of human actions on the environment, to recommend governmental policies related to Earth science, to analyze the feasibility of land-development projects, to predict certain events, and so on. But geologists are not Earth-bound. There is no reason to restrict the science of geology to a single *place*, such as Earth. Principles discovered by geologists apply to other astronomical bodies as well!

Technological innovations from space exploration enable geologists to play an ever-increasing role in scientific investigations of the Moon, other planets, and moons of other planets. Modern geology has grown to be the science of Earth and other rocky bodies of the Solar System.

PART 1—EARTH AS A SYSTEM

Earth scientists generally conceptualize Earth as a dynamic system composed of five interacting *subsystems* or *spheres.* These are the lithosphere, hydrosphere, atmosphere, cryosphere, and biosphere.

Earth's **lithosphere** is the solid, outermost layer of the planet. It consists of solid bedrock, fragmented rock (regolith), and soil (regolith mixed with organic debris sufficient to support plant growth). The lithosphere is 60–100 km thick (40–60 mi). It rests on the **asthenosphere,** a weak zone of the upper mantle where rocks flow plastically due to intense heat and pressure. The lithosphere is not a single, rigid, eggshell-like covering. It is a mosaic of numerous rigid plates that are moved by the slow plastic flow of the asthenosphere. Zones between adjacent plates, called **plate boundaries,** are regions of common earthquakes and occasional volcanic activity.

Earth's **hydrosphere** is all of the liquid water on the planet's surface and in the ground (lithosphere). Most of the hydrosphere is salt water, contained in oceans that cover about 70% of our planet. The U. S. Geological Survey has noted that, if all of the water on Earth could be put into a 55-gallon drum, then slightly more than 53 gallons of that water would be ocean water. Only about one-fourth of a gallon would be water in the ground. Only about one-hundredth of a gallon would be the water in lakes and streams. The remainder would be water vapor in the atmosphere (about one-eighth of a gallon) and water frozen in the cryosphere (slightly over a gallon).

Earth's **atmosphere** is the mass of gases (air) that surrounds the planet. It consists of about 75% nitrogen, 20% oxygen, and small amounts of other gases including argon, carbon dioxide, and water vapor. Air pressure is created as gravity pulls this air mass against the planet's surface. Atmospheric currents (winds) form due to regional variations in the air pressure, air convection (motion caused by unequal heating), and Earth's rotation. Atmospheric temperatures on Earth's surface range from recorded extremes of +58°C (+136°F) in the Libyan desert (September 13, 1922) to −89°C (−129°F) at Vostok, Antarctica (July 21, 1983).

Earth's **cryosphere** is the ice and frost that form due to freezing of portions of the hydrosphere or atmosphere. Therefore, the cryosphere is water ice on Earth's surface. Most of it exists in the polar ice sheets, plus permafrost (permanently frozen moisture in the ground).

The **biosphere** is the living part of Earth's system, the part that is organic and self-replicating. It is the total of all organisms (plants and animals) living in the other four spheres.

All of Earth's subsystems, except for the biosphere, are evident from space as distinct entities (Figure 1.1). Yet, these distinct systems interact and influence one another to form the integrated, dynamic planetary system. Any significant change in one subsystem generally causes changes in other subsystems.

PROCESSES AND CYCLES OF CHANGE

Changes in Earth's planetary subsystems are caused by numerous physical and chemical processes. These involve inorganic and organic materials in solid, liquid, or gaseous states *(phases).* Figure 1.2 reviews some of these processes and the changes they cause. Note that many processes have opposite effects: melting and freezing, evaporation and condensation, dissolution and chemical precipitation, photosynthesis (food production) and respiration (food consumption or "burning"). The process called sublimation also is reversible: a solid changing directly to a gas, or a gas changing directly to a solid. Such effects cause chemical materials to be endlessly cycled and recycled between two or more states and between two or more subsystems.

Hydrologic Cycle

The **hydrologic cycle** (water cycle) involves several processes and changes related to all three phases of water and all subsystems of Earth (Figure 1.3). Thus it is among Earth's most important cycles.

The cycle operates like this: water (hydrosphere) evaporating from Earth's surface produces water vapor (atmospheric gas). The water vapor eventually condenses to form aerosol water droplets (clouds). The droplets can combine to form raindrops or snowflakes (atmospheric precipita-

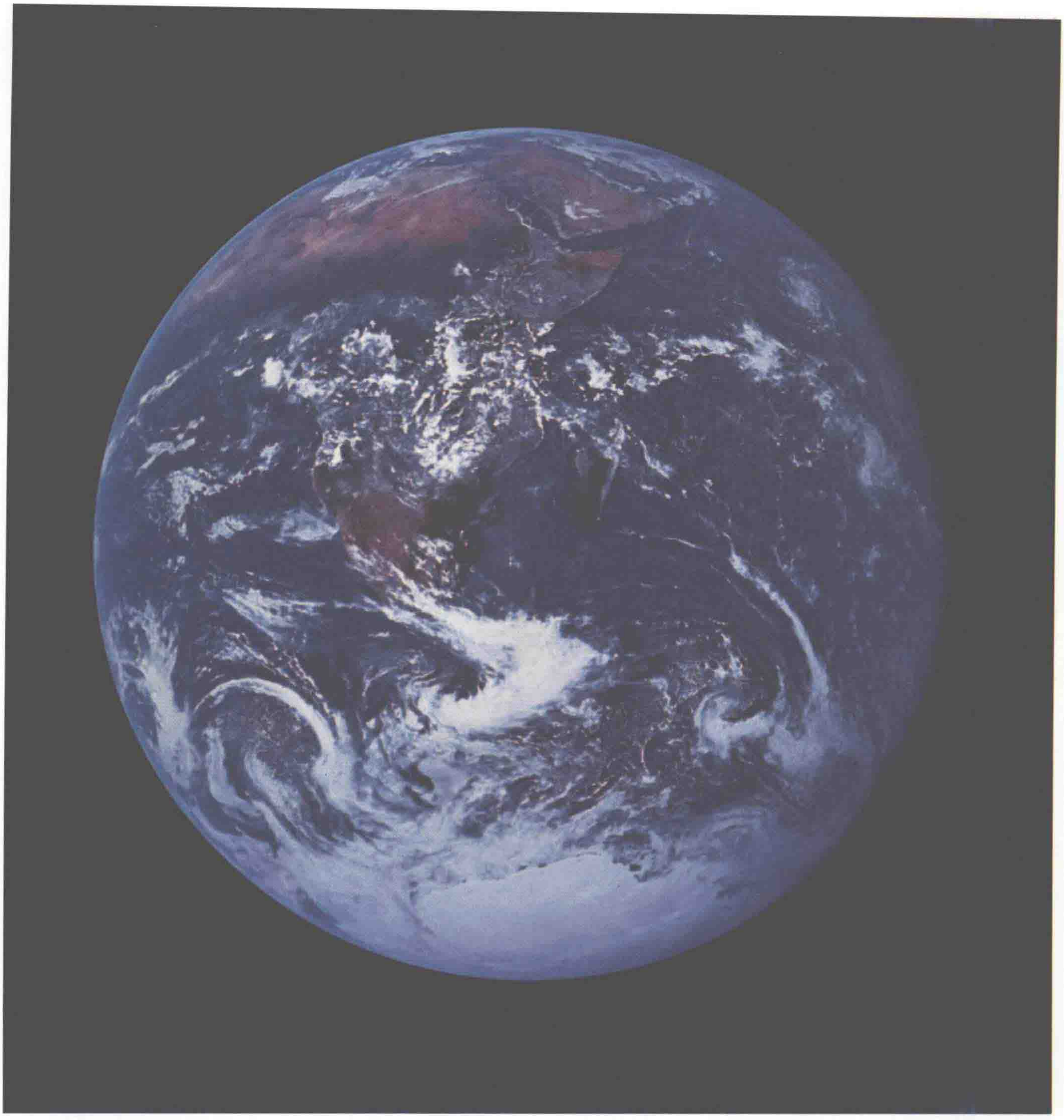

FIGURE 1.1 *Apollo 17* photograph of Earth. Note brown land areas (lithosphere), white Antarctic ice sheet (cryosphere), white clouds (atmosphere), and blue ocean (hydrosphere). (Photo courtesy of NASA)

COMMON PROCESSES OF CHANGE		
Process	Kind of Change	Example
Melting	Solid phase changes to liquid phase.	Water ice turns to water.
Freezing	Liquid phase changes to solid phase.	Water turns to water ice.
Evaporation	Liquid phase changes to gas (vapor) phase.	Water turns to water vapor or steam (hot water vapor).
Condensation	Gas (vapor) phase changes to liquid phase.	Water vapor turns to water droplets.
Sublimation	Solid phase changes directly to a gas (vapor) phase, or gas (vapor) phase changes directly to solid phase.	Dry ice (carbon-dioxide ice) turns to carbon dioxide gas, or the reverse.
Dissolution	A substance becomes evenly dispersed into a liquid (or gas). The dispersed substance is called a solute, and the liquid (or gas) that causes the dissolution is called a solvent.	Table salt (solute) dissolves in water (solvent).
Vaporization	Solid or liquid changes into a gas (vapor), due to evaporation or sublimation.	Water turns to water vapor or water ice turns directly to water vapor.
Reaction	Any change that results in formation of a new chemical substance (by combining two or more different substances).	Baking soda (sodium bicarbonate) and vinegar (acetic acid) react to form water, sodium, and carbon dioxide gas.
Atmospheric precipitation	A physical change in the atmosphere whereby a gas phase turns to droplets of liquid, or a liquid phase turns to solid particles.	Water vapor turns to rain, snow, or hail in the atmosphere.
Chemical precipitation	A solid that forms when a liquid solution evaporates or reacts with another substance.	Salt forms as ocean water evaporates. Table salt forms when hydrochloric acid and sodium hydroxide solutions are mixed.
Photosynthesis	Sugar (glucose) and oxygen are produced from the reaction of carbon dioxide and water in the presence of sunlight (solar energy).	Plants produce glucose sugar and oxygen.
Respiration	Sugar (glucose) and oxygen undergo combustion (burning) without flames and change to carbon dioxide, water, and heat energy.	Plants and animals obtain their energy from respiration.
Transpiration	Water vapor is produced by the biological processes of animals and plants (respiration, photosynthesis).	Plants release water vapor to the atmosphere through their pores.
Evolution	Change through time.	Biological evolution, change in the shape of Earth's landforms through time.

FIGURE 1.2 Common processes of change on Earth.

tion). Snowflakes can accumulate to form ice (cryosphere) that sublimates back into the atmosphere or melts back into water. Both rainwater and meltwater soak into the ground, evaporate back into the atmosphere, drain back into the ocean, or are consumed by plants and animals (which release the water back to the atmosphere via transpiration).

This endless recycling of water undoubtedly has occurred since the first water bodies formed on Earth billions of years ago. Your next drink may include water molecules that once were part of a glacier or that once were consumed by a thirsty dinosaur!

The water cycle doesn't just run by itself. It is driven by energy, which must come either from the Sun or from Earth's interior. This energy keeps the processes of the cycle (evaporation, etc.) functioning like machinery in a sort of water-recycling factory. Heat energy from the Sun, during daytime and especially in summer, causes evaporation, melting of ice, and sublimation of ice to gas. Heat energy from volcanic activity causes the same phenomena. The absence of solar heat during night

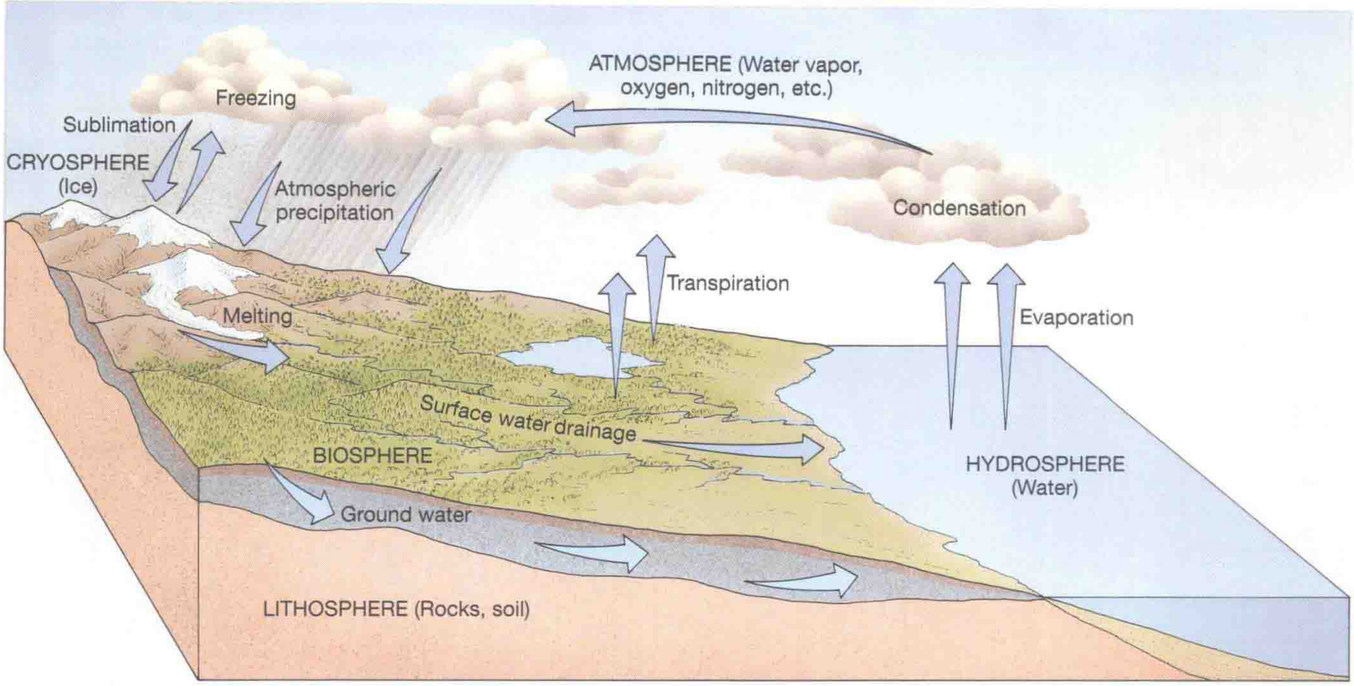

FIGURE 1.3 The hydrologic cycle (water cycle). Note the relation of processes of change in water (evaporation, condensation, freezing) to Earth's subsystems (lithosphere, cryosphere, hydrosphere, atmosphere, biosphere).

and winter, or the absence of volcanic activity, can cause condensation, freezing of water, and sublimation to solid.

Photosynthesis

The process of **photosynthesis** is also driven by the Sun's energy, in the form of light. It is the process by which plants convert carbon dioxide and water into their own sugar food, using energy from sunlight. A byproduct of photosynthesis is oxygen, which is used by animals to burn food and release energy.

Therefore, photosynthesis enables the exchange (cycling) of oxygen and carbon dioxide between plants and animals. This oxygen-carbon dioxide exchange involves both the biosphere and atmosphere. It ensures that oxygen is present for animals to breathe, that carbon dioxide does not reach levels toxic to animals, and that Earth's greenhouse effect does not fluctuate dramatically.

Greenhouse Effect

The **greenhouse effect** is an insulation effect. Atmospheric gases like carbon dioxide and water vapor absorb heat energy that otherwise would be radiated back into space. By storing this heat energy, they maintain the warmth of Earth's surface. However, too much insulating atmospheric gas undoubtedly would cause global warming, and too little insulating gas undoubtedly would cause global cooling.

Volcanoes

Volcanoes also notably influence Earth's planetary system. They explosively eject into the atmosphere molten rock material (liquefied lithosphere), rock fragments (cinders, ash), and gases (Figure 1.4). Large rock fragments then settle to the ground, where they combine with lava flows to build up the surface of the lithosphere. Dust-sized rock fragments can remain suspended in the atmosphere for many years, along with water vapor, sulfur dioxide gas, nitrogen gas, carbon dioxide gas, and hydrogen gas from the eruption.

When Mt. Pinatubo in the Philippines erupted on 12 June 1991, an immense plume of ash, dust, and gases shot nearly 30 km into the atmosphere. Shortly thereafter, ash fell on Singa-

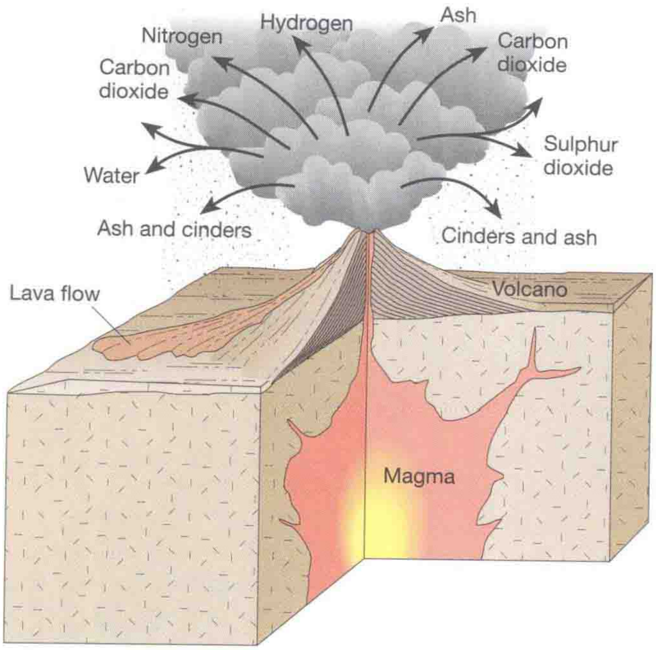

FIGURE 1.4 A typical volcano erupting on Earth, showing liquid (lava), solid (ash, cinders), and common gaseous components (water vapor, carbon dioxide, nitrogen, hydrogen, sulfur dioxide).

pore and other cities 3200 km (2000 mi) away (Figure 1.17). By mid-July a hazy band of dust and gas blanketed equatorial parts of the entire Earth! Sulfur dioxide had by then combined with atmospheric water vapor to produce tiny droplets of sulfuric acid, a sort of sulfuric acid aerosol spray. These tiny droplets act as billions of tiny prisms. They bend solar light rays enough to scatter many of them back into space, so the amount of solar energy reaching Earth's surface decreases and global cooling occurs.

The full effects of the Mt. Pinatubo eruption were not fully determined when this was written, but some atmospheric cooling and acid rain can be predicted on the basis of historical evidence. When Mt. Tambora in Indonesia erupted massively in 1815, atmospheric haziness caused the historic 1816 "year without a summer." Northern Hemisphere temperatures during that famous summer fell 2–3°C (3–6°F) below normal, and early frosts destroyed crops in New England.

OTHER PLANETARY SYSTEMS

Earth's planetary system is unique compared to other planets of our Solar System. To appreciate this uniqueness, consider the three other terrestrial planets (i.e., the inner rocky planets): Mercury, Venus, and Mars.

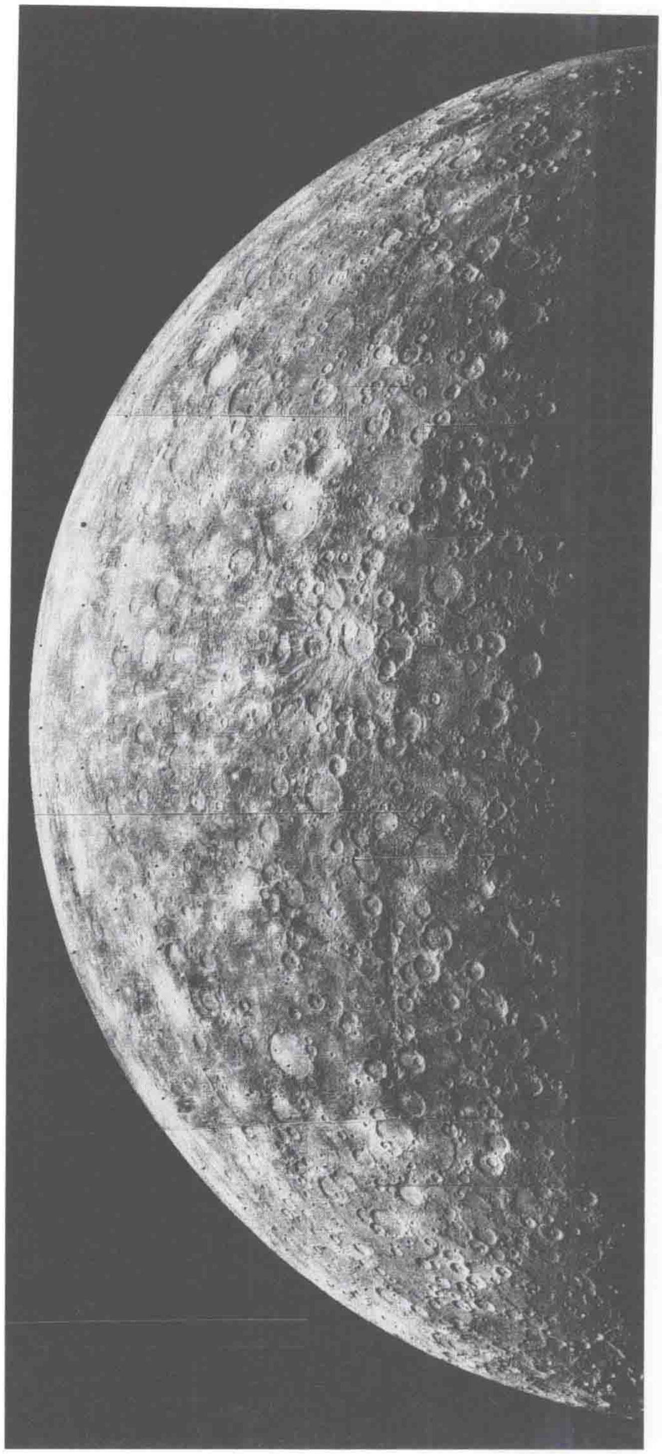

FIGURE 1.5 Photographic mosaic of the planet Mercury, constructed from *Mariner* data. (Photo courtesy of NASA)

Mercury

Mercury is a tiny planet, only about 1/3 the diameter of Earth. Most data available for Mercury were obtained by NASA's *Mariner 10* spacecraft, which photographed the planet in 1974 only 19,000 km (12,000 mi) from its surface. A mosaic of *Mariner* photographs (Figure 1.5) reveals that most of its surface is heavily cratered and shattered from meteorite bombardment. Notably absent are Earthly features such as volcanic cones, clouds, ice, water bodies, and a recognizable atmosphere.

Mercury's very thin atmosphere contains only traces of helium, hydrogen, neon, and argon. The thin atmosphere and closeness to the Sun also cause Mercury to undergo dramatic day-night temperature changes. Surface temperatures range from about +320°C during the day to −170°C at night (+608°F to −274°F). In addition to extensive cratering, such extremes of hot and cold undoubtedly have helped produce a barren landscape of rocky ridges, boulder fields, and regolith patches.

Venus

Venus is the closest planet to Earth in both distance and size. Its diameter is only 5% smaller than Earth's. Nevertheless, remote sensing and robotic sensing indicate that Venus possesses a very dense atmosphere of about 96% carbon dioxide, plus small amounts of nitrogen, neon, argon, and water vapor. Sulfur dioxide gas from erupting volcanoes mixes with the water vapor to produce aerosol droplets and yellowish clouds of sulfuric acid that hide the planet's surface (Figure 1.6A).

Both the United States and the former Soviet Union launched probes to penetrate the thick Venusian clouds, and both projects provided valuable data. NASA's *Mariner 6* probe traveled within about 34,000 km (21,000 mi) of the planet, discovering that the surface reaches 480°C (900°F). The probe also found water vapor in the Venusian atmosphere. This was determined by spectroscopic analyses of electromagnetic radiation from the planet, including light.

Subsequent *Pioneer-Venus* spacecraft launched by NASA (1978, 1979) used radar reflections to map the planet. They also dropped probes into the Venusian atmosphere and onto the Venusian lithosphere. One probe indicated sulfuric acid droplets in the atmosphere, but such droplets were not found at the surface. Apparently, the sulfuric acid droplets and raindrops evaporate before falling onto the lithosphere.

By this time, the Soviets also had obtained valuable data. In 1975 and 1982, their robotic probes *Venera 9* and *10* each transmitted a black-and-white photograph of the Venusian surface. *Venera 13* and *14* returned color images in 1982. However, none of the Pioneer-Venus or Venera probes survived long in the harsh Venusian environment. *Venera 14* transmitted data for only 68 minutes before it succumbed! One of the Venera photographs (Figure 1.7) shows a rocky, cracked, arid surface with regolith. The robotic probe found that the rocks have the composition of basalt, a common volcanic rock on Earth (Figure 4.9).

On 4 May 1989, the four-ton *Magellan* radar-mapping spacecraft was launched toward Venus from the Space Shuttle *Atlantis*. The spacecraft arrived at Venus in August 1990 and continues to image the planet at the time of this writing. NASA released *Magellan's* vivid radar images of Venus like the mosaic in Figure 1.6B and the oblique view in Figure 1.7.

Compared to Earth, Venus's surface is generally smooth, interrupted by volcanoes and deep cracks (rifts). The perspective radar image in Figure 1.7 reveals fractured lava plains and volcanoes. On the left in the image is Gula Mons volcano, about 3 km high (1.8 mi). A lava flow extends hundreds of kilometers from Gula Mons to the foreground of the image.

In the planetary mosaic (Figure 1.6B), well-defined craters are absent, despite the likelihood that Venus has undergone the same meteoritic bombardment as Mercury, Earth, the Moon, and Mars. Perhaps the craters were obliterated by volcanic processes. It also is probable that many meteorites were pulverized in the Venusian atmosphere due to its intense air pressure (90–100 times that on Earth). Such pressure probably is sufficient to crush meteorites smaller than 100 m in diameter, showering a shotgun-like blast of rocky debris into the Venusian lithosphere. Such a model may account for the dark, circular blotches scattered sparsely over the planet, instead of craters.

Mars

Mars is about half the diameter of Earth and is much farther from the Sun. It also has received much study by NASA and the U. S. Geological Survey. As early as 1962, NASA's *Mariner 2* spacecraft passed within 34,800 km (21,600 mi) of the planet. That was followed by flyby and orbiting spacecraft in 1965 *(Mariner 4)*, 1969 *(Mariner 6* and *7)*, and 1971 *(Mariner 9)*.